كلية العلوم و التقنيات فاس
ⵜⴰⵙⴷⴰⵡⵉⵜ ⵏ ⵜⵙⵏⴰⵏⵜⵉⵏ ⴷ ⵜⵉⵙⵏⵉⵜⵉⵏ
Faculté des Sciences et Techniques de Fès

جامعة سيدي محمد بن عبد الله
ⵜⴰⵙⴷⴰⵡⵉⵜ ⵙⵉⴷⵉ ⵎⵓⵃⵎⵎⴷ ⴱⵏ ⵄⴱⴷⵍⵍⴰⵀ
Université Sidi Mohamed Ben Abdellah

Centre d'Etudes Doctorales : Sciences et Techniques de l'Ingénieur-USMBA

Ecole doctorale Sciences Exactes et leurs Applications-UPPA

N° d'ordre 42/2021

THESE DE DOCTORAT

Dans le cadre d'une cotutelle entre l'Université Sidi Mohamed Ben Abdellah &

L'Université de Pau et des Pays de l'Adour

Présentée par

Mlle: Fatima Zohra GARGAB

Spécialité : Génie Energétique

Sujet de la thèse : Optimisation technico-économique et fabrication d'un chauffe-eau solaire Marocain.

Thèse présentée et soutenue le jeudi 03 Juin 2021 au Centre de conférences devant le jury composé de :

Nom prénom	Titre	Etablissement	
Driss CHENOUNI	PES	Université Sidi Mohamed Ben Abdellah, ENS-Fes	Président
Laurent ROYON	PES	Université Paris Diderot	Rapporteur
Rachid SAADANI	PH	Université Moulay Ismail	Rapporteur
Abdelouahad AIT MSAAD	PH	Université Sidi Mohamed Ben Abdellah	Rapporteur
Mohammed EL-GANAOUI	PES	Université de Lauraine	Examinateur
Amine ALLOUHI	PH	Université Sidi Mohamed Ben Abdellah	Examinateur
Tarik KOUSKSOU Abdelmajid JAMIL Ali BENBASSOU	PH PES PES	Université de Pau et des Pays de l'Adour France Université Sidi Mohamed Ben Abdellah, EST-Fes Université Sidi Mohamed Ben Abdellah, EST-Fes	Directeurs de thèse

Bader IKKEN	Directeur général de l'IRESEN	Invité d'honneur

Laboratoires d'accueil : **Technologies innovantes (USMBA-Maroc)/Laboratoire des Sciences pour l'Ingénieur Appliquées à la Mécanique et au Génie Electrique (UPPA-France).**

Contents

1. Acknowledgment I

2. **Nomenclature** II

3. General introduction VII

Part *I*: Solar water heater in Morocco: new promoter Project SOL'R SHEMSY; technical and strategical studies, statement and evaluations of national context. 1

Chapter I: *11 years of the national energy strategy; a development towards new technological adventures and promoter projects example SOL'R SHEMSY* 2

1. International energy statement (global energy context) 2

1.1. Renewable energy around the world 2

1.2. The solar thermal technology WORDWIL 4

2. Morocco energy context evaluation and statement 6

2.1. Morocco has exceptional green energy potential. 6

2.2. The historical context 7

2.3. The national energy strategy results and brakes 7

2.4. The new strategic orientation and forecasted results 8

3. The solar thermal in Morocco 11

3.1. Project lunched 11

3.2. Moroccan market of solar water heater 11

4. The SOL'R SHEMSY project; a promoter project for solar thermal in Morocco. 14

Chapter II: *Energetic, economic and environmental analysis of thermosiphon solar water heaters in Morocco.* 17

1. Technological context. 17

2. Methodology 19

3. Simulation process. 22

3.1. Examined configuration 22

3.2. Climatic data and geographical specification 23

3.3. Load profile 24

3.4. Physical modeling 25

3.5. Performance indices 32

4. Model validation 33

5. Results and discussion 34

5.1. Energetic evaluation 34

5.2. Economic assessment 35
5.3. Environmental assessment 39

Chapter III: *Energy Efficiency of social Buildings Comparative study between active and passive systems Via TRNsys.* 41

1. Passive solutions 43
1.1. The Building case study 43
1.2. Simulation model and hypothesis 44
2. Active solutions 50
2.1. Daily Hot water needs estimation 50
2.2. Individual SWH 51
2.3. Collective SWH 63
3. Economic study 72
3.1. *Active solution savings* 73
3.2. Passive solutions savings 77
3.3. Financial analysis 78
3.4. Economies comparative ratios : active VS passive 82
3.5. Payback time 83

Part *II*: The solution: solar water heater SOL'R SHEMSY/ development SHEMSY Network (experimental platform, controllers and management system) 87

Chapter IV: *Solar water heaters Technologies, standards and manufacturing materials* 88

1. History vs. current solar thermal technology 88
2. Domestic solar water heaters technologies and types 89
2.1. Active solar water heating systems 89
2.2. Passive solar water heating systems 90
3. The main components of a solar water heater. 91
3.1. The solar thermal panel 91
3.2. storage tank 92
3.3. *The heat transfer fluid* 92
3.4. The circuits and pipes 93
3.5. The heat exchanger 94
3.6. An expansion vessel or safety valve 94
3.7. pump and accessories 95
4. European standardization 95
4.1. *What are European standards?* 95
4.2. Standards types 95
4.3. European standardization and tests of solar thermal system 96

4.4. Certifications types for solar thermal systems; SWH 99
5. The materials 101
5.1. Storage tank 101
5.2. Collectors 109
***Chapter V**: SHEMSY domestic solar water heater: the best solution for Moroccan social and economic context* 115
1. SHEMSY' prototyping procedure 115
2. SHEMSY' products: general description 117
2.1. Presentation 117
2.2. Commercial designation 118
2.3. Area of use 118
3. Description SHEMSY STAR/SHEMSY STAR+ 118
3.1. Components 118
4. SHEMSY' SWH performances. 123
5. Development of an experimental plat form for research studies 132
5.1. System description 132
5.2. Weather station 140
5.3. Testing the experimental installation 142
***Chapter VI**: Development of a Control system* 147
1. Controllers: generality 147
1.1. Controller types 147
2. Solar hot water control system 153
2.1. Pump controller 153
2.2. Auxiliary heater control 156
3. Optimized management of the backup and regulating system of a solar water heater TRNsys modeling. 157
3.1. Methodology and simulation 157
3.2. Simulation results and analysis 161
4. SHEMSY'S controllers 166
4.1. Description 167
4.2. Functioning 168
4.3. SHEMSYs' controller types 169
4.4. The SHEMSY control system and connection with the CLOUD 174
4.5. Use: the architecture of Shemsy network 176
Part *III*: Manufacturing process, Business plan and quality management system design 178
***Chapter VII**: Technical study: SHEMSY products Manufacturing process* 179

1. Process 179
1.1. Storage tank 180
1.2. Evacuated tubes 180
1.3. exchanger (for forced circulated SWH) 180
1.4. Support Structure 180
2. Production means Characteristics. 180
2.1. Selection of machines 180
3. Location of the means of production 180
3.1. Choice of production process type 181
3.2. Organization of the means of production 181
3.3. Production rate (cadence) 182
4. The layout of the production unit 185
4.1. General Layout 185
4.2. Detailed Layout 186
5. Economic evaluation of the manufacturing process 187
5.1. Investment Requirements 188
5.2. Operating Requirements 189
Chapter VIII:** SHEMSY project detailed financial study: **BUSINESS PLAN 193
1. Moroccan target clientele study and Rivalry 193
1.1. Qualitative study 193
1.3. Rivalry study 198
2. Marketing strategy 198
2.1. Porter model 198
2.2. Market segmentation and targeting 199
2.3. Strategic Objectives 201
2.4. Marketing Mix 201
3. Financial study 204
3.1. development of initial funding plan 204
3.2. Development of the forecast income statement 206
3.3. Development of forecast income statement with the interim management balances. 209
3.4. Financial statement 210
3.5. break-even (profitability threshold) 211
4. The company judicial framework 212
4.1. The selection criteria 212
***Chapter IX:** implementation of a quality management system: SHEMSY SWH.* 214
1. General presentation of the quality management system 214

1.1. The objective 214
1.2. Quality Management Principles 214
1.3. Design of the quality management system 215
2. Quality Management System Design ISO 9001-V2015 215
2.1. Organizational Context 215
3. Leadership 218
3.1. Leadership and Commitment 218
3.2. Development of quality policy 219
3.3. Roles and Responsibilities and Authorities within the Company 219
4. Planning 219
4.1. Risk Management 219
4.2. Quality Objectives 223
4.3. Planning for Changes 223
5. Support 223
5.1. Human Resources & Competence 223
5.2. Infrastructure 224
5.3. Awareness & Communication 224
5.4. Documented Information 224
6. Carrying out Operational Activities 225
6.1. Product and Service Requirements 225
6.2. Control of products and services provided by external providers 225
6.3. Production Control and Service Delivery 226
6.4. Control of Finished Product 230
6.5. Mastering the means of measurement 231
6.6. Product Identification and Traceability 231
7. Performance Evaluation 231
7.1. Monitoring, Measurement, Analysis, and Evaluation 231
7.2. Internal Audit 231
7.3. Management Review 232
8. Improvement 232
8.1. Non-Compliance and Corrective Action 232
8.2. Continuous improvement 233
9. ISO 9001 Sol'R-Shemsy product certification 233
9.1. ISO 9001-V2015 233
9.2. ISO 9001-V2015 Certification 233
7.General conclusion and perspectives 236

7.1. General conclusion 236
7.2. Perspectives.. 237

Liste of figures

Figure 1: renewable share of total final consumption, 2018. 3
Figure 2: estimated renewable share of heating and cooling in buildings 2018. 3
Figure 3: annual additions of renewable power capacity and total 2013-2019 [7] 4
Figure 4: global thermal capacity in operation GWth. 4
Figure 5: distribution of the total installed capacity by collector type in the world 2018. 4
Figure 6: Distribution by type of solar thermal collector in operation by the end of 2018. 5
Figure 7: The m^2 of collector technologies installed around the world. 5
Figure 8: dependence energy ratio [12]. 9
Figure 9: the share of renewable energy in the energy mix. (a)energy consumption(b)installed power [12]. 10
Figure 10: temporary jobs created VS cumulative permanent employment [8]. 10
Figure 11: the ratio of CO_2 emissions to total primary consumption [12]. 10
Figure 12: Ranking of the most equipped Mediterranean countries in solar thermal in 2016 [15]. 11
Figure 13: Evolution of the total installed area per inhabitant in Morocco compared to the world [15]. 12
Figure 14: Evolution of cumulation of the installed area in the world and Morocco [15]. 12
Figure 15: Evolution of the unit wholesale price of thermal collectors (MAD per m^2) [18]. 12
Figure 16: Evolution of the area installed annually in Morocco (black squares) and its cumulation (blue circles) [15]. 13
Figure 17: Evolution of greenhouse gas emissions avoided by thermal installations [15]. 13
Figure 18: : Turnover evolution (solar thermal Moroccan market) [15]. 14
Figure 19: domestic solar water heaters sales in Morocco. 14
Figure 20: the study flowchart methodology. 21
Figure 21:Thermosyphon system schematic. 22
Figure 22: weather data (a)Agadir(b)Tangier (c) Fez (d) Ifrane (e) Marrakech(f) Errachidia 24
Figure 23: Realistic Moroccan load profile for hot water consumption. 25
Figure 24: The equivalent electrical pattern of heat transfer. 29
Figure 25: Thermosyphon diagram executed under TRNSYS program. 32
Figure 26: Solar fraction of Michaelides study versus validation study. 34
Figure 27: (a)- Collector's efficiency. (b)- Solar fraction. 34
Figure 28: (a)-Total annual gains (with state subsidies). (b)-Total annual gains (without state subsidies). 37
Figure 29: (a)- Cumulative gains for buildings (non-subsidies scenario). (b)- Cumulative gains for Modern Moroccan houses (non-subsidies scenario). (c)- Cumulative gains for villas (non-subsidies scenario). 38
Figure 30: cumulative area of the SWH installed in Morocco since 2000 and expectations. 39
Figure 31: the building model with the Google Sketch UP software. 43
Figure 32: the architectural plan of the ground floor and a representative floor. 44
Figure 33: TRNSYS information diagram for multi-zone building 45
Figure 34: the building zoning. 46
Figure 35: occupation schedule. 47
Figure 36: Hourly heating and cooling profile. 47
Figure 37: Low demand energy need. 51
Figure 38: standard demand energy need. 51
Figure 39: High demand energy need. 51
Figure 40: the flowchart of individual solar water heater system. 52

Figure 41: The daily profile of domestic hot water use. 56
Figure 42: FPC validation results 57
Figure 43: ETC validation results. 57
Figure 44: Fes irradiation variation. 57
Figure 45: Low demand temperature variation. (a)FPC (b) ETC........ 58
Figure 46: Standard demand temperature variation. (c)FPC(d) ETC........ 58
Figure 47: High demand temperature variation. (e)FPC (f) ETC........ 59
Figure 48: Low demand temperature variation. (g)FPC(h) ETC 59
Figure 49: Standard demand temperature variation. (i)FPC(j) ETC........ 60
Figure 50: High demand temperature variation. (k)FPC (l) ETC 60
Figure 51: Low demand temperature variation (m)FPC (n)ETC. 61
Figure 52: Standard demand temperature variation. (o)FPC (p) ETC 61
Figure 53: High demand temperature variation. (r) ETC q)FPC........ 61
Figure 54 Low demand ;monthly energy performances(s)FPC (t) ETC.: 62
Figure 55: Standard demand; monthly energy performances(v) ETC(u)FPC. 62
Figure 56: High demand ;monthly energy performances(w)FPC (y) ETC. 62
Figure 57: monthly energy demand for collective SWH. 64
Figure 58: Simulation information flow diagram of the collective solar system. 65
Figure 59: panel assembly. 67
Figure 60: System temperature variation (FPC) in cloudy day. 69
Figure 61: System temperature variation (ETC) in cloudy day. 69
Figure 62: System temperature variation (FPC) in clear day. 70
Figure 63: System temperature variation (ETC) in clear day. 70
Figure 64: System temperature variation (FPC) in intermittent cloudy day. 71
Figure 65: System temperature variation (ETC) in intermittent cloudy day. 71
Figure 66: (a) flat plat collector, (b) evacuated tube collector........ 72
Figure 67: (c) flat plat collector, (d) evacuated tube collector (efficiencies). 72
Figure 68: SWH production energy for low demand........ 73
Figure 69: SWH production energy for standard demand 73
Figure 70: SWH production energy for high demand. 74
Figure 71: : Annual energy of the back-up system for a low demand for DHW. 74
Figure 72: Annual energy of the back-up system for a standard demand for DHW. 74
Figure 73: Annual energy of the back-up system for a Hight demand for DHW. 75
Figure 74: Air conditioning and heating consumption ratio. 77
Figure 75: forced circulation water heaters. 90
Figure 76: thermosyphon solar water heater. 91
Figure 77: flat plate collectors' components [171] 110
Figure 78: Evacuated tube collector components [179]. 112
Figure 79: SOL'R SHEMSY SWH model. 116
Figure 80: Cascade method for prototyping. 116
Figure 81: thermosiphon SWH SOL'R SHEMSY (real prototype). 117
Figure 82: the horizontal incident radiation kWh/m^{2}. 123
Figure 83: the outside temperature (Fes/zone 3). 123
Figure 84: the solar fraction Fes case study (zone 3). 124
Figure 85: energy production VS requirements (fes/Zone 3). 124
Figure 86: Heat loss on collector (fez). 125
Figure 87: optical collector loss (Fez). 125
Figure 88: hot water temperature variation / irradiation. 126

Figure 89: CO_2 emissions avoided in fes. 126
Figure 90: SHEMSY's solar fraction for the six climatic zones in Morocco. 127
Figure 91: hot water temperature (a)FEZ(b)IFRANE (c)MARRAKECH (d)TANGIER (e)AGADIR (f)ER-RACHIDIA. 128
Figure 92: the solar contribution.(a)agadir(b)errachidia(c)fes(d)ifrane(e)Marrakech(f)tangier. 129
Figure 93 : auxiliary heater consumption (a)agadir(b)errachidia(c)fes(d)ifrane(e)Marrakech(f)tangier. 130
Figure 94: Energy savings (kWh) .(a)agadir(b)errachidia(c)fes(d)ifrane(e)Marrakech(f)tangier. 131
Figure 95: the experimental installation developed. 133
Figure 96: experimental installation(connexions and components). 139
Figure 97: weather station- EST FES. 140
Figure 98: DS18B20 . 140
Figure 99:BME280 . 140
Figure 100 :Rain sensor RG-11. 141
Figure 101: Davis enemometer. 141
Figure 102: Light sensor. 142
Figure 103: utra-violet light sensor 142
Figure 104: measurements of the temperature from 11 to 20 january 2019. 143
Figure 105: Display interface of the controller. 143
Figure 106: temperatures variation- experimental installation. 144
Figure 107: temperature of an operating period. 144
Figure 108: temperatures of a good functioning period in March. 145
Figure 109: temperatures evolution in a day (12 march 2019). 145
Figure 110: monthly hot water consumption. 146
Figure 111: Water consumption from 06 to 15 March 2019. 146
Figure 112: Graphic function of the differential controller[50]. 148
Figure 113: The PID controller Operation[191]. 149
Figure 114: RL controller. 151
Figure 115: Comparison of transient thermal response of the thermal zone for global and local PID, F-PID and GA-F-PID regulators [203]. 152
Figure 116: differential control system flowchart. 154
Figure 117: differential control with switching valve flowchart. 155
Figure 118: differential control system with external exchanger flowchart. 156
Figure 119: : the simulation flowchart. 158
Figure 120: Load profile. 158
Figure 121: : Tank prototype and physical diagram of the thermal stratified tank. 159
Figure 122: stratification level in storage tank (a)Highly stratified, (b) moderately stratified (c) fully mixed and non-stratified 160
Figure 123: The electrical consumption of the auxiliary heater. 161
Figure 124: Solar fraction of various auxiliary heater positions. 162
Figure 125: stratification number in various tank positions. 162
Figure 126: comparison of differential and feedback controller. 163
Figure 127: Outlet temperature of collector and storage tank variation 164
Figure 128: The temperature Variation in the storage tank. 164
Figure 129 : Variation of incident solar radiation and water flow. 164
Figure 130: Power consumption of the pump in the region of Fez and Er-Rachidia. 165
Figure 131:Load profile 2. 165
Figure 132: the variation of pump consumption using different daily water flow rate. 165

Figure 133: Load profile 3. 166
Figure 134: the variation of pump consumption using 166
Figure 135: SHEMSY controller flowchart. 168
Figure 136: SHEMSY BASIC. 170
Figure 137: SHEMSY PRO. 171
Figure 138: SHMESY LAB. 172
Figure 139: SHEMSY NETWORK. 174
Figure 140: SHEMSY CLOUD connector. 176
Figure 141: SHEMSY SWH components. 179
Figure 142: Islets cadence. 183
Figure 143: Each operation time (%). 184
Figure 144: heat pipe operation time %. 184
Figure 145: islet rate after balancing. 185
Figure 146: The general layout of the production unit. 186
Figure 147: Administration building. 187
Figure 148: SWH users. 194
Figure 149: SWH types used. 194
Figure 150: SWH costumer choice reasons. 194
Figure 151: Ideal water heater characteristics. 195
Figure 152: SWH respondents' perceptions. 195
Figure 153: Barriers to use SWH. 195
Figure 154: Why Moroccan use SWH. 196
Figure 155: distribution of SWH technologies consumed in Morocco. 196
Figure 156: Consumer point of view about SWH problems. 196
Figure 157: "would you be interested in this type of water heater? even with a little high price?". 197
Figure 158: SWH psychological purchase price. 197
Figure 159: Break-even point (profitability) and neutral for thermosiphon case. 212
Figure 160: Structure of the company's documentary system 225
Figure 161: ISO 9001 certification process [26]. 234
Figure 162: (a) The solar exergy distribution for a representative day of august (summer). 238

Liste of tables

Table 1: table comparative of water heater technologies. 15
Table 2: Optimal tilt angle. 22
Table 3: Thermosyphon solar water heater characteristics. 22
Table 4: General Information of the climatic zones under investigation. 23
Table 5: consumption profile of the validation study. 33
Table 6: Technical parameters of the validation study. 33
Table 7:Distribution of houses in Morocco according to the 2014 census. 35
Table 8: Distribution of occupied houses per climatic zone in Morocco. 36
Table 9: The number of TSWH to be installed. 36
Table 10: The total gains for different type of houses according to the two scenarios (with and without subsidies). 38
Table 11: The annual CO2 emissions avoided by the integration and the generalization of the TSWH. 39
Table 12: the conventional building envelope 44
Table 13: Regulatory ventilation flow rates. 47
Table 14: Thermal Characteristics of Insulated Building Walls and Floors 48
Table 15: building envelope action on the glazing. 48
Table 16: Thermal Characteristics of the Building Envelope for the RTCM 49
Table 17: heating and cooling annual demand (kWh/m²/year). 49
Table 18: technical characteristic of collectors and tanks (individual SWH). 55
Table 19: Validation results. 57
Table 20: technical characteristic of collectors and tanks (collective SWH). 67
Table 21: piping technical characteristics. 68
Table 22: Efficiency of DHW production systems. 73
Table 23: Energy savings achieved for the different scenarios of DHW production. 76
Table 24: Savings of passive solutions kWh/year. 77
Table 25: kWh butane price. 79
Table 26: electricity kWh price. 79
Table 27: Annual invoice for production of DHW by conventional systems. 80
Table 28: Energy bill of auxiliary systems. 81
Table 29: Amount saved by installing a solar water heater for an individual building. 81
Table 30: Annual energy bill for heating and cooling for an individual building. 82
Table 31: Savings rate achieved. 82
Table 32: Savings using the active system SWH. 83
Table 33: Savings using the passive system SWH. 83
Table 34: Return on investment time of individual solar water heaters. 84
Table 35: Return on investment time of collective solar water heaters. 85
Table 36: payback time of passive actions. 85
Table 37: optical efficiency and loss coefficients of solar thermal collectors. 98
Table 38: SHEMSY'S products. 118
Table 39: SHEMSYs collectors types. 118
Table 40: characteristics of SHEMSYs' collector. 119
Table 41: collectors' components characteristics (STAR +). 119
Table 42: Absorber characteristics. 120
Table 43: SHEMSY's products sumary. 122
Table 44: technical characteristics of FPC. 135

Table 45: ETC technical characterestics. 135
Table 46:storage tank technical characteristics. 136
Table 47: transfer group characteristics. 137
Table 48: circulation pum technical characteristics. 137
Table 49: the reduction rate.......... 162
Table 50: controllers prices 173
Table 51: Thermal energy accounter prices 173
Table 52: Storage tank operating cycle. 182
Table 53: Heat pipe operating cycle. 183
Table 54: Manifold pipe operating cycle. 183
Table 55: support operating cycle. 183
Table 56: Machinery, Equipment and Technical Installation; economic. 188
Table 57: Transportation equipment; economic evaluation. 189
Table 58: Office materials; economic evaluation. 189
Table 59: Computer equipements; economic evaluation 189
Table 60: Raw material economic evaluation. 190
Table 61: electricity consumption of the production unit. 191
Table 62: monthly total salaries. 192
Table 63: Expected sales 197
Table 64: Rivaly. 198
Table 65: forces that can influence SHEMSY project. 199
Table 66: the segmentation criteria adopted in SHEMSY project. 200
Table 67: Clients segments 200
Table 68: investments MAD. 205
Table 69: WCN thermosiphon SWH case MAD. 205
Table 70: the initial financing plan for thermosiphon SWH. 206
Table 71: turnover for three next years (MAD) 207
Table 72: raw material coast's needs. 207
Table 73: water and electricity charges. 207
Table 74: staff salary costs. 208
Table 75: social security charge, thermosiphon SWH case. 208
Table 76: depreciable elements. 208
Table 77: depreciation charges ; thermosiphon SWH case. 208
Table 78: forecast annual income statements: thermosiphon SWH (200L) case. 209
Table 79: forecast income statement with interim management balances: thermosiphon SWH case 210
Table 80: financial statement: thermosiphon SWH case. 211
Table 81: break-even point and neutral calculation: thermosiphon SWH case. 212
Table 83: List of Process Drivers. 218
Table 84: the QMS Procedure Sheets 218
Table 85: risk occurrence frequency. 220
Table 86: risk impact Severity. 221
Table 87: Risk Mapping Interpretation. 221
Table 88: Risk Prevention Action Decision. 222
Table 89: Means of product control provided by external suppliers. 226
Table 90: Means for controlling manufacturing processes. 227
Table 91: Interpretation of indicator Cp [12], [13]. 228
Table 92: Interpretation of indicator Cpk [12], [13]; 228

Table 93:production decision. 230

1. Acknowledgment

First of all, I would like to express my gratitude to my two PhD supervisors, Mr. Ali Benbassou and Mr. Abdelmajid Jamil from Sidi Mohamed Ben Abdellah university (USMBA-Maroc), and my supervisor Mr. Tarik Kousksou from université de Pau et des Pays de l'Adour (UPPA-France) for suggesting an original research topic that has allowed me to flourish both of my academic and intellectual levels, working on such interesting national project wich will have a very remarkable effect in Morocco, thank you for giving me the opportunity to participate and making a special added value on this important national project.

A very special gratitude for Mr. Abdelmajid Jamil for all support, advices and care during these years of research and all my university career. He is supervisor and big brother; I learned a lot from this special person from his expertise and his human being. Special thanks for Mr. amine Allouhi for all his advices, help and assistance preparing my papers. All my gratitude also for Mr. Tarik Kousksou for his efforts making good communication and harmony of my work between the two universities. I would like to warmly thank all the team for the time they gave to me during these four years of scientific research and for the good atmosphere that has always prevailed.

I also thank the Institut de Recherche en Energie Solaire et Energie Nouvelle (IRESEN-Morocco) to have support this special project for which I feel a strong belonging, and to have offered me all the favorable conditions to carry out my scientific research.

In addition, I would like to thank my mother for her wise counsel and sympathetic ear. She is always there for me. her love and existence were my first motivation during all my life. And making her proud and happy is my priority goal.

Fatima Zohra GARGAB

2. Nomenclature

I_{coll}	Total radiation on tilted surface [kJ/ h/ m²]	U_{api}	Conductance for heat losses from collector inlet pipe [Kj/ h/ k]
Q_{ucoll}	Energy rate from heat source [kJ / h]	Nc	Number of parallel collector risers [-]
Q_{DHW}	Energy rate to load [kJ / h]	d	Pipe diameter [mm]
Q_{aux}	Auxiliary heating load [Kj/ h]	L	Pipe length [mm]
F_{sol}	Solar fraction of the system [%]	V	Tank volume [L]
E_{coll}	Efficiency of the collector [%]	D_h	Header tank diameter [mm]
C_{sc}	Capacity of solar circuit [L]	D_r	Riser tank diameter [mm]
KT	Thermal losses of the tank [kJ / h/ m²]	H_0	Vertical distance between outlet of tank and inlet to collector [mm]
Pmax	Maximum pressure [bar]	Hc	Vertical distance between outlet and inlet of collectors [mm]
$Q_{aux,max}$	Maximum heating rate [Kw]	L_{ci}	Length of collector inlet [mm]
(UA)s	Overall UA value for storage tank [kJ /h/ k]	L_{co}	Length of collector outlet [mm]
U_{Apo}	Conductance for heat losses from collector outlet pipe [Kj/ h/k]	L_h	Length of collector headers [mm]
L_i, L_0	Length on inlet and outlet piping [mm]	T_{co}	Collector outlet temperature [°C]
d_i,d_o	Diameter of collector inlet and outlet pipes [mm]	T_{ci}	Collector inlet temperature [°C]
IAM	Incident angle modifier	T_a	Ambient temperature [°C]
b_0	Negative of the 2nd order coefficient in the IAM curve fit equation	G	Collector flow rate per unit area [kg/ h/m²]
I_T	Total incident radiation per unit area [kJ /h/ m²]	G_{test}	Collector mass flux at test conditions [kg/ h/m²]
I_t	Global radiation incident on the solar collector [kJ /h/m²]	U_L	Heat loss coefficient [kJ /h/ K/ m²]
I_d	Diffuse horizontal radiation [kJ /h/ m²]	F’	Collector efficiency factor
I_{bT}	Beam radiation incident of the solar collector [kJ /h/ m²]	F	Friction factor
g	Gravitational constant [N.m²/ kg²]	$F_{R(\tau\alpha)}$	Intercept efficiency corrected for non-normal incidence
C_p	Specific heat of working fluid [kJ /kg/°C]	F_RU_L	Slope of the collector efficiency curve (kJ h-1 K-1 m-2).
$\dot{m}$	Thermo siphon flow rate [kg /h]	F_R	Collector heat removal efficiency factor
v	Velocity of the fluid [m/ s]	A_c	Collector area [m²]
f	Friction factor for flow in pipes	S	Solar radiation absorbed by the collector [kJ/hr]
Re	Reynolds coefficient	T_c	The set temperature [°C]
k	Node number	T_f	Cold water temperature [°C]
K	Correction coefficient for additional friction due to developing flow in the pipe	T_{Be}	Inlet tank temperature [ºC]
Nx	Number of equal sized collector nodes	T_{Bs}	Outlet tank temperature [ºC]
r	Ratio of collector heat removal efficiency factor, FR, to the test conditions	$Q_{ext-bal}$	Energy transfer to the user [kJ]
Hp	The friction head losses on the pipes	M	Mass of fluid inside the pipe [kg]
h_{Li}	Frictional head loss in the ith node on the pipe	UA	Overall loss by conductance [kJ/h]
h	Altitude above sea level [m]	j,k	Refer to the liquid segments in pipe
C	Capacitance of the collector, including the fluid [kJ/K]	S	the area of the heat flow passage section [m²]
T	Fluid temperature at any point [°C]	X	the space variable in the direction of the flow [m]
T_B	Individuel tank temperature [°C]	(i)	The index of the node,
T_p	The solid surface temperature [°C]	M_f	Fluid mass of the collector [Kg]

Tf	the temperature of the fluid before contact with the solid [°C]	T_{aw}	the average temperature of the absorbent wall [°C]
hc	Coefficient of thermal transmission by convection [W/ m² °C]	h_p	the overall coefficient of loss of the absorbent wall [W/ m² °C]
q_{cf}	Heat transfer fluid flow rate [W/°C]	U	heat transfer coefficient [W / m²K]
e_i	the collector background thickness [m]	Qth	the energy demand [kWh]
e_p	the thickness of the absorbent wall [m]	F_P	The average number of persons in a unit dwelling.
Tout	The output temperature [°C]	F_e	The average number of persons in a unit dwelling.
Tmix	temperature in the mixing valve [°C]	F_s	simultaneity indicating factor
$\dot{m_{out}}$	output of the mixing valve [kg/h]	Sp	piping area [m²]
Q_{loss}	pipe loss [W]	T2	The temperature at the bottom of the hot water tank (regulation) [°C]
T1	the collector outlet temperature (regulation) [°C]	Cp	Dispersion indicators(production)
Cpk	the centering indicator around the target	Pr	Prandtl factor

Greek symbols			
θ	Incident angle for beam radiation [°]	β	Collector Slope above the horizontal plane [°]
$(\tau\alpha)$	Product of the cover transmittance and the absorber absorptance	ρ_i	Density of ith node [kg/ m³]
$(\tau\alpha)_g$	$(\tau\alpha)$ for ground reflected radiation	η	Solar water heater efficiency.
$(\tau\alpha)_s$	$(\tau\alpha)$ for sky diffuse radiation	η_0	Zero loss efficiency.
$(\tau\alpha)_n$	$(\tau\alpha)$ at normal incidence	λ	Thermal conductivity [W.k-1.m-1].
$(\tau\alpha)_b$	$(\tau\alpha)$ for beam radiation depends on the incidence angle	ϕ_{cd}	energy transferred by conduction [W]
ΔP_i	Change in pressure across the ith node [bar]	ϕ_{cv}	energy transferred by convection [W]
Δh_i	Height of the ith node [mm].	ϕ_r	energy transferred by radiation [W]
Δt	Simulation step [hr].	α_{ps}	the absorption coefficient of the absorbent wall related to radiation solar
ΔT	Temperatures difference [°C].	τ_{cs}	the transmission coefficient of the transparent cover related to the solar radiation
ϕ_{sa}	The solar flux absorbed [W]	λ_{air}	The thermal conductivity of air [W/m.K]
ϕ_p	The flux lost by the absorbent wall [W]	α_{pi}	the absorption coefficient of the plate related to radiation
ϕ_u	the useful flow [W]	α_{ci}	the coefficient of absorption of cover related to radiation
$G(i,\gamma)^*$	solar incident illumination (flux density) on the collector [W]	λ_i	the thermal conductivity of the collector bottom (w/m°K)
$\phi_{c,w-c}$	the energy exchanged by convection-conduction between the absorbent wall and the cover [W]	λ_p	Thermal conductivity of the absorbent wall [w/m°K]
$\phi_{r,w-c}$	the energy exchanged by radiation between the absorbent wall and the cover [W]	η_C	collector efficiency [%]
$\phi_{c,c-a}$	the energy exchanged by convection between the cover and the outside air [W]	η_{sys}	system efficiency [%]
$\phi_{r,c-a}$	the energy exchanged by radiation between the cover and the external environment [W]	Nµ	Nusselt factor
ϕ_{s-c}	the Solar energy absorbed by the transparent cover [W]	h_{wind}	the wind speed [m/s]

ϕ_L	Absorber heat losses [W]		
$h_{c,p-c}$	the coefficient of heat transfer between two parallel surfaces delimiting an enclosed space containing air [W/ m^2 °C]		

Abbriviations			
IRESEN	Institut de recherche en Energie solaire et énergies nouvelles	CSTB	Centre Scientifique et Technique du Bâtiment
AMEE	Agence Marocaine pour l'Efficacité Energétique	FPC	Flat plate collector
HCP	Haute commissariat des plans	ETC	Evacuated tube collector
ROI	Return on Investment [years]	UC	Unglazed water collector
SWH	Solar water heater	CPC	cylindro-parabolic collector
TSWH	Thermosiphon solar water heater	DWHR	Drain water heat recovery
DSWH	Domestic solar water heater	TPCT	Two phase cloed thermosiphon
RE	Renewable energy	PCM	Phase change material
EN	European norm	CTSPCM	cascade thermal storage phase change material
ISO	International organization for standardization	PTT	Phase transition temperature
CEN	Comité Européen de Normalisation	EPA	electronic protection anode
TS	Technical specification	ACI	Anode to current imposed
NF	Norme française	PUF	polyurethane foams
ESTIF	European solar thermal industry federation	PVC	polyvinyl chloride
DHW	Domestic hot water.	IAM	Incident angle modifier
DSWH	Domestic solar water heating.	EE	Energy efficiency
MENA	Middle-east and north Africa region.	MAD	Moroccan dirham
GDP	Gross Domestic Product	BAS	Building automation system
PI	Proportionnelle – Intégrale	WCN	Working Capital Requirement
PID	Proportionnelle – Intégrale – Dérivée	MMH	Mpdern Moroccan House
RL	Reinforcement learning	PPAs	Power purchase agreements
ANN	artificial neural networks	PV	Photovoltaique
CDM	Clean development mechanism	CESE	Conseil economique, social et envi.
DC	Direct courant	ONEE	Office national d 'eau et d'électricité
NAS	Network Attached Storage	CSP	Concentrateur solaire parabolic
PSO	particle swarm optimization	CCPI	Climate change performance index
VAT	Value added tax	LPG	Liquified petroleum gas
MASCIR	Moroccan foundation of advanced science innovation and researcher	PROMASOL	Programme de développement du marché marocain des chauffes eau solaire
CDER	Centre de développement des énergies renouvelables	MEM	Moroccan Energy Ministry
RTCM	Réglementation thermique de construction marocaine	SMB	Small and medium business
SF	Solar fraction	WTO	World trade organization

Abstract

Using solar energy for domestic hot water production is a simple option to reduce fossil fuel consumption and greenhouse gas emissions. In Morocco, solar thermal energy for domestic hot water production still has a very discreet penetration, far below the enormous potential linked to the country's available sunshine.

The low number of solar installations in buildings is partly due to the highly subsidized conventional energy (LPG and electricity); this offset the solar option benefits in reducing household energy bills. On the other hand, there is a lack of awareness of solar energy opportunities, both by the general public and by actors in the construction sector.

Domestic hot water production can represent a significant percentage of the estimated annual energy consumption of 25% in the residential sector. This has led Morocco to launch several projects, namely the PROMASOL program, which has allowed to develop in recent years, a particular activity in the solar sector, centered mainly on the installation of domestic hot water production equipment in individual dwellings. On the other hand, the objectives' development and achievement are still blocked by the factors mentioned above. Besides, this sector's satisfaction in full evolution is currently only done by the importation of these systems, which makes their excessive price.

In this directive, a new project was created to overcome this problem; SOL'R SHemsy, a collaborative project between (IRESEN: institute of research in Solar Energy and New Energy) and USMBA (University Sidi Mohammed Ben Abdellah), whose objective is the technological transfer and adaptation. The development and implementation of the project is the subject of this thesis. Whose objective is to propose and design a Moroccan SWH with an accessible and competitive price guaranteeing the best performances. The product must also be adapted to European standards to validate its performance and safety for consumer.

The thesis project led this challenge to the end; from the SHEMSY SWH proposal after a range of technical, economic, environmental, and strategic studies, until the realization of the solar water heater in the form of a prototype. The proposed product meets all requirements regarding adaptation to the Moroccan context, economic (sales price), and climate (best performance adapted to local weather conditions). The proposal for this solution is accompanied by a design of the manufacturing process and a financial study presented in the form of a complete business plan based on a relevant study of the Moroccan market. The thesis project was finalized by defining a quality management system necessary for sound production management throughout the proposed process.

Key words: SOL'R SHemsy, solar water heater (SWH), technology transfer, technology adaptation, Morocco, accessible price, European standards, performance, buildings.

Résumé

L'optimisation de la consommation énergétique et la réduction des émissions des gaz à effet de serre oblige aujourd'hui l'intégration de toute la typologie des énergies renouvelable. A savoir la production solaire d'eau chaude sanitaire.

Au Maroc la pénétration de l'énergie solaire thermique pour satisfaire les besoins en eau chaude sanitaire est très lente et discrète, et n'est pas en adéquation avec l'énorme potentiel d'ensoleillement que dispose le territoire. Cette faiblesse est dû d'une part aux fortes subventions dédiées aux énergies conventionnelle (électricité et GPL), ainsi que les prix élevés des CES disponible sur le marché marocain. Ces éléments neutralisent les avantages des systèmes solaires thermiques de la réduction de la facture énergétique des ménages. D'autre part on ne peut pas nier la méconnaissance des avantages que proposent ces systèmes par la population ; consommateurs ou acteurs du secteur de construction.

Dans le secteur résidentiel, la production d'eau chaude sanitaire peut représenter un pourcentage significatif de la consommation énergétique annuelle estimé à 25%. Ce qui a poussé le Maroc d'évoluer dans ce sens par le billet de plusieurs projets ; à savoir le programme PROMASOL qui a permis de développer durant les dernières années, une certaine activité dans le secteur solaire, centrée principalement sur l'installation d'équipements de production d'eau chaude sanitaire dans des logements individuels. En revanche l'évolution et l'atteinte des objectifs est toujours bloquée par les facteurs cités précédemment. En plus la satisfaction de ce secteur en pleins évolution ne se fait actuellement que par l'importation de ces systèmes ce qui fait de leur prix excessif.

Dans cette directive qu'un nouveau projet à vue le jour pour surmonter cette problématique ; SOL'R SHemsy qui est un projet de collaboration entre (IRESEN : Institut de Recherche en Energie Solaire et Energie Nouvelle) et USMBA (Université Sidi Mohammed Ben Abdellah), dont l'objectif est le transfert et l'adaptation technologique. Le développement et la réalisation du projet fait l'objet de la présente thèse. Dont l'objectif est de proposer et concevoir un CES marocain avec un prix accessible et compétitive garantissant les meilleures performances, le produit doit être aussi adapté aux normes européennes afin de valider sa performance et sa sécurité vis-à-vis le consommateur.

Le projet de thèse a mené ce défi jusqu'au bout ; de la proposition du CES shemsy après une panoplie d'études technique, économiques, environnementales, et stratégique, jusqu' a la réalisation du chauffe-eau solaire sous forme de prototype. Le produit proposé répond à toutes les exigences en termes d'adaptation au contexte marocain ; économique (prix de vente) et climatique (meilleures performances adaptées aux conditions météo locales). La proposition de cette solution est accompagnée d'une conception du procédé de fabrication, et une étude financière présenté sous forme de business plan complet qui s'est basé sur une étude pertinente du marché marocain. Le projet de thèse a été finalisé par une définition d'un système de management qualité nécessaire à la bonne gestion de production tout au long du procède proposer.

Mots-clés : SOL'R SHemsy, chauffe-eau solaire (CES), transfert technologique, adaptation technologique, Maroc, prix accessible, normes européennes, Performances, bâtiments.

3. General introduction

To assess Morocco's situation today, it is necessary to refer to two critical elements of the evolution, its energy situation concerning the strategy, consumption, the projects launched, and the economic environment reaction to these projects assessing the investment market.

Morocco ranks 68th for the Investment Environment, achieving 13-place progress over the last decade [1]. The country has progressed in rankings for each element of this pillar. Significant reforms have been undertaken to strengthen intellectual property rights and investor protection, thereby creating a climate of confidence conducive to investment, and above all, innovation and technological adaptation to local contexts. The financing ecosystem is an incredibly potent point in Morocco. Moreover, Morocco has made considerable progress since the beginning of the millennium. GDP per capita has increased by more than 70% in real terms. Absolute and relative poverty rates decreased from 7.1% to 1.4% and from 21.4% to 19.7%, respectively, between 2012 and 2017[2]. Public finances have been managed prudently, thanks to the government's significant improvements to the investment environment, a substantial revision of the insolvency code in 2018, and more vital intellectual property protection. Besides, a series of reforms have improved business start-up conditions by substantially reducing the time spent complying with regulatory and tax obligations.

However, Morocco faces significant challenges. As with the rest of the world, the coronavirus epidemic means less trade and more public deficits for some time. It will weigh more heavily on the nation's declining economic growth challenge over the past two years; This creates many tensions, the most important being the increase in public spending, the pressure on the labor market, and the increased demands on public services. However, Morocco has many assets to navigate in these tricky waters. While this coronavirus outbreak has halted much of the global economic activity, it will be fundamental to ensure innovation, the integration of new technology, knowledge transfer, and productivity. They effectively stimulate economic growth and prosperity.

More recently, the technological revolution has enabled millions of people to participate in the commercial, political, and social debate through more straightforward and cheaper access to new technologies. Countries open economically and technologically are more productive, and there is a clear correlation between increased openness and productivity growth. On the other hand, in an uncompetitive market or not designed to foster participation and well-being for all, growth stagnates, protected industries take root, and nepotic capitalism proliferates.

In this economic directive, Morocco thought of embarking on a whole range of industrialization projects related to the new technology and the local manufacture of photovoltaic panels. Besides, in recent years the debate on solar thermal has been launched by adopting a promoter project to industrialize Moroccan solar water heaters to participate and this economic evolution by adding value to a much more flexible investment environment. On the other hand, benefit from innovation and technological adaptation to the Moroccan context. Furthermore, to improve the Moroccan energy situation by participating in the launch of a new strategic energy version that combines energy, economy, and social. Emphasizing the 2009 strategy vision's relevance and the desire to increase the share of renewable energies in installed electricity to 42% in 2020 and 52% in 2030. However, there are still some shortcomings in strategy implementation. In the Moroccan energy strategy first visions, Morocco has aimed to achieve a primary energy saving of about 12% by 2020 and 15% by 2030 [3]. An energy efficiency plan has been put in place covering all sectors and, in particular, the building sector, which has a significant energy saving potential. In this regard, the Ministry of Housing and City Policy has undertaken a series of actions to optimize energy consumption and promote renewable energy at the housing and city levels. In this sense, the Quality and Technical Affairs Department conducted a study on integrating solar water heaters (SWH) into the collective building. Given the importance of this sector and its significant share.

The housing sector's energy consumption structure analysis highlighted the link between housing and energy, highlighting the sector's importance as an engine of growth of the national economy and its energy consumption. In this respect, the sector offers exciting opportunities for energy savings and RE/EE technologies deployment. Besides, the construction sector in Morocco is characterized by rapid development, with minimal thermal quality buildings, generating discomfort, and significant energy consumption. This sector, which accounts for almost a third of the national energy consumption, plays a significant role in Morocco's economic and social development, with a contribution to the national GDP of nearly 7% and employment of 9% of the working population. This role is expected to be further strengthened by a public policy that has set itself to reduce the housing deficit in 2016 to 400,000 units, estimated in 2012 at nearly 600,000 units. The annual production of housing is thus, on average, 150,000 units, compared to almost 170,000 units in 2013[3].

Indeed, the use of solar thermal energy for domestic hot water production is one of the significant challenges of the transition to energy-efficient buildings. Today, this energy source used in buildings is imperative to deal with fluctuations in oil prices, uncertainty in energy supplies, and climate change challenges. In Morocco, 750,000 m^2 of solar thermal collectors have been installed. However, despite this substantial expansion, the results remain very modest, taking into account the country's favorable climatic conditions with annual global irradiation between 1,800 and 2,000 kWh/m^2per year [4]. This result is due to the difficulty of integrating solar water heaters to the Moroccan consumer-facing its purchasing power and the high price of this technology.

For the Social and Environmental Economic Council, it was clear that the energy strategy should be revisited (natural decision after 11 years) and be underpinned by a renewed approach. The new strategy must place the citizen at the center of its entire approach, focusing on purchasing power, economic and technological opportunities, job creation, reduction of inequalities, protection of the environment, etc. In line with the evolution of the global policy framework, the energy issue must be more general and become in the Sustainable Development Goals service.

Furthermore, several projects have been launched in this new strategic vision, namely, the project SOL'R SHemsy. Creating a collaboration canal between scientific research and industry through innovation and proposal of a Moroccan solar water heater with better performances comparable to international products, which obeys European standards, especially with a very reasonable price and accessible by society—taking into account the approach of citizen integration into the projects of Morocco's new energy vision today eight. This project will enable Morocco to embark on a new industrial adventure, contributing both to the development of the energy sector and economy, and it is through the creation of wealth and jobs opening new fertile ground for the labor market.

The thesis project falls within SOL'R SHemsy project framework, aiming to design and propose a new technological variant of solar water heaters adapted to the local context. The design concerns a Moroccan product with local manufacture in terms of the realization and the raw material. Then the product must be presented under accessible prices by the social. To develop this model after the technological variant proposal, a technical, economic analysis was made for the assembly of the best possible combinations (material, performance, and costs). Once the model was optimized, it was presented under a complete prototype whose numerical simulations already prove technical and technological feasibility. The product will then be tested and validated experimentally to monitor its operation under the actual climatic and technical conditions. An economic analysis is then elaborated in an effective business plan, which surrounds the technical, human, and material parameters necessary for the SOL'R SHemsy production unit implementation, accompanied by a proposal from the production process.

All the work carried out in this project is presented in chronological order in this report:

The first chapter situates the thesis project, giving an overview of the Moroccan energy situation between the launch of the energy strategy and its new revisions with its approaches. The solar thermal market was also presented in figures, assessing the project's needs and feasibility, which was presented at the end of this chapter.

The project's first stage was completing technical, technological, economic, and strategic feasibility studies, which are presented in the following two chapters. The first chapter details a study on the generalization of solar water heaters to meet the Moroccan residential sector's domestic hot water needs. The study was carried out on a technical, economic, and environmental level to study the impact of this project on all three aspects. The second study is presented in the third chapter, which highlights the importance of solar water heaters' solution compared to passive solutions aiming to improve the building's energy efficiency. The case study was carried out on a social building, studying the technical, investment, and economic parameters.

The fourth phase consists of the second phase of the project by identifying the system and the manufacturing materials to add this benchmark to the mechanical studies to present the best solution. A study of the different European standards for solar water heaters is also presented in this chapter with an exhibition of tests and their operative mode, the bodies and laboratories recommend, and the procedure for obtaining certification for SOL'R SHemsy products.

The fifth chapter presents the prototyping phase, which consists of the previously designed model implementation. The chapter details all the technical characteristics used. These specifications were determined based on the dynamic modeling and simulation results developed. The aim was to bring together the features that generate optimized performance at a competitive cost. Besides, this chapter also includes the setting up of a didactic solar installation. The various thermal, hydraulic, and electrical components have been illustrated, their functional connection, and the possible configurations to be set up for testing and analysis. Thus, this facility presents a platform of laboratory tests necessary for the product developed validation under the quality requirements. The indispensability of this installation in scientific research is also worth mentioning, allowing us to carry out experiments that will enrich the scientific productions by validating theoretical studies.

The sixth chapter's objective is to study the backup system and the solar water heater regulator. A proposal of the optimal design, towards finally a concrete realization of the SHemsy regulator model, must be integrated into the SHemsy products and tested on various thermal solar products and installations. The chapter presents a bibliographical study and a technical study of the SWH control system, and finally, it describes the proposed SHemsy Controller solution. It includes all the details of the controller's components, its operation, the flowchart, and the detailed program of its management and control logic. It also presents all the technical characteristics of the different components of the control system.

After having proposed solutions, a proposal for the manufacturing procedure was presented in the seventh chapter. The process is then evaluated economically by presenting a business plan accompanied by a market study in the eighth chapter.

To conclude, it was necessary to propose a production quality management model in the SHEMSy factory in the last chapter.

Part *I*: Solar water heater in Morocco: new promoter Project SOL'R SHEMSY; technical and strategical studies, statement and evaluations of national context.

***Chapter I**: 11 years of the national energy strategy; a development towards new technological adventures and promoter projects example SOL'R SHEMSY*

Introduction

This chapter introduces the present thesis project; it situates renewable energies in the world by presenting the latest figures communicated throughout the world. Next, the chapter will focus on Morocco by evaluating its energy strategy between the launch's targets in 2008 and the current state to define the relevance of this strategy by presenting the various obstacles and problems that led to the failure to achieve some objectives. A forewarning of the new strategic direction's results is explained by presenting the obstacles and last objectives set by Morocco's decision-makers.

Moving from general to specific, a focus on thermal solar in Morocco is also made to assess the situation of the current Moroccan market, its problems, and opportunities. This whole approach was to draw a clear context of SOL'R SHEMSY project, which is a national investment project that aims to improve the solar thermal market while proposing solutions to the problems and exploiting the existing opportunities.

1. International energy statement (global energy context)

1.1. Renewable energy around the world

To satisfy energy demand reliably, International efforts generally acknowledge the complementary nature of energy efficiency and renewable energy deployment and measures. Both able to have significant incomes, including lower energy costs on all levels, reduced climate and environmental impacts by improving air quality and public health, increased grid reliability, economical process, and jobs. Recognizing the potential to reduce significantly gas emissions, all partners, institutions, and non-governmental organizations, Coalitions of governments, corporations have boosted global energy efficiency efforts.

2018 has shown an increase of 2.3% of global energy demand, it was described as the best rise during a decade [5]; This was because of strong global economic increase (3.7%) and to significant energy demand of cooling and heating in some regions. China, the u. s. and India together accounted for much 70% of the whole demand increase. Besides, 1.7% of additional carbon dioxide (CO_2) emissions have been shown because of fossil fuel rise during 2018. in contrast, 2017 accounted for 18.1% as renewable energy part of the total final energy consumption [6].

2019 is another record-breaking for renewable energy globally, as over 200 gigawatts (GWth) additional power capacity as the highest increase ever (dominated by solar photovoltaic technology). The expansion and decline of the renewable energy market were derived by government policy in previous years. Meanwhile, to all or any corners of the globe, capacity installations and investment continued to increase and improve. The remarkable cost reductions in some technologies encouraged the private sector to record renewable power capacity by signing power purchase agreements (PPAs) [7].

In 2019 no increase in CO_2 emissions. Despite the final energy demand and consumption increase, the following two years increase [8]. This positive stagnation was due mainly to some countries' focus on improvements in energy efficiency and renewable energy shares, which declines in emissions from the power sector. It is also due to fuel switching from coal to gas in some cases around the world.

Significant growth in renewable energy Investment in 2019, although it is slow. In the electricity-generating Domaine, much more investment converged to renewable power technologies, including nuclear power, natural gas, and coal generating technologies. Overall, 2% growth of global new investment in renewable power compared to 2018 – as costs continued to decrease – reaching some USD 301.7 billion. This considerable investment is mostly represented by wind and solar power generating technologies, and for the first time, wind power outweighs solar since 2009 [9].

How the energy is used defines the energy demand share (for example, renewable energy). excluding electricity used for cooling, heating, and transport, the highest renewable energy share is due to the use in the power sector, such as building appliances and lighting, where the growth is quick. in 2017 this share was about 17% of total final energy consumption. However, in 2018 the transport has 32% of the share in contrast to 3.3% for renewable energy as the lowest share. Come to thermal energy, including water and space heating and industrial process heat; it was about 51%; however, 10.1% was produced by renewable technologies [10].

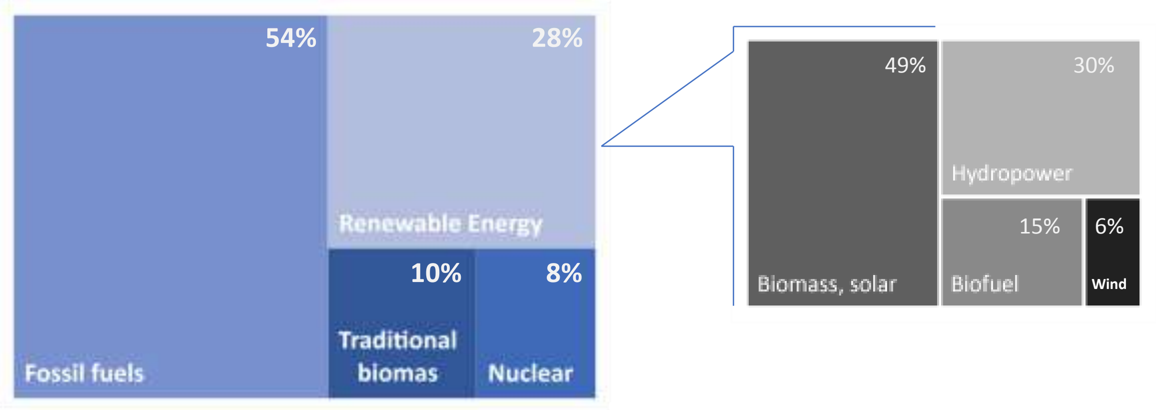


Figure 1: renewable share of total final consumption, 2018.

Besides, in building, renewable energy is remarkably growing by an annual ratio of 5.3%. Nowadays, to reduce energy use in the building is seen as high adoption of building heat electrification (the use of electric heat pumps, for example), which increases as a cost-effective and efficient method and grows the share of renewables in the sector using the renewable electricity [11].

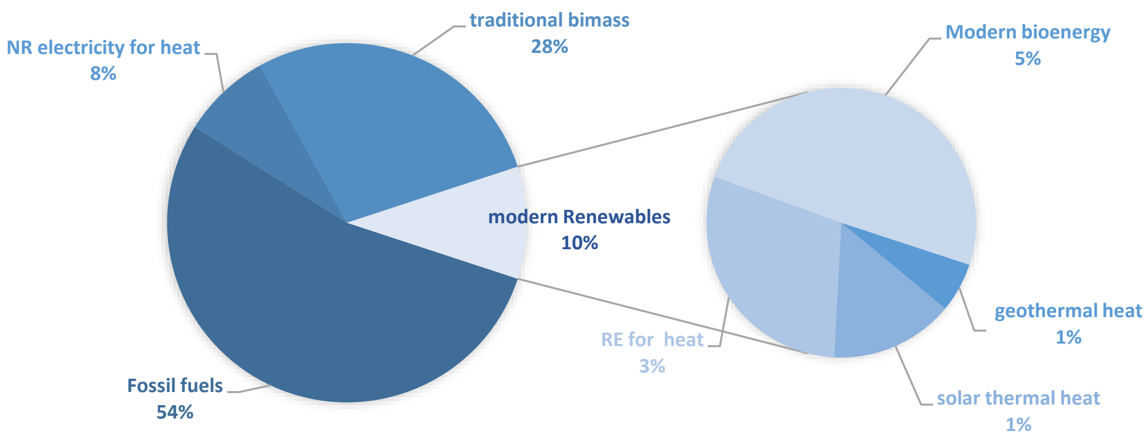


Figure 2: estimated renewable share of heating and cooling in buildings 2018.

Fig. 3 shows that in 2019 renewable energy reached a global total installed of 2588 GWth. More than 200 GWth of new renewable power capacity production. In 2018 the average ration growth was maintained at more than 8% over the previous five years (of Installed power capacity)

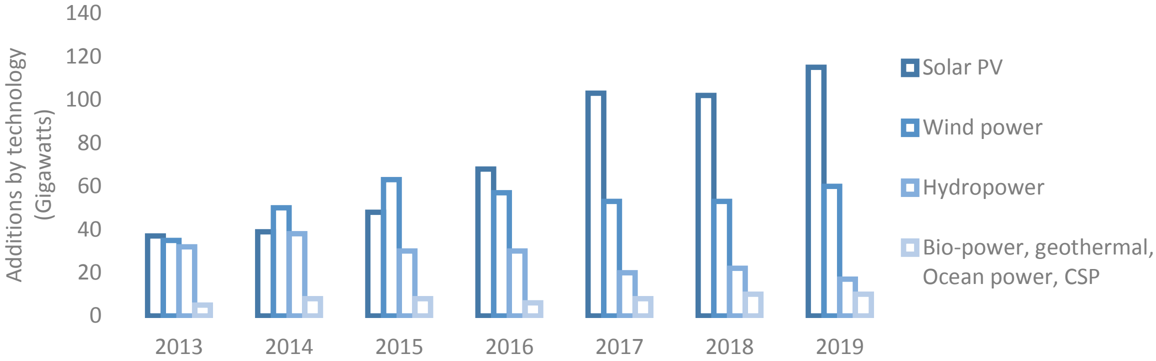


Figure 3: annual additions of renewable power capacity and total 2013-2019 [7] .

1.2. The solar thermal technology WORDWIL

Fig. 4 shows global solar thermal capacity evolution. In the world the installation in operation grew from 62 GWth to 479 GWth between 2000 and 2019 equivalent to 89 million m^2 to 684 million m^2 respectively.

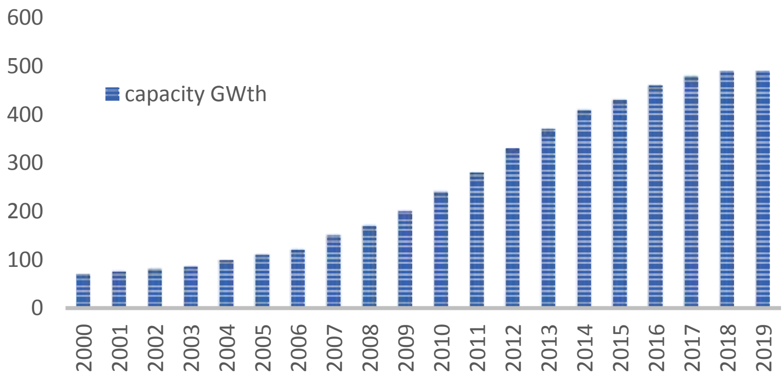


Figure 4: global thermal capacity in operation GWth.

This total installed capacity in operation is represented by several solar thermal technologies such as: the evacuated tube collectors with a total capacity of 340 GWth equivalent to 485.7 million m^2 and 70.4%, the flat plat collectors represent 23.2% which is 112.2 GWth or 160.3 million m^2 .

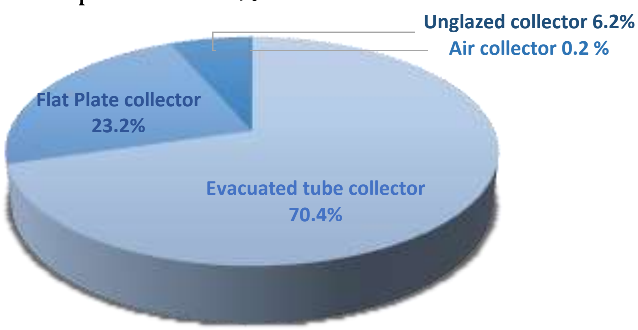


Figure 5: distribution of the total installed capacity by collector type in the world 2018.

This global distribution has a different share when to regions and countries; Fig. 6 shows that the dominant technology in the MENA region is FPC compared to the world with only 8% of ETC contribution in the total installation in operation.

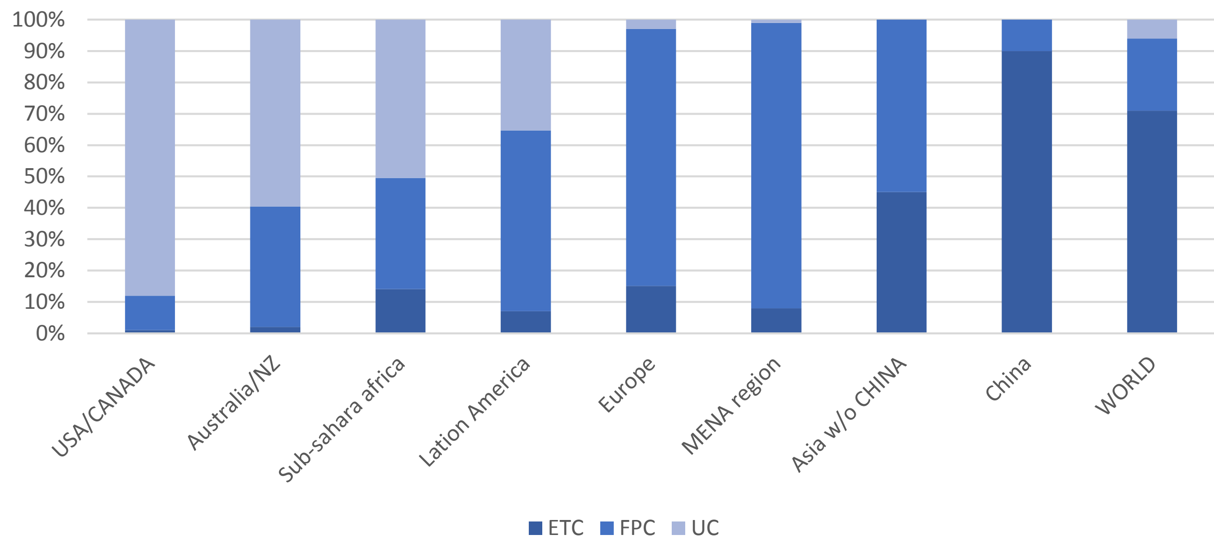


Figure 6: Distribution by type of solar thermal collector in operation by the end of 2018.

Fig. 7 shows the capacity in operation details in all countries. Making a zoom on the MENA region and especially Morocco, the FPC is the only technology present (available data). Which shows the negligence of other technologies and the weak thermal energy production Domaine in Morocco, focusing more on PV and wind energy.

Country	Water Collectors [m²]			Air Collectors [m²]		TOTAL (excl. concentrators) [m²]
	unglazed	FPC	ETC	unglazed	glazed	
Albania		250,037	8,010			258,047
Argentina	18,636	20,786	49,496			88,918
Australia	5,556,000	3,449,000	211,000	370,000	12,800	9,598,800
Austria	338,255	4,694,348	86,022		4,678	5,123,303
Barbados		236,544				236,544
Belgium	45,000	546,167	99,350			690,517
Botswana		11,308	2,221			13,529
Brazil	5,998,282	9,954,957	129,962			16,083,201
Bulgaria		137,680	4,920			142,600
Burkina Faso		3,082	779			3,861
Canada	790,124	70,617	49,823	423,227	50,114	1,383,905
Cape Verde		2,163				2,163
Chile	65,550	234,528	54,305		300	354,683
China		45,950,000	436,360,000	7,000	3,000	482,320,000
Croatia		217,500	12,067			229,567
Cyprus	2,213	761,682	23,567			787,462
Czech Republic	500,000	472,914	142,798			1,115,712
Denmark	20,500	1,649,078	9,197	4,300	18,000	1,701,075
Estonia		9,730	7,790			17,520
Finland	11,800	36,590	19,933			68,323
France (mainland)+	99,671	2,499,656	187,720	9,658	1,100	2,797,805
Germany	520,090	17,206,000	2,097,500		20,800	19,844,390
Ghana		2,494	887			3,381
Greece		4,691,000	22,000			4,713,000
Hungary	18,300	233,700	75,100	3,418	2,300	332,818
India	0	4,371,402	9,139,299	0	12,150	13,522,851
Ireland		211,821	121,586			333,407
Israel	39,000	4,748,434				4,787,434
Italy	43,800	4,042,411	634,703			4,720,914
Japan		3,605,145	81,210		281,669	3,968,024
Jordan*	5,940	982,482	272,084			1,260,506
Korea, South		1,706,196	184,959			1,891,155
Latvia		12,192	3,240			15,432
Lebanon		352,821	479,844			832,665
Lesotho		1,514	738			2,252
Lithuania		7,900	10,800			18,700
Luxembourg		56,463	8,900			65,363
Northern Macedonia		60,319	36,418			96,737
Malta		58,287	14,572			72,858
Mauritius**		132,793				132,793
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Morocco*		451,000				451,000
[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

Figure 7: The m² of collector technologies installed around the world.

2. Morocco energy context evaluation and statement

Morocco has always maintained overall consumption in line with its development level. Thus, the energy mix is dominated by hydrocarbons (52% in 2019) mainly for transport and coal (33% in 2019) for electricity generation.
The 2009 strategy, which is still the current framework for action, was a break in the sense that it brought a leadership ambition in renewable energy (RE). As part of this strategy, Morocco wants to increase the renewable energy share in installed capacity to 42% in 2020 and 52% in 2030. This strategy was based on

Five strategic directions: (i) a diversified and optimized mix around reliable and competitive technological choices, (ii) the mobilization of national resources through the ramp-up of renewable energies, (iii) energy efficiency as a national priority, (iv) strengthening regional integration, and (v) sustainable development.
Four fundamental objectives: (i) the generalization of access to energy at competitive prices, (ii) the security of supply and availability of energy, (iii) the control of demand, and (iv) the preservation of the environment

2.1. Morocco has exceptional green energy potential.
Morocco has exceptional potential for wind and solar energy. It is estimated at approximately 500 TWh/year [12] distributed between onshore wind (350 TWh) with an average load rate of 5000 hours and solar (150 TWh) with a minimum conservative load rate of 2500 hours. The same potential, at least equivalent, is available around offshore wind power.
Therefore, the exploitation of this potential would project the country among the significant energy-producing countries, ahead of Venezuela and just behind Nigeria, with a production equivalent to 86 MTep annually or about 1.65 million barrels per day.
With resources at least five times higher than its energy demand (and not only electricity) and considering the prospects of new sources to come, the Kingdom is preparing to strengthen its energy position and sees tremendous opportunities opening up to it. Morocco has been identified in several studies, including the World Energy Council and Frontier Economics,3 as one of the countries with the most competitive renewable energy potential globally; This is as much a function of the size of its deposit as of its availability.
The geographical distribution of developable sites on the national territory allows the smoothing and relative maintenance of energy available on the grid.

As for solar energy, Morocco has a potential of 2,500 to 3,000 hours of sunshine per year or an average of 8.15 minutes per day. The sunshine is spread over almost the entire national territory and is even more intense on the Atlas' eastern slopes.
This excellent complementary availability of wind and solar is an international exception and represents an undeniable asset to marginalize the intermittent effect. Which was long considered a hindrance to the development of renewable energy sources, is increasingly being rejected, thanks to the massification of sites into renewable energy sources. Indeed, numerous solar and wind energy sites spread across a territory, make it possible to smooth production, prevent brutal variations, and preserve the energy system. In this sense, experts are now talking more about variability than the intermittence of renewable energies; This is all the truer since smart grids, existing storage solutions, and future **technological developments** are likely to strengthen the control of renewable production.

Thus, through the synergy between wind and solar, the Moroccan energy potential can be realized by maximum exploitation of renewable energy resources and a significant strengthening of their share in the energy mix while ensuring a robust, resilient, and economically viable national energy system.

2.2. The historical context

In 2008, Morocco faced many challenges. An energy system marked by an extreme dependence on the outside world, a predominance of petroleum products and hydrocarbons in general, sustained growth in demand, increased rural electrification, and high price and price volatility. As experienced in the 1990s, offloading risks led to an increase in imports from Spain (17% in 2007). The state's finances were under constant strain, with oil prices over 100 USD, a massive energy bill that continued to rise, and subsidies reaching 25 billion Dirhams in 2008. Faced with these challenges, and following the royal orientations of Her Majesty's speech of July 30, 2008, the Kingdom launched a reflection intending to develop a new energy strategy with a dual objective, both to resolve supply difficulties but also to reduce energy dependency, in particular by relying on renewable energies and paving the way for the energy transition.

2.3. The national energy strategy results and brakes

Despite the relevance of the 2009 strategy's vision and the break it has initiated, with the desire to increase the share of renewable energy in installed electricity to 42% in 2020 and 52% in 2030, the CESE notes some shortcomings in the implementation of this strategy[12].

2.3.1. The positive result

The strategy made it possible to secure the supply, to initiate the liberalization of the electricity market and position Morocco at the forefront of the climate agenda

- **A secure supply of hydrocarbons**: Thanks to a structured, extensive network, initiated before the national energy strategy and consolidated since then, Morocco has managed to ensure its supply of hydrocarbons. The national energy strategy has contributed significantly to strengthening hydrocarbon storage activity, particularly in port capacities.
- **Better stability of electrical availability:** At the end of 2018, Morocco has an installed power of 10,938 MW, 34% of which are renewable energy sources with an electrification rate of 99.7%. In terms of stability, it should be noted that no incidents of offloading have been reported over the past ten years, which reflects the good technical mastery of the ONEE teams.
- **Strengthening concessional production:** Concessional production, whether fossil-based or Renewable energy accounts for 84% of the electricity mix.
- **A reform of the legal and regulatory framework that has benefited energy-intensive industries:** the adoption of Law 13-09 on renewable energy, a private electricity producer, exclusively from a renewable source, may sell its deliverable to private users, under a tripartite electricity purchase contract (producer, customer, ONEE). Besides, the law 54-14 of the self-generation of electricity, adopted in 2015, authorizes legal persons of public or private law to produce their needs.
- **Launch of the first major renewable energy projects**: From 2018, significant projects in renewable energies are being developed. The Noor Ouarzazate Complex, the world's first multi-technology complex with an installed capacity of 580 MW, divided into four units, was commissioned in 2018. In the same year, the Laayoune project was deployed with an installed capacity of 85 MW. Two other major projects are underway: the Noor Midelt I solar power plant with a total capacity of 800 MW, comprising 605 MW of PV and 190 MW of CSP and Noor Tafilalt of 120 MW of PV. At the end of 2019, renewable energies' installed capacity reached

3,701 MW, or 34% of the total power: 1,220 MW for wind, 711 MW for solar, and 1,770 MW for hydraulics.

- **Morocco's unique positioning in the international climate agenda**: Morocco, very committed to the fight against global warming despite a low rate of CO_2 emissions (less than 2.5 T/capita/year), was one of the very first countries in the world to deposit its first Determined Contribution at the national level. The organization of COP22 concretized the recognition of Morocco's efforts in the framework of the climate agenda in Marrakech in 2016. Recently, Morocco ranked second, just behind Sweden, in the Climate Change Performance Index (CCPI 2019).

2.3.2. Inadequacies and brakes

- **Expensive technological choices and low local industrial integration:** Concerning PV prices, the CSP technology is now proving, despite the advantage of storage, relatively expensive and no longer justified in the future, especially since local industrial integration levels are low, they do not justify the additional cost.
- **Low achievement of energy efficiency targets:** Established as a priority in the framework of the national energy strategy published in 2009, energy efficiency was a response to the control of demand in the same way as developing renewable energies, concerning the control of supply. The national energy efficiency strategy, adopted by the Government Council in 2017, considers energy efficiency as a factor of competitiveness and social progress and sets out targets by the consumer sector (industry, construction, agriculture, public lighting, and transport). More than 100 measures have been adopted on the economic, environmental, and social fronts. The energy savings targets, revised downwards from the initial ambition in 2009, are now 5% by 2020 (compared to 12% initially) and 20% by 2030
- **A financial imbalance of public sector enterprises**: ONEE's debts, despite slight improvements, show a structural fragility of its business model. In addition to the difficulties of technical and non-technical losses, VAT credits, or old debts in arrears, ONEE is not financially autonomous and regularly requests the financial support of the State.
  - **Governance not adapted to the evolution of the sector**
  - **Limited benefits for the citizen**
  - **Transport weighs heavily on the country's energy bill and**
  - **has many challenges**
  - **An electricity market still locked Given the benefits of the 2009 strategy, as well as the apparent limitations identified,**

indeed, the recent results of the energy strategy implementation and the focus on the photovoltaique renewable technology mentioned above requires the adoption of new strategic orientations.

2.4. The new strategic orientation and forecasted results

The energy strategy adopted in 2009 has consolidated many achievements and must now be revisited. It is necessary to focus on exploiting this deposit to position the Morocco as the energy transition leader. The exploitation of the Moroccan potential conducted in an integrated and inclusive way should benefit the citizen, the economy, and the State.

The current energy paradigm of dependence and uncertainty can even be reversed entirely. Morocco can meet its own energy needs and help meet the demand of countries with the same potential, particularly in Europe. Energy, which has only been an external ingredient of growth today, can become its catalyst. In doing so, Morocco must ensure that the right mechanisms are in place to maximize the potential without creating adverse collateral effects. Therefore, the new energy strategy will have to make social justice and environmental protection equal to technical and economic efficiency. For a new structured strategy, the CESE recommended:

- Given its potential and global developments, Morocco will need to place renewable energy at the center of new and better-defined strategic choices
  - Increasing the share of green electricity in the energy mix to lower costs and decarbonize
  - Decentralized production and digitalization
  - enable energy efficiency to play its full role in the energy transition
  - The transformation of mobility towards quality, mass, clean, digitalized, and electric public transport
  - Natural gas, a key to competitiveness for industry
  - Developing energy resources still under-explored, and the need to control logging
  - Energy sector governance needs to evolve to encompass all components of the energy transition and overcome barriers
  - Strengthening exchanges with Europe and building African partnerships
  - Launch of new energy sectors and strategic partnerships with Europe and Asia
  - **Training, research, development & innovation**: Invest more in human capital to build a pool of business skills and networks of researchers and engineers engaged in a global dynamic, both national and regional. And promote the initiatives undertaken by the ecosystem approach of the OCP group and its partners (IRESEN, MASCIR, etc.), which is the subject of this project, which is a partnership project between IRESEN and USMBA;

To predict the result of this new energy strategy, a prospective modeling to quantify these benefits. Several scenarios have been carried out by CESE to assess the options to be adopted [8]:

- **The scenario I** "**business as usual**" or continuity of current public policies:
- **Accelerated Scenario II**: This scenario, which starts from Scenario I, studies the socio-economic impacts resulting from voluntary energy demand management. improvement of energy efficiency +decentralization + progressive reform of the LPG subsidy, clean and electric mobility, and greater use of untapped technologies.
- **Scenario III «in orbit»:** this scenario, which starts from scenario II +Power-to-X linked to hydrogen as well as electricity export and energy-intensive industries.

Applying this new vision, the energy could fall to 32% by 2050

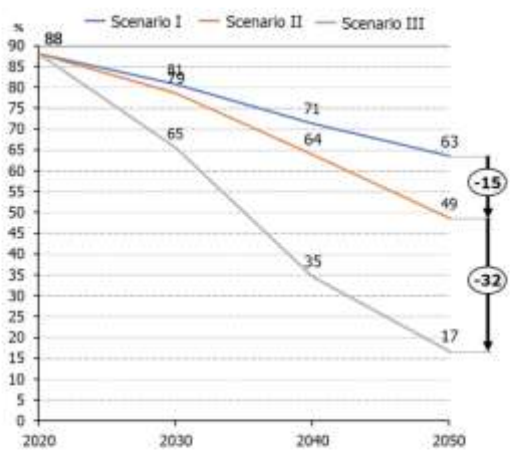


Figure 8: dependence energy ratio [12].

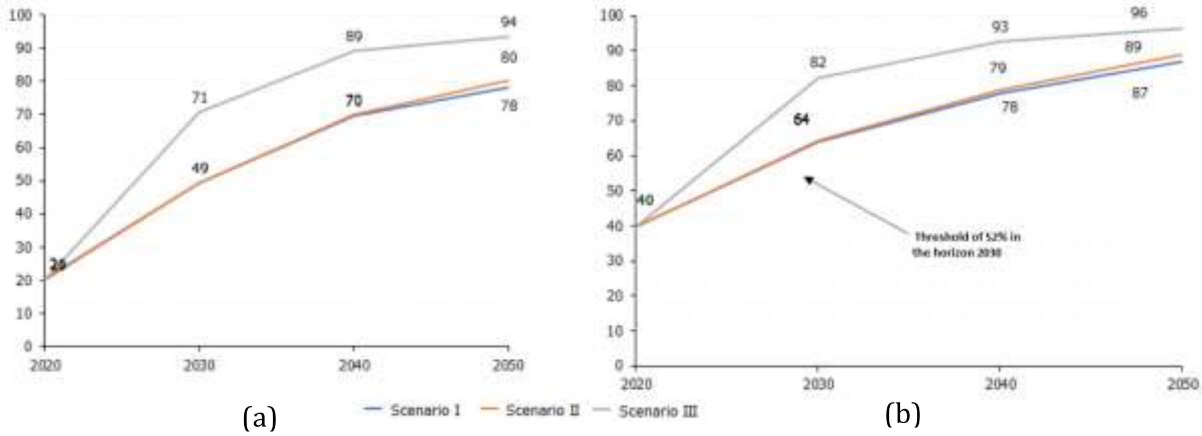


Figure 9: the share of renewable energy in the energy mix. (a)energy consumption(b)installed power [12].

By 2050, most of the energy consumed in the territory would be produced locally and of renewable origin: 78% in the case of the first scenario, 80% for the second, and 94% for the most ambitious.

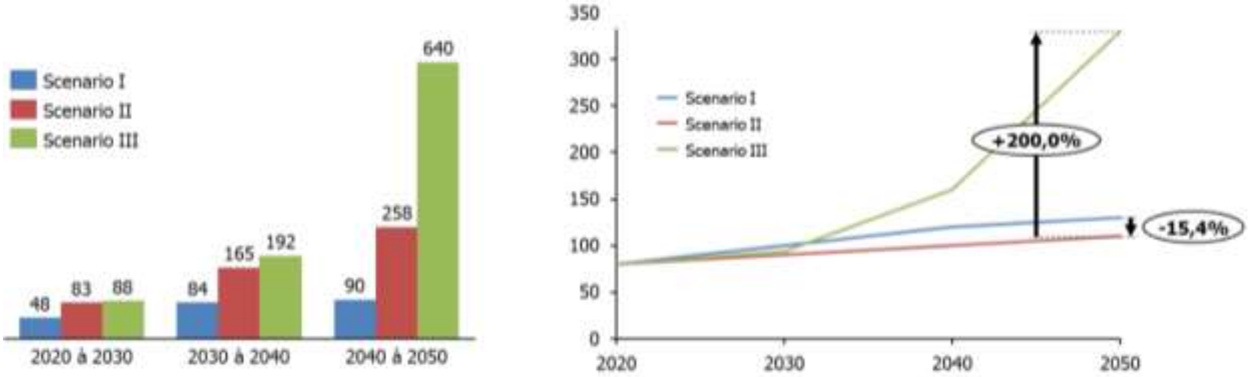


Figure 10: temporary jobs created VS cumulative permanent employment [8].

These jobs concern, in particular, the jobs of installers, integrators, logisticians, industrial processes, auditors, sales representatives, service companies (equipment engineering, systems, mechanics, electronics, software, financing, insurance, etc.), and service providers in various operating and maintenance streams

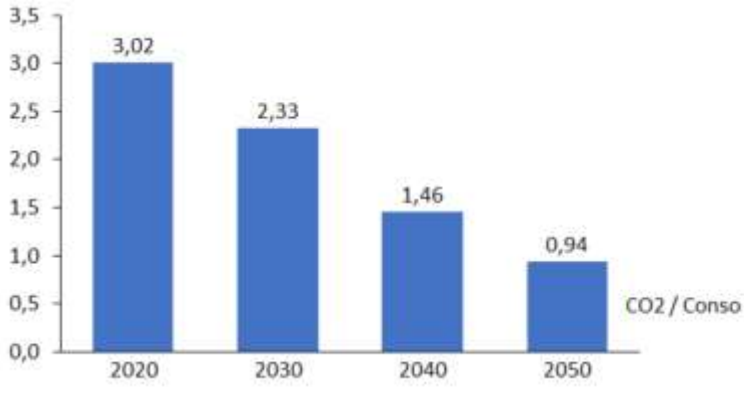


Figure 11: the ratio of CO_2 emissions to total primary consumption [12].

Measures to improve and electrify transport would make it possible to improve levels of CO_2 emissions, despite the sharp increase in energy consumption—the change from 3.02 tep to 0.94 in 2050[12].

3. The solar thermal in Morocco

3.1. Project lunched

The solar thermal market in Morocco was launched with the impetus of implementing the PROMASOL program. Indeed, the Moroccan Ministry of Energy and Mines launched this program in 2002 to promote the market of solar water heaters (CES) in Morocco by improving quality and certification, awareness campaigns, and training of qualified solar water heater installers. The program's management was entrusted to the Centre for the Development of Renewable Energies (CDER) under the MEM supervision. From an environmental perspective, PROMASOL has managed to reduce approximately 1.3 million tons of carbon dioxide (CO_2) since its creation in 2002. Concerning its economic impacts, PROMASOL increased the installed area of solar water heaters from about 36,000 m^2 to more than 220,000 m^2 in 2008 [9]. In terms of its social outcomes, the program has contributed to creating hundreds of jobs directly through the training and certification of installers and indirectly through specialized companies' creation.

This program aims to install 440,000 m^2 of solar thermal collectors in 2012 and 1.7 million m^2 in 2020. In terms of annual thermal energy output, these figures correspond to 1,190 GW/h by 2020. This program will avoid the emission of 920,000 tons of CO_2 per year and create 920 permanent jobs [13].

3.2. Moroccan market of solar water heater

Figure 9 shows the level of equipment of the Mediterranean countries that were ahead of Morocco in 2016[14].

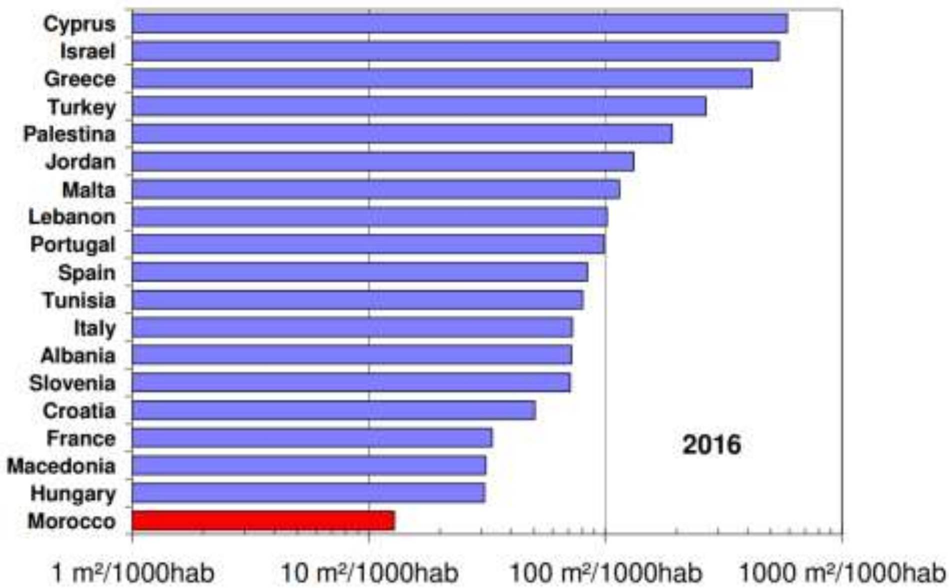


Figure 12: Ranking of the most equipped Mediterranean countries in solar thermal in 2016 [15].

To benchmark Morocco in the world, compare its solar thermal equipment (installed area per 1'000 inhabitants) with the global average.

Morocco's equipment level has always remained around four times lower than the global average; This means, notably, its equipment level remained parallel to the world's equipment level. Despite its good sunshine, Morocco is still not among the countries installed capacity in 2018 but, it is listed in the third group of countries (total of five), having between 20 and 70 m^2 for 1'000 habitants [16].

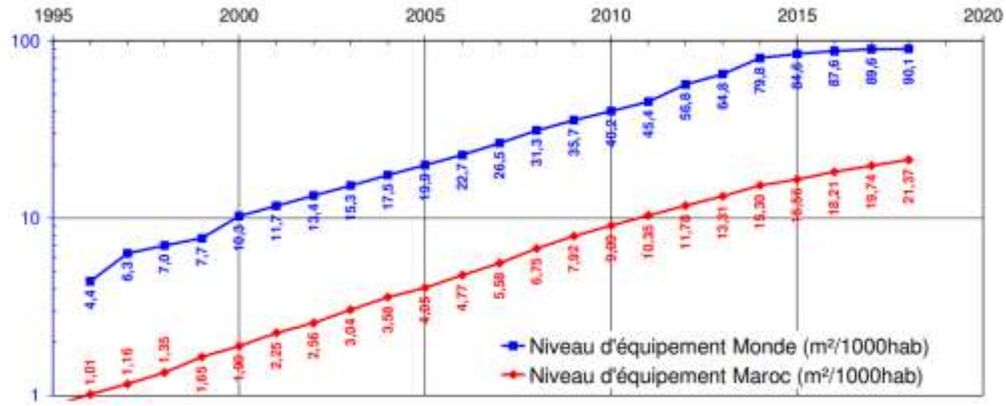


Figure 13: Evolution of the total installed area per inhabitant in Morocco compared to the world [15].

Morocco's share of installed solar thermal capacity is low but remained stable for three decades, around 0.10%. This means that the growth observed in Figure 13 and 14 has been parallel to the world trend [17].

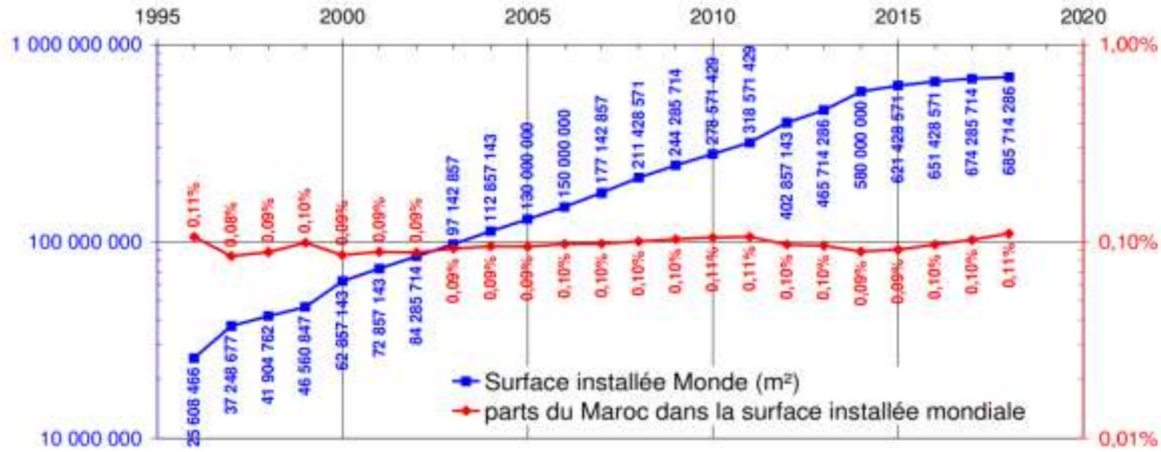


Figure 14: Evolution of cumulation of the installed area in the world and Morocco [15].

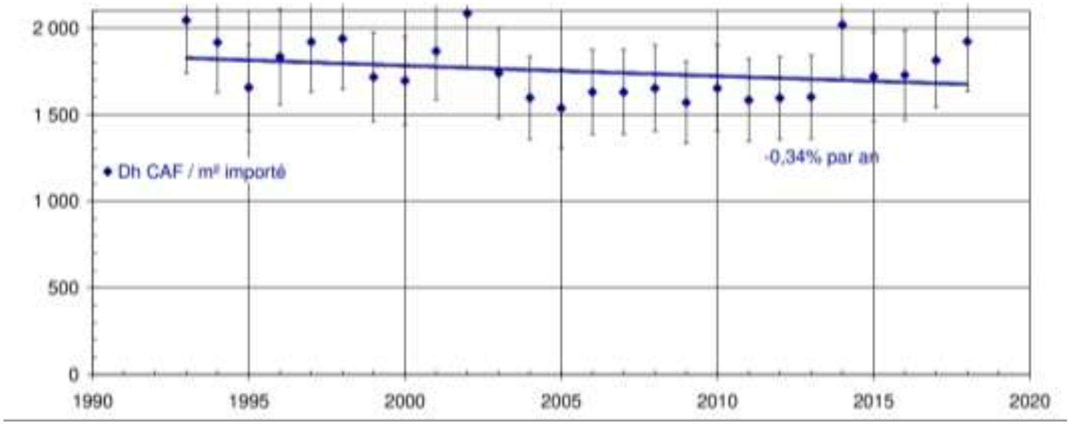


Figure 15: Evolution of the unit wholesale price of thermal collectors (MAD per m²) [18].

On a 30-year scale, Figure 15 shows that:

- Prices in Dh/m^2, Cost Insurance and Freight (CIF, blue diamonds in Figure 15), fluctuated by 15% (vertical blue bars in Figure 15) around a prolonged decrease of nearly 0.34% per year (decreasing blue curve in Figure 15). Solar thermal is no longer in the maturation phase and no longer undergoes a "learning curve." Thus, prices would have lost only 5 to 6% in 30 years, which is low but appreciable considering inflation and increased purchasing power [18].

The thermal energy produced by solar collectors has always been more profitable than that produced by grid electricity. Even very modest, this drop in prices combined with the rise in electricity prices has made this profitability even more attractive. Although "fair play," this competitiveness goes unnoticed because of the formidable competitor of thermal energy produced by butane gas, which is heavily subsidized. Indeed, the withdrawal of the compensation 12 kg bottle would place its price around 120-140 MAD and not 40 MAD. Because of this, in Morocco, a solar water heater depreciates in 10 years against its butane gas competitor, regardless of the advantages related to comfort and safety of use.

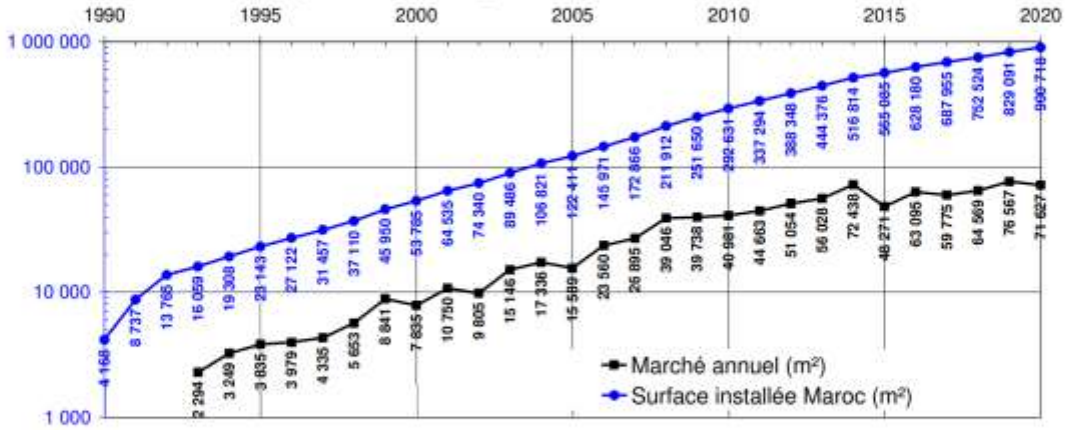


Figure 16: Evolution of the area installed annually in Morocco (black squares) and its cumulation (blue circles) [15].

The annual demand has almost multiplied by 15 in 25 years or average growth of nearly 11% per year, which is not very fast compared to the growth of other renewable energies such as photovoltaics [19]. It is even surprising that the demand is maintained over such a long period despite the harsh competition of butane gas.

Besides Since 1995 (almost 16% per year), the greenhouse gas emissions avoided by solar thermal electricity production slightly exceed 0,4 million tons of CO_2 equivalent in 2018 and contribute to reducing 1.47% of greenhouse gas emissions from electricity produced in Morocco [15].

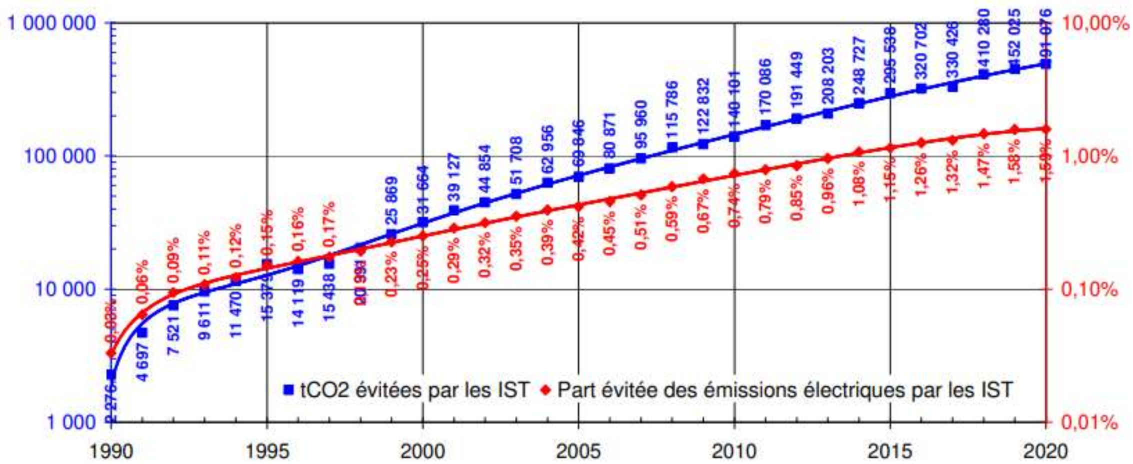


Figure 17: Evolution of greenhouse gas emissions avoided by thermal installations [15].

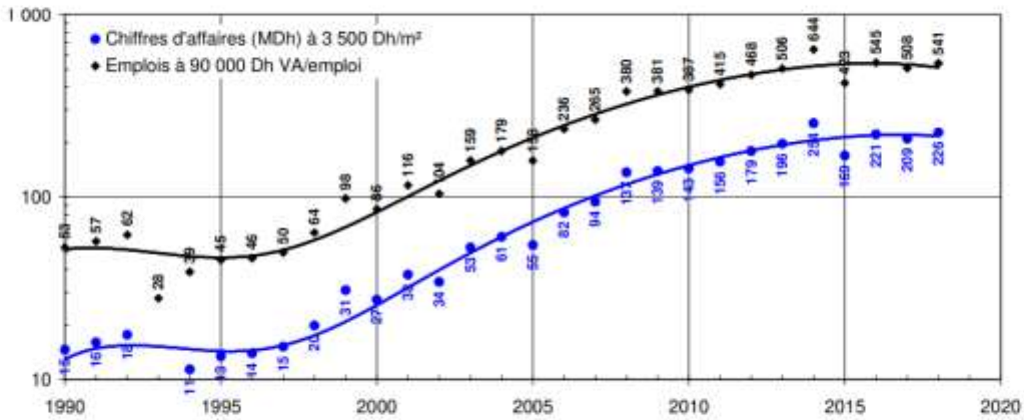


Figure 18: : Turnover evolution (solar thermal Moroccan market) [15].

The installation of solar thermal systems would have contributed to creating a few dozen jobs until around 2007. The number of jobs created amounted to a few hundred until around 2018 and seemed to stagnate around a little over 200 [15].

Solar water heaters (SWH) domestic have always dominated the sales of the market. They tend to dominate it more and more to exceed 80% after having fallen around 75% in the middle of the decade 2000-2010, probably under the PROMASOL Program's impetus [13], which was led by AMEE (Moroccan Agency of Energy Efficiency).

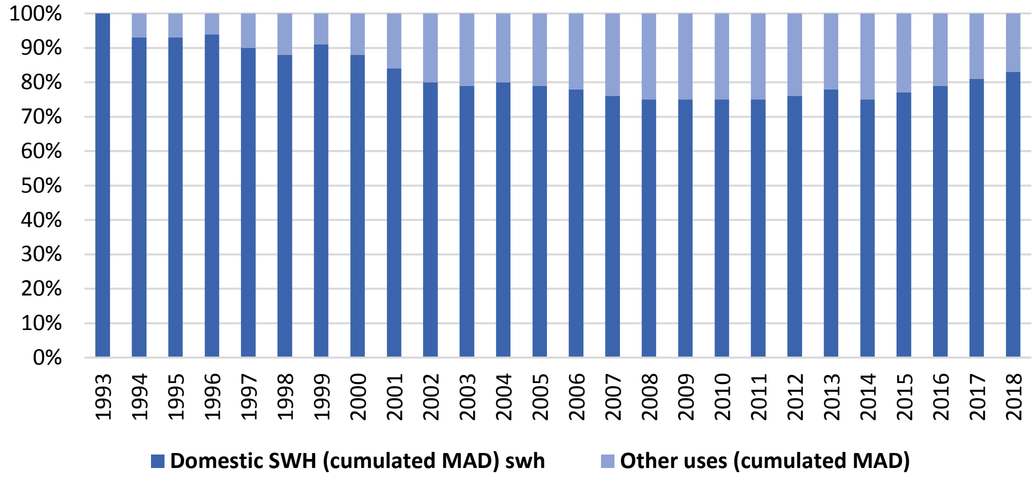


Figure 19: domestic solar water heaters sales in Morocco.

4. The SOL'R SHEMSY project; a promoter project for solar thermal in Morocco.

Based on the latest figures which shown the importance of solar thermal and its improvement, and the new strategic development of Morocco presented above Morocco offers several investment opportunities in the solar thermal energy sector by the programs launched previously discussed.

Including the project: «Sol'R-Shemsy» its main objective is to develop and market a solar water heater 100% Moroccan meeting European standards, with the best quality/price ratio in the social market.

The project to manufacture Moroccan solar water heaters will be prioritized because of its economic benefits (save up to 75% energy compared to electric or gas water heaters Table 1).

And protect the environment (fumes containing CO_2, thermal power plants), no radioactive danger, and bulky waste (nuclear power plants) but significantly reduce fatal accidents due to gas water heaters. According to the toxicology department of the National Institute of Hygiene, two thousand eight hundred twenty-eight cases of gas poisoning were recorded in 2015[3] and an average of 60 deaths each year due to inhalation of gas.

Water heater type	***solar***	***Gas***	***Electric***
Advantages	Useful with 100% free energy, produces no polluting emissions and no toxic or hazardous waste for the environment or health.	Gas is cheaper than electricity.	Installs very easily. Several capacities are available for meet different needs.
disadvantages	More suitable for sunny areas	Only suitable for a small draw-off, it is rather polluting.	consumes much energy
maintenance	Cleaning of solar panels. Verification of coolant pressure	Annual maintenance is mandatory (as for a gas boiler).	No special maintenance; however, the safety group must be checked regularly.
energy savings	40-75%	–	–
ROI	7-16 ans	–	–

Table 1: table comparative of water heater technologies.

Collaborators and budget

SOL'R shemsy it is a collaborative project between IRESEN and univessity Sidi Mohammed Ben Abdellah especially EST(ecole superieur de technologie).
Budget Global: 5 958 000 MAD
Financement de l'IRESEN : 3 550 000 MAD

The objective principal

Develop and industrialize a solar water heater «made in Morocco» compliant with European standards and with a better quality/price ratio of the market for the social.
The project is directly involved in the national energy strategy highlighting solar thermal technology through:

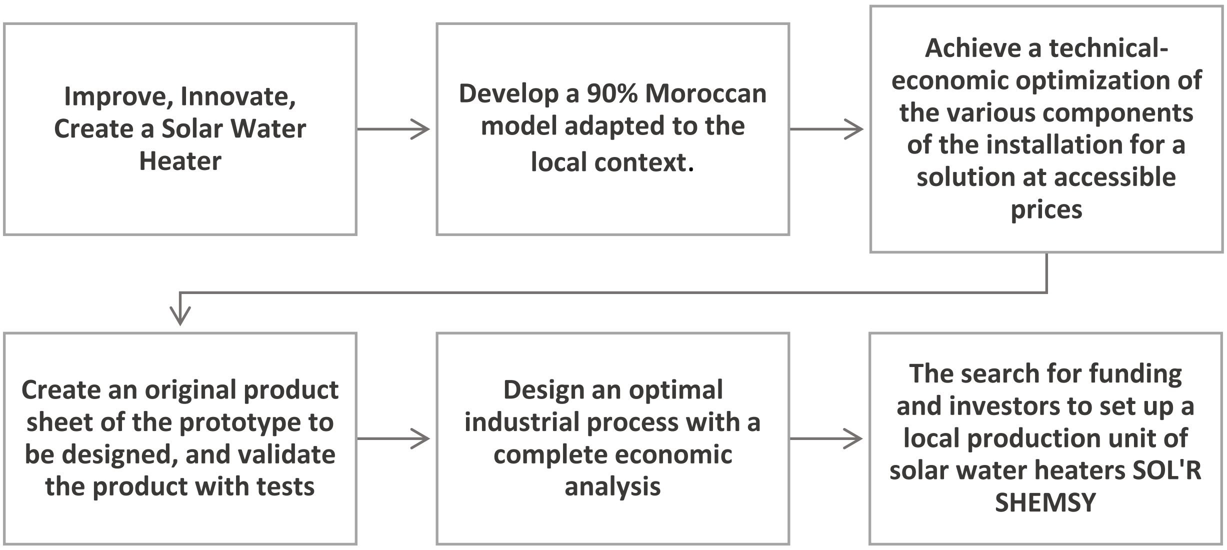
- The presentation of a solution adapted to the Moroccan context (social, economic, and environmental)
- National industrialization of solar thermal technology.
- The generalization of solar water heaters for various uses.
- Ease of integration into the industrial sector (technological mastery, encouraging prices, etc.).

Specific objectives and motivations

In addition to the project's principal and direct objective, this new industrial adventure will achieve several gains formulated under specific goals and make sources of the national motivation behind this project promoter.
Social: job creation.
Environment: Reduction of CO_2 emissions.
Safety: Reducing the death rate caused by gas water heaters.

Economy: Wealth Creation and National Economic Development.
Scientific research and technology: Mastering and adapting technology to the national context and benefiting from technology transfer.

Specific objectives and methodology:
To achieve the main objective, a list of specific objectives has been met and respected according to the following chronology



Conclusion
This chapter provided an overview of the thesis subject. By presenting an overview of the global situation of solar thermal and the Moroccan market's situation with its various shortcomings and problems, this allowed tracing the context of SOL’R SHEMSY project while identifying the reason for the creation of this new Moroccan industrial adventure. Finally, the chapter presented the strategy and methodology of work to achieve the objectives set out, while describing the stages of the project, which will be presented as a result in the following chapters.

Chapter II: *Energetic, economic and environmental analysis of thermosiphon solar water heaters in Morocco.*

Introduction

This chapter presents a detailed analysis of thermal performances and economic profitability of direct thermosyphon solar water heaters (TSWH) for residential requirements in Morocco. The optimum design parameters were defined and investigated using the dynamic TRNSYS simulation program. The optimum system was simulated under the six climatic conditions of Morocco in order to assess the related performances in terms of the collector efficiency and solar fraction. The major finding of this work is that large-scale integration of TSWH into Moroccan residences could provide up to 70% of thermal energy loads. An economic study was also developed to predict the life-cycle savings generated by generalization of this technology in Morocco for all residential building's categories. Approximately 1250 Million USD as national economies can be achieved. The environmental effects were also assessed to achieve the aims of this work and to evaluate the CO_2 emissions avoided due to this environmentally friendly solution.

1. *Technological context*

TSWH has become the most used technology around the world to heat water. It is defined as a passive solar technology based on natural convection, without the necessity of using a mechanical or an electrical power to pump and circulate the fluid neither its control. Fluid's circulation is the result of the density difference caused by the solar fluid heating considered as a driving force. Thermosyphon is described as the oldest technology which was introduced into the world market. Its performance is equal to the active systems and remains efficient in some cases. Hence, it can be concluded that the thermosyphon technology is the simpler system that could be designed [20]. The performance of solar water heaters has been developed and assessed theoretically and experimentally in several works. For example, Michaelides et al. [21] studied, different configurations of solar water heating systems, especially the under meteorological and socio-economic conditions of Cyprus, using different load profiles where the results showed that the solar fraction balanced between 89 and 63% depending to the consumption pattern studied (low and high). Moreover, Carlsson et al. [22] studied the thermosyphon system by replacing the traditional materials with polymeric ones, in order to compare the thermal and financial performances. It was found that the total energy costs could be reduced considerably using the polymeric material. Further detailed analyses on Thermosyphon performances were also investigated by Kalogirou et al. [23]. Authors studied the performance of a TSWH considering a series arrangement and formulated a novel heat exchanger model to evaluate the effects of many parameters such as the inclination angle, coupling geometries and aspect ratio on the global performance. The most influential parameter was found to be the aspect ratio which affected to temperature and efficiency according a linear trend [24], [25]. Many researchers have focused on innovative techniques to improve the efficiency of TSWH; Vasiliev [26] discussed using of new two-phase termosyphons technologies with advanced performances in order to study identical long construction with different working fluids, to examine the thermal performances especial the resistance which can be lowed using the vapordynamic thermosiphon (VDT) thernosyphons and polymeric loop two-phase under different parameters such us the inclination. The innovation continuous to appear in many other works, such as Piotr Felinski's [27] study which applies the phase change material (PCM) and the paraffin in evacuated tube collectors for domestic hot water application, to evaluate the effect of this materials and thermal performance. The results showed that the use of evacuated tube collector (ETC) with PCM and paraffin allowed height water temperatures and improved solar fractions during the peak loads and the periods of lowest solar radiation intensities under the typical meteorological year conditions, compared to the conventional types. While the conventional ETC showed in several works right performances in terms of water temperatures, yields, energy and exergy efficiencies for many applications; thermosyphonic and forced models [28], [29], [30]. Koffi et al. [31] studied theoretically and experimentally a TSWH with an internal exchanger in order to assess the effect of some operating parameters on the outlet temperature and collector thermal efficiency. This study was investigated for Ivory Coast climatic conditions in 2014. Zerrouki et al [32] studied the outlook for the use of a thermosyphon system manufactured in Algeria to predict its efficiency under the Algerien climatic conditions. Another study, with the same purpose was carried out under clear nights conditions and using the thermosyphon system with at-plat collectors by Runsheng Tang et al. [33]. Many other works were developed recently to study the general performances TSWH. For instance, Zeghib et al. [34] in Algeria presented a new theoretical simulation model, to predict the performance and the system behaviors under a thermosiphonic operation. The model was carried out using a flat plat collector with an area of 2 m^2 for a volume of 200L. Consequently, the theoretical analysis results height heat energy output, and satisfying efficiencies of collector and auxiliary heater improved by the good stratification of the model designed compared to the fully mixed conventional models. Vieira et al. [35] performed a multi-parametric study of SWH system under the climatic conditions of Brisbane in Australia, using EnergyPlus 8.6 software. The model's calculations and analysis showed that the split systems perform better than thermosiphon system in terms of service level and energy efficiency. Another parametric study based on the load profiles influence was carried out by ERICH HAHNE [36]. The analysis was performed using a solar combisystem using a storage tank with an internal thermosiphonally driven discharge unit, operating under realistic profiles of 1-min scales and a constant total yearly demand. The results showed that the load profile have a severe influence on the system performances, this is explained by the significant role of the duration and the flow rates of DHW on the stratification and temperatures. S. Fung et al [37] presented two existing systems in his work, drain water heat recovery (DWHR) system and two domestic solar water heaters (DSWH) intended for two houses, the study aims to evaluate the performances and the recovery potential of systems, using two collector technologies; flat plat collector and ETC. as a result the DWHR present an effectiveness of 50%, and the productivity of collectors was evaluated.

Several works were investigated to study other types of solar water heaters. The analysis of Hobbi et al. [38] could be cited as example. Authors simulated and optimized a forced circulation using the flat plat collectors for residential SWH application in Montréal CANADA, the study aims to show the importance of solar energy which could provide between 83-97 % of the hot water demand in summer. The aim is to improve the efficiency of systems integrated in buildings, in order to reach economical and efficient buildings. Something that can be achieved with a multitude of actions [39], [40]. Thermosyphon effect have several other technological uses, Chen and Yang [41] solve the efficiency problem for concentrating solar cells due to their height temperature, by the integration of the loop thermosyphon in the heat dissipation system. Different fluid for the operating thermosyphon loop where used. The results of theoretical and experimental analyses showed that the acetone is better than water and ethanol in term of heat transfer. Solomon et al. [42] focused on the closed system presenting the comparison between the two phase closed thermosyphon (TPCT), porous copper coating and the uncoated, the results showed that difference in heat transfer coefficients between the two cases at an angle of 45 ° is 44% at a heat flux of 10 kW.m-2.furthermore more the copper coating is thin more the wall temperature of the evaporator is significant and the heat transfer coefficient is increased, which makes the thin coating a suitable for cooling high-density power. Kousksou et al. [43] presented a numerical study which is concerned with the integration of phase change materials (PCMs) in solar-based domestic hot water (DHW) systems, so as to enhance its overall performances. In the literature, many works join to the technical study an economic analysis to present a significant result, especially for the strategically and policies works [44]. Recent economic studies regarding solar water heaters integration were published. The techno-economic benefits and reliabilities of solar water heaters using the Monte Carlo analysis were estimated by Rezvani et al. [45]. They focused on a product range manufactured by a local company in Australia. Sokka et al. [46] focused on the environmental impacts of solar energy. Greenhouse gas emissions and mitigation of climate change reduction were studied which is the main aim of the global climate policy.

For Morocco, solar energy is a crucial economic issue in coherence with the choice of sustainable development and the related energy policy, which aims promoting renewable energies to meet 20% of the country's domestic energy needs, improving energy efficiency to achieve 12% reduction by 2020. Solar energy utilization is expected to play a pivotal role in environment protection and social development [47], [48]. This orientation leaded many actions, laws and projects to integrate green solutions precisely the solar within different sectors, especially the building sector which presents 20.4% of the national total energy consumption, this sector is characterized, firstly by a quick development because of fast population growth and an increasing urbanization rate [47]. Through this study, large-scale integration of TSWH into various types of buildings in Morocco is discussed energetically and financially based on climatic data of six different climatic zones of Morocco. The performance indicators describing the system in this work are the solar fraction and the collector efficiency. The simulation outputs were then used to develop the economic study, which aims to quantify the possible financial gains of generalizing the utilization of TSWH in the domestic sector of Morocco. This assessment was made by comparing the solar system with conventional gas heaters which is the most used heating option in the country, two scenarios of subsidies elimination for conventional energy sources are discussed and national potentiality of CO_2 emissions reduction resulting from generalizing this kind of water heaters is assessed.

2. *Methodology*

The TSWH is simulated using TRNSYS program. Main operating and design parameters were introduced; the design parameters include general specifications of the used thermal collector, storage tank and auxiliary system. Weather data files for the various Moroccan climatic zones are then integrated into the simulation process. A realistic load profile is as well considered for accurate prediction of thermal loads and system performances. Based on the hourly output data, namely water outlet in the solar collector and temperature inside the tank, energetic performance indexes were built. These indexes are the monthly solar fractions and collector thermal efficiencies.

Based on the evaluated useful energy produced by the TSWH and the total thermal loads required, a large-scale economic study is developed to examine the potential of generalizing these systems into the Moroccan residential sector. This evaluation is based on a comparison of cumulative energy savings generated by switching from the conventional gas heaters to TSWH. Finally, it was possible to estimate the overall reductions in CO_2 emissions.

The assessment is believed to be sufficiently accurate as it follows a rational methodology for quantifying the full-scale economic impact of generalizing these solar systems. First of all, it was necessary to evaluate the number of capita per climatic zone. This parameter is not yet available in national database. These data are available only in a regional basis. Therefore, it was essential to convert the available regional data to comply with the climatic zoning. A schematic diagram of the followed methodology is shown in Fig. 20.

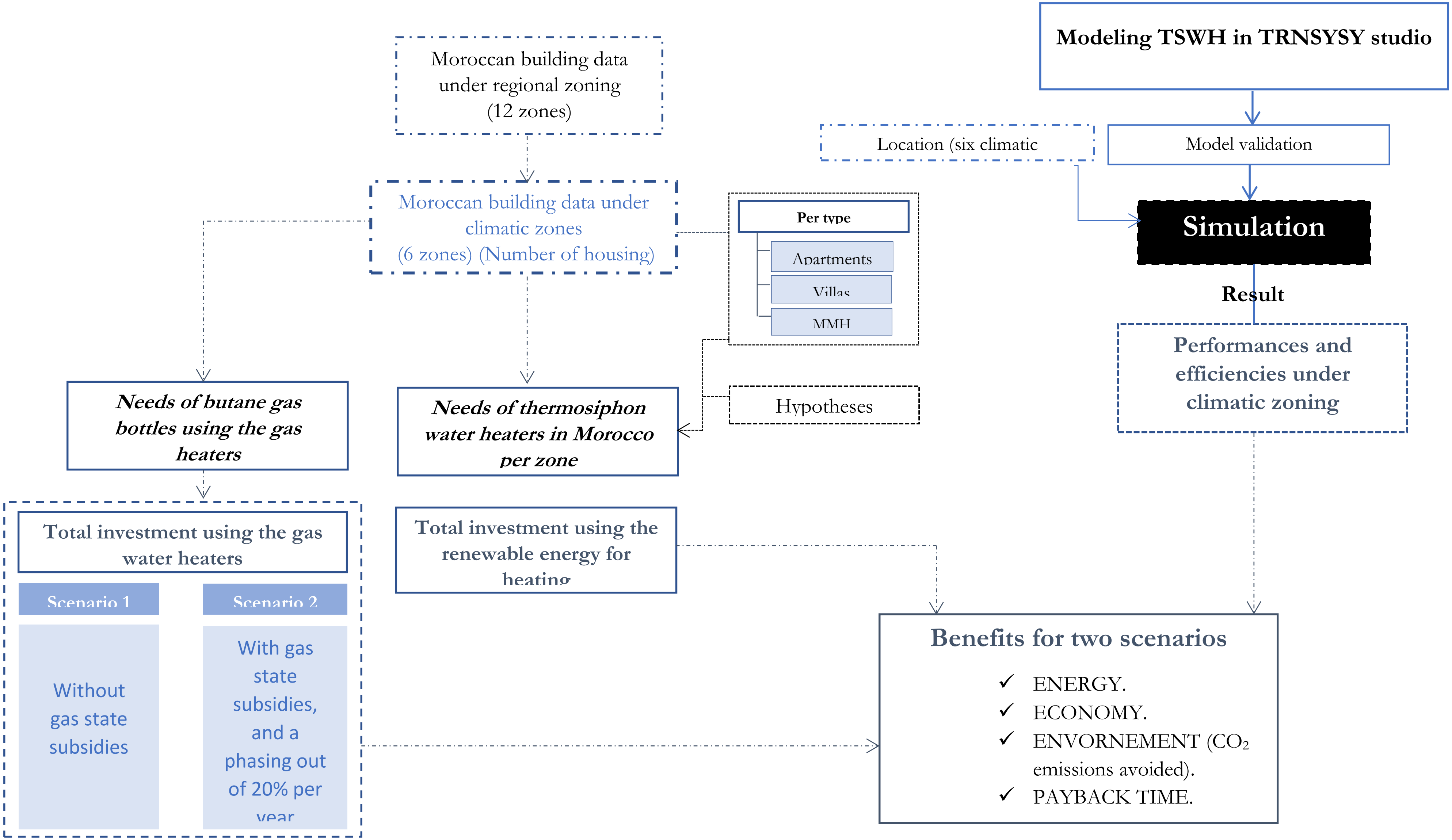


Figure 20: the study flowchart methodology.

3. Simulation process

3.1. Examined configuration

The TSWH consists of a flat plate collector connected to an auxiliary heater integrated inside a horizontal tank as presented in Fig. 21. First of all, optimum tilt angles per each zone were determined. These angles are summarized in Table 2.

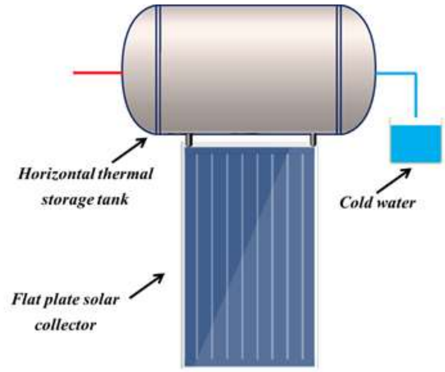


Figure 21:Thermosyphon system schematic.

zone	AGADIR	MARRAKECH	ERRACHIDIA	FES	IFRANE	TANGIER
Optimal angle	30°	31°	31°	32°	30°	32°

Table 2: Optimal tilt angle.

Moreover, the technical characteristics of the solar collector used during the simulations under TRNSYS are presented in the Table 3.

Parameter	Value	Unit
Collector area	2.2	m^2
Intercept efficiency	0.74	-
Efficiency slope	12.33	$kJ\ h^{-1}m^{-2}K^{-1}$
Tested flow rate	30	$kg\ h^{-1}m^{-2}$
Collector slope	30-32	°
Number of parallel collector risers	10	-
Riser diameter	0.2	mm
Header diameter	0.2	mm
Header length	1.0	mm
Collector inlet to outlet distance	1.273	mm
Collector inlet to tank outlet distance	0.25	mm
Collector inlet diameter	0.2	mm
Length of collector inlet	1.0	mm
Collector outlet diameter	0.2	mm
Length of collector outlet	1.0	mm
Outlet pipe losses coefficient	15	$kJ\ h^{-1}\ m^{-2}.K^{-1}$
Tank volume	202	L
Fluid specific heat	4.190	$kJ\ kg^{-1}\ K^{-1}$
Fluid density	1000.0	$kg\ m^{-3}$
Tank configuration	HORIZENTAL	-
Maximum heating rate	2	kW
maximum pressure	8	bar
thermal losses of the tank	1,8	$kW\ h^{-1}\ m^{-2}$
capacity of solar circuit	5	L

Table 3: Thermosyphon solar water heater characteristics.

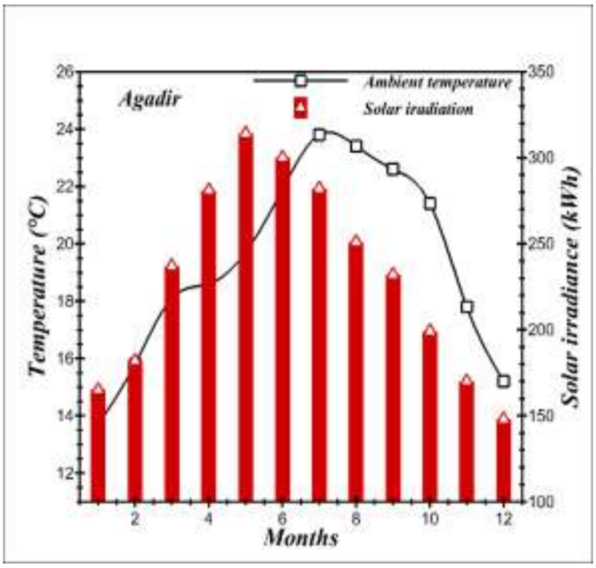
3.2. Climatic data and geographical specification

The Moroccan climatic conditions used to assess the thermal performance of the thermosyphon are presented in Table 4 and Fig. 22 This new climatic zoning is actually established by the Moroccan Agency of Energy Efficiency (AMEE).

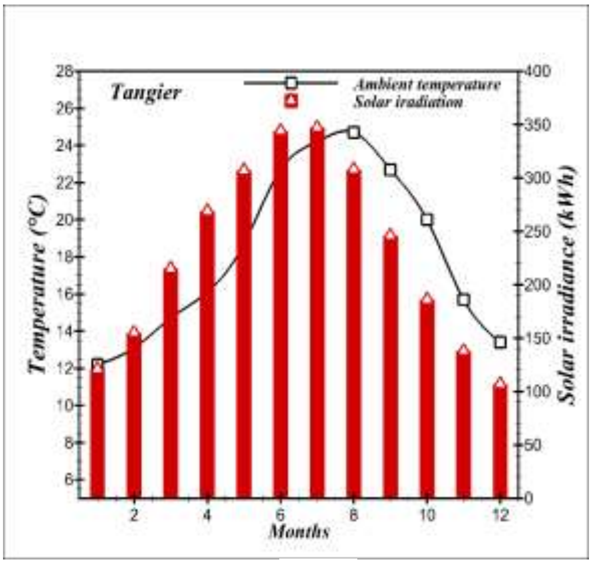
climatic zone	representative city	Altitude (m)	coordinates	climate	Temperature °C
Z1	AGADIR	31	30°25'N9°36'W	Subtropical-semiarid	14.3–23.2
Z2	TANGER	20	35°46'N 5°48'W	Mediterraneanhot	12.6–24.2
Z3	FES	403	34°03'N 4°58'W	Mediterranean/continental	9.6–26
Z4	IFRANE	2019	33°32'N 4°58'W	Humidtemperateclimate	6.2–25.4
Z5	MARRAKECH	457	31°37'N 8°00'W	Semiarid	12.4–28
Z6	ER-RACHIDIA	141	31°55'N 4°25'W	Hot desert	9.1–33.2

Table 4: General Information of the climatic zones under investigation.

Because the Moroccan climate exhibits a great variability according to the geographical zone, it was necessary to perform a segmentation of the whole territory into areas with similar overall meteorological specifications. Accordingly, the Moroccan Agency of Energy Efficiency (AMEE) [49], proposed a climatic fragmentation of Morocco according to six climates, each climate is evidenced by a representative city. Table 4 shows general information about these zones. Also, the main meteorological data (i.e. average ambient temperature and solar irradiations on a monthly basis) affecting the energetic performance of TSWHs is displayed in Fig. 22 One can observe that the climate presents a remarkable variety which is expected to influence greatly the overall thermal behavior and performance of TSWHs.



(a)



(b)

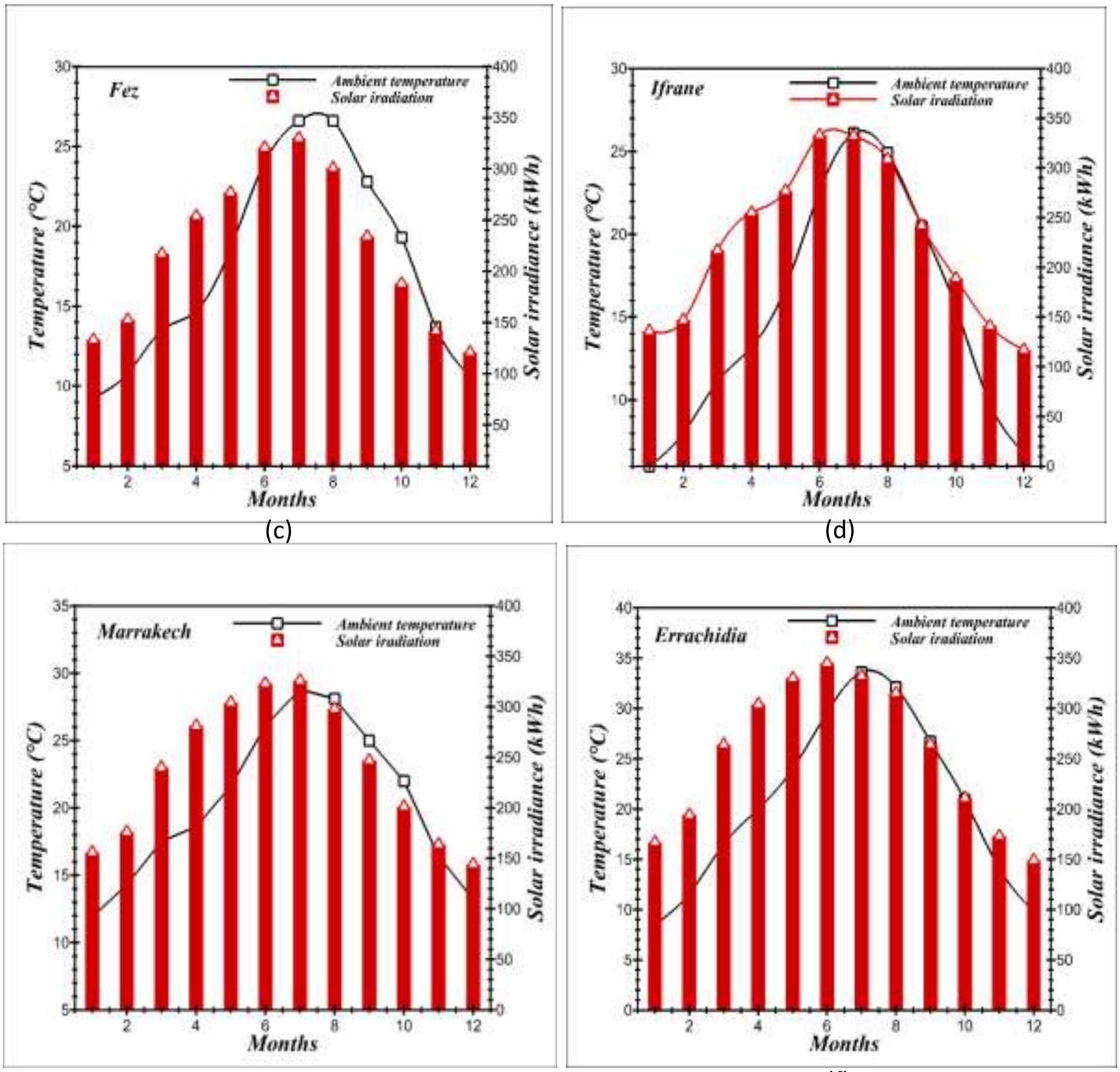


Figure 22: weather data (a)Agadir(b)Tangier (c) Fez (d) Ifrane (e) Marrakech(f) Errachidia

3.3. Load profile

The distribution of the hourly hot water consumption is affected by different factors. It varies according to the seasons, days, or the habits of each considered Moroccan family. Various hot water load profile has been studied on the literature review such as the constant, the early morning, the late morning, rand, or the late afternoon profiles. For the present study, the consumption of 200 liter per day is described according to the realistic load profile presented in the Fig. 23.

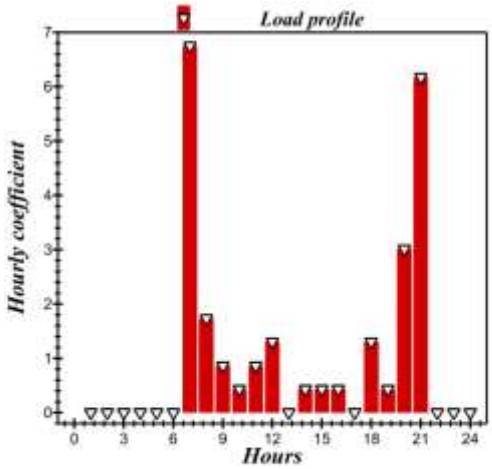


Figure 23: Realistic Moroccan load profile for hot water consumption.

3.4. Physical modeling

The conventional heat transfer modes use the Solar Energy from the incident radiation to the domestic hot water all the path traveled by this energy: the radiation, the convection (natural and forced depending on the configuration of the SWH), and conduction.

The following equation describes conduction:

$$\phi_{cd} = -\lambda S\overrightarrow{grad(T)} \quad (1)$$

$$\phi_{cd} = -\lambda S\frac{\partial T}{\partial x} \quad (2)$$

ϕ_{cd} is the heat flow by conduction (W), S is the area of the heat flow passage section (m^2), λ is the thermal conductivity (W/m. °C) et X is the space variable in the direction of the flow (m).

In contrast the natural convection is the fluid movement is caused by density variations caused by temperature variations within the fluid, as is the case with thermo-circulation. But the forced one is induced by a cause independent of the differences in temperature (pump, ventilation, etc.), which is the case pf forced circulation SWH. Newton's Law governs this transfer mechanism:

$$\phi_{cv} = h_c S(T_p - T_f) \quad (3)$$

ϕ_{cv}: Convective heat flow (W), T_p is the solid surface temperature (°C), Tf is the temperature of the fluid before contact with the solid (°C) and hc is Coefficient of thermal transmission by convection (W/ m^2 °C).

on the other hand, radiation is described by the fundamental law of Stefan-Boltzmann:

$$\phi_r = \varepsilon\sigma S(T_P^4 - T_\infty^4) \quad (3)$$

For SWH studied the absorption of incident radiation heats the absorbent wall. The fluid circulating under this wall recovers by convention part of this energy absorbed and has a rise in temperature [T_{fo}-T_{fi}] through the collector. (T_{fo} is the fluid outlet temperature and T_{fi} is the inlet temperature to the collector.

The type 45 operates according to a mathematical model [50] which presents the various phenomena describing its operation. The Bernoulli formula can be applied to define the pressure drop in the thermosyphon system's nodes (equation (4)):

$$\Delta P_i = \rho_i g\Delta h_i + \rho_i g h_{Li} \quad (4)$$

where (i) is the index of the node, Δh_i the height of the ith node , ρ is the density, $h_{Li}$is the frictional head loss in the piping, and g is the gravitational constant.

The flow rate on the thermosyphon system must be involved in order to satisfy the conditions describing the total pressure differences, which are determined using the equation above at any time by the next expression (5):

$$\sum_{i=1}^{i=N} \rho_i \Delta h_i = \sum_{i=1}^{i=N} \rho_i h_{Li} \tag{5}$$

The overall thermal assessment of the collector is done by decorticating the collector. The thermal balance of the absorbent wall is written:

$$\phi_{sa} = \phi_p + \phi_u + \phi_{st} \tag{6}$$

ϕ_{sa}Is the solar flux absorbed, $\phi_p$is the flux lost by the absorbent wall, $\phi_u$is the useful flow transmitted to the fluid and $\phi_{st}$is the flow stored in the collector that is written:

$$\phi_{st} = M_f C_f \frac{\partial T}{\partial t} \tag{7}$$

And M_f is Fluid mass of the collector defined by:

$$m_i C_i = M_f C_f \tag{8}$$

(i) Representing the different components of the collector, T is the average temperature of the collector and t is the time. So, it is concluded that the power absorbed by the collector is:

$$\phi_{sa} \approx \tau_{cs} \alpha_{ps} G(i,\gamma)^* S \tag{9}$$

$G(i,\gamma)^*$Is solar incident illumination (flux density) on the collector (W), $\alpha_{ps}$is the absorption coefficient of the absorbent wall related to radiation solar and τ_{cs} is the transmission coefficient of the transparent cover related to the solar radiation. If the heat transfer fluid does not change state, the useful energy is written:

$$\phi_u = q_{cf}(T_{fo} - T_{fi}) \tag{10}$$

q_{cf} Heat transfer fluid flow rate (W/°C) = mass flow rate x heat capacity. It can be written under the equation bellow:

$$Q_u = r\, S\big(F_{R(\tau\alpha)}\, I_T - F_R U_L (T_{ci} - T_a)\big) \tag{11}$$

$$r = \frac{F_{R(use)}}{F_{R(test)}} = \frac{G\left(1 - \exp\left(-\frac{F' U_L}{G C_P}\right)\right)}{G_{test}\left(1 - \exp\left(-\frac{F' U_L}{G_{test} C_P}\right)\right)} \tag{12}$$

The assessment of energy transfer requires the loss analysis. Furthermore, the thermal losses of the collector are put considering the collector global losses coefficient h_L, the average temperature of the absorbent wall T_{aw} and T_a the External air temperature in the form:

$$\phi_L = h_L (T_{aw} - T_a) S \tag{13}$$

In the case of a flat plate collector, the average temperature T_{aw} can be initially calculated by:

$$T_{aw} = \frac{3T_{fo}+T_{fi}}{4} + \Delta T \tag{14}$$

For the collector the temperature in the Kth node is calculated by the next expression (15):

$$T_{ck} = T_a + \frac{I_T F_{R(\tau\alpha)}}{F_R U_L} + \left(T_{ci} - T_a - \frac{I_T F_{R(\tau\alpha)}}{F_R U_L}\right) \ exp\left[\frac{F\prime U_L}{G\ C_p}\ \frac{(k-1/2)}{N_x}\right] \tag{15}$$

where Nx is the number of nodes over which the size of the collector deviates to obtain the weight of the fluid in the collector.

The changes in the fluid heat transfer coefficient results in F' and UL which are considered negligible. The combination of the intercept efficiency at normal incidence FR (τα)n, and the Incidence Angle Modifier (IAM). ((τα))n allow to calculate The parameter FR(τα) (16):

$$\frac{(\tau\alpha)}{(\tau\alpha)_n} = \frac{I_{bT}\frac{(\tau\alpha)_b}{(\tau\alpha)_n} + I_d \frac{1+cos\,\beta}{2}\frac{(\tau\alpha)_s}{(\tau\alpha)_n} + I_g \frac{1+cos\,\beta}{2}\frac{(\tau\alpha)_g}{(\tau\alpha)_n}}{I_T} \tag{16}$$

where the incidence angle modifiers for ground and sky diffuse radiation is calculated using the next equation (17):

$$\frac{(\tau\alpha)_b}{(\tau\alpha)_n} = 1 - b_0\left(\frac{1}{\cos\theta} - 1\right) \tag{17}$$

The outlet temperature from the flat plat collector is finally deduced as (18):

$$T_{CO} = \frac{Q_u}{\dot{m}C_p} + T_{Ci} \tag{18}$$

solar collector performance: The efficiency of a collector is defined related to the incident solar flux as follows (i is the inclination of the collector relative to the ground (horizontal)):

global efficiency: $$\eta = \eta_0 - \frac{K(T_P - T_a)}{G} \tag{19}$$

internal efficiency: $$\eta_i = \frac{\phi_u}{\phi_{sa}} \tag{20}$$

optical efficiency: $$\eta_0 = \frac{\phi_{sa}}{G(i,\gamma)^*} \tag{21}$$

Thermal assessment of different components: The thermal exchanges between the absorbent wall and the outside in a covered solar collector is done convectively

Assumptions:

- The inertia of the absorber and bottom is neglected
- The temperature fields T_c of the cover, T_p of the absorber, and T_b of the bottom are uniforms.
- Coverage is opaque to radiation.
- The blanket, absorber, and bottom are assumed to be gray bodies with different optical properties vis-à-vis solar radiation in the interval [0, 3 m] and to radiation [>3 m].

Thermal losses:

Many types of losses are present in the system; the most important one is the frictional head loses especially on the pipes, and the equation below describes this type of losses (22):

$$H_p = \frac{fLv^2}{2d} + \frac{Kv^2}{2} \tag{22}$$

The parameter F is the friction factor, determined according to the value of the Reynolds coefficient Re which describe the nature of the flow and corrected to take in account the frictions on the connecting parts of pipes. The head loses pipe varies according to the position and the conditions in the system, these specifications are taken into account by the coefficient K, e.g. loses due to different types of bends, the parts of the tank which are connected to the collector.
The thermal performance of collector is modeled according to the Hottel- Whillier equation. Many parameters describe the system: the equation bellow (23) defines the F'UL parameter which is calculated by the FrUL and G parameters determined on the test conditions.

$$F'U_L = -G_{test}\, C_P \ln\left(1 - \frac{F_R U_L}{G_{test} C_p}\right) \tag{23}$$

Absorber heat losses can be written

$$\phi_L = \phi_{c,w-c} + \phi_{r,w-c} = \phi_{c,c-a} + \phi_{r,c-a} - \phi_{s-c} \tag{24}$$

$\phi_{c,w-c}$Is the energy exchanged by convection-conduction between the absorbent wall and the cover.
$\phi_{r,w-c}$ is the energy exchanged by radiation between the absorbent wall and the cover.
$\phi_{c,c-a}$ is the energy exchanged by convection between the cover and the outside air.
$\phi_{r,c-a}$ is the energy exchanged by radiation between the cover and the external environment.
ϕ_{s-c} is the Solar energy absorbed by the transparent cover.
Each of these flows can be expressed as follows:

$$\phi_{c,p-c} = h_{c,w-c}(T_P - T_c)S \tag{25}$$

$h_{c,p-c}$is the coefficient of heat transfer between two parallel surfaces delimiting an enclosed space containing air.
$\phi_{r,w-c}$Can be calculated by considering the absorbent wall and the roof as two infinite parallel surfaces (the distance between them is small in front of their width and length) gray and opaque (hypothesis of the opaque coverage to the radiation), these hypotheses allow to write:

$$\phi_{r,w-c} = \sigma \frac{T_P^4 - T_C^4}{\frac{1}{\alpha_{pi}} + \frac{1}{\alpha_{ci}} - 1} S \tag{26}$$

Which can also be written

$$\phi_{r,w-c} = h_{r,w-c}(T_P - T_c) \tag{27}$$

$\phi_{c,c-a}$ Which depends mainly on the wind speed, can be calculated by:

$$\phi_{c,c-a} = h_{c,c-a}(T_c - T_a)S \tag{28}$$

$$\phi_{r,c-a} = \sigma\alpha_{ci}(T_c^4 - \varepsilon_a T_a^4)S = \sigma\alpha_{ci}(T_c^4 - T_{sky}^4) \quad (29)$$

$$\phi_{r,c-a} = h_{r,c-a}(T_c - T_a)S \quad (30)$$

$$\phi_{s-c} = \alpha_{cs}G(i,\gamma)^* \quad (31)$$

The energy lost by the absorbent plate can then be written:

$$\phi_p = (h_{c,w-c} + h_{r,w-c})(T_P - T_c)S = (h_{c,c-a} + h_{r,c-a})(T_c - T_a)S - \alpha_{cs}G(i,\gamma)^*S \quad (32)$$

If $\alpha_{cs} \approx 0$ (for glass), the following simplified expression is obtained:

$$\phi_p = \frac{T_p - T_a}{\frac{1}{h_{c,w-c}+h_{r,w-c}} + \frac{1}{h_{c,c-a}+h_{r,c-a}}} S \quad (33)$$

Thermal assessment at nodes

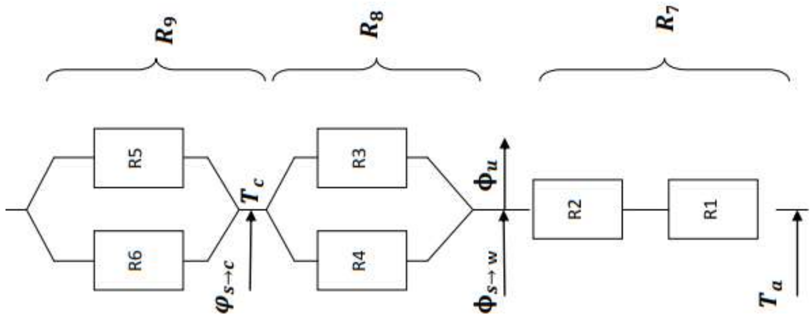


Figure 24: The equivalent electrical pattern of heat transfer.

The thermal assessment at nodes can be expressed:

$$\phi_{s-c} + \frac{T_p - T_c}{R_8} = \frac{T_c - T_a}{R_9} \quad (34)$$

$$\phi_{s-w} = \frac{T_p - T_c}{R_8} + \frac{T_p - T_a}{R_7} + \frac{\phi_u}{S} \quad (35)$$

$$R_1 = R_6 = \frac{1}{h_{wind}} \quad (36)$$

h_{wind} is the wind speed:

$$h_{wind} = 5.7 + 3.8U_{wind} \quad (37)$$

$$R_2 = \frac{e_i}{\lambda_i} \text{ and } R_3 = \frac{1}{h_{r,w-c}} \quad (38,39)$$

And

$$h_{r,w-c} = \sigma \frac{(T_P^2 + T_C^2)(T_p - T_c)}{\frac{1}{\alpha_{pi}} + \frac{1}{\alpha_{ci}} - 1} \quad (40)$$

α_{pi} is the absorption coefficient of the plate related to radiation, and α_{ci} is the coefficient of absorption of cover related to radiation.

$$R_4 = \frac{1}{h_{c,w-c}} \quad (41)$$

$h_{c,w-c}$ is calculated by the following correlation:

$$h_{c,w-c} = Nu\frac{\lambda_{air}}{b} \tag{42}$$

And $$Nu = 1 + 1.44\left(1 - \frac{1708(1.8\sin\beta)^{1.6}}{Ra\cos\beta}\right)\left(1 - \frac{1708}{Ra\cos\beta}\right) + \left(\frac{Ra\cos\beta}{5830}\right)^{0.666} + 1 \tag{43}$$

β Is the angle of the inclination of the flat plate collector, b is the thickness of the airstrip separating the glass from the absorbent plate (m), and $\lambda_{air}$is the thermal conductivity of air (W/m.K).

$$R_5 = \frac{1}{h_{r,c-a}} \tag{44}$$

$$h_{r,c-a} = \sigma\alpha_{ci}\frac{T_c^4 - \varepsilon_a T_a^4}{T_c - T_a} \tag{45}$$

$$h_p = \frac{1}{\frac{1}{h_{c,w-c}+h_{r,w-c}} + \frac{1}{h_{wind}+h_{r,c-a}}} + \frac{1}{\frac{e_i}{\lambda_i} + \frac{1}{h_{wind}}} \tag{46}$$

h_{wind} is the wind speed (m/s), e_i is the collector background thickness (m), and $\lambda_i$is the thermal conductivity of the collector bottom (w/m°K).

Determination of the temperature profile of the absorbent wall in the OY direction

The thermal balance of the piece of the plate (absorbent) of unit length between y and y + dy is written: $$\phi_{sa} - \lambda_p e_p\left(\frac{\partial T}{\partial y}\right)_y = -\lambda_p e_p\left(\frac{\partial T}{\partial t}\right)_{y+dy} + h_p(T_m - T_a)dy \tag{47}$$

$\lambda_p e_p$Is the thickness and thermal conductivity of the absorbent wall, $h_p$is the overall coefficient of loss of the absorbent wall, and $\phi_{sa}$is the density of solar energy absorbed by the plate.

$$\frac{\partial^2 T_p}{\partial y^2} = \frac{h_p}{e_p\lambda_p}\left(T_p - T_a - \frac{\phi_{sa}}{h_p}\right) \tag{48}$$

Assuming that $\overline{\overline{T_p}} = T_p - T_a - \frac{\phi_{sa}}{h_p}$ and $\omega^2 = \frac{h_p}{e_p\lambda_p}$ (49,50)

We obtain $$\frac{\partial^2 T_p}{\partial y^2} - \omega\overline{T_p} = 0 \tag{51}$$

We solve the equation we get the expression of the useful flow gained by each tube per unit length in the Ox direction of the flow:

$$d\phi_u = F'S[\phi_{sa} - h_p(T_f - T_a)] \tag{52}$$

$$F' = \frac{\frac{1}{h_p}}{\left[\frac{1}{[(1-D_e)F+D_e]h_p} + \frac{1}{h_i\pi D_i} + \frac{e_i}{\lambda_i\pi D_i}\right]} \tag{53}$$

F' appears as the ratio of thermal resistance to transfer between the plate and the outside on the thermal resistance to transfer between the fluid and the outside. F' is therefore a number less than or equal to the unit called absorbent plate efficiency factor.

The plate between y = 0 and $y = \frac{l-D_e}{2}$. It plays the role of a heating fin related to the tube.

The fin efficiency is: $$F = \frac{\tan[\omega(1-D_e)]}{\frac{\omega(1-D_e)}{2}} \quad (54)$$

Temperature profile in the direction of fluid flow

Consider a tube of length L among the n tubes of the collector, the fluid enters the tube at temperature T_{fi} and comes out at temperature T_{fo}. Each tube gains a useful flow $d\phi_u$per unit length in the Ox direction of the fluid flow from the above.

Perform a thermal assessment on the portion of the fluid in a tube between the distances x and x +dx from the tube inlet; it is written:

$$\frac{\dot{m}_f}{n} C_f \frac{\partial T_f}{\partial X} = d\phi_u dx \quad (55)$$

$\dot{m}_f$is total fluid flow in the absorber consisting of n tubes in parallel (kg/s), and C_f is the heat capacity of the fluid(J/kg).

$$\frac{\dot{m}_f}{n} C_f \frac{\partial T_f}{\partial X} = F'\left[\phi_{sa} - h_p\left(T_f - T_a\right)\right]dx \quad (56)$$

By integration between 0 and x, the longitudinal temperature profile of the fluid is obtained:

$$\frac{T_f(x) - T_a - \frac{\phi_{sa}}{h_p}}{T_{fi} - T_a - \frac{\phi_{sa}}{h_p}} = \exp\left[-\frac{nF'h_p}{\dot{m}_f C_f} x\right] \quad (57)$$

And by integration between x = 0 and x = L, we obtain the following expression of the output temperature T_{fo} of the fluid in which S is the surface of the absorber

$$\frac{T_{fo} - T_a - \frac{\phi_{sa}}{h_p}}{T_{fi} - T_a - \frac{\phi_{sa}}{h_p}} = \exp\left[-\frac{SF'h_p}{\dot{m}_f C_f}\right] \quad (58)$$

The average temperature of the fluid in the absorber can also be calculated by

$$T_{fav} = \frac{1}{L}\int_0^L T_f(x)dx \quad (59)$$

$$T_{fav} = T_a + \frac{\phi}{h_p} + \left(T_{fi} - T_a - \frac{\phi_{sa}}{h_p}\right)\frac{\dot{m}_f C_f}{nSF'h_p}\left[1 - \exp\left(-\frac{nSF'h_p}{\dot{m}_f C_f}\right)\right] \quad (60)$$

Useful energy

The useful energy gained on the total surface S of the absorber can be calculated by

$$\phi_u = n\int_0^L d\phi_u dx \quad (61)$$

$$\phi_u = SF_R\left[\phi_{sa} - h_p\left(T_{fi} - T_a\right)\right] \quad (62)$$

$F_R$is the conductivity factor of the absorber defined by:

$$F_R = \frac{\dot{m}_f C_f}{Sh_p}\left[1 - \exp\left[-\frac{SF'h_p}{\dot{m}_f C_f}\right]\right] \quad (63)$$

Instant efficiency

The overall efficiency of the previously studied collector is finally written:

$$\eta = F_R[\eta_0 - \frac{h_p(T_{fi}-T_a)}{G(i,\gamma)^*} \qquad (64)$$

The heat energy released by the fluid in the storage tank

To calculate the heat flow released by the heat transfer fluid to the used fluid in the storage tank, we are supposed to know the temperature at the inlet and outlet of the heat transfer tank

$$\phi_u = mC_f(T_{fo} - T_{fi}) \qquad (65)$$

The thermosyphon diagram executed under TRNSYS program is shown in Fig. 25. The different module's types used in this study are presented as follows:

- Weather data (TYPE109-TMY2) this component reads meteorological data generated by meteonorm software and supply them in the TMY2 format. It calculates the necessary solar radiation for the calculation of TRNSYS software at any surface tilt.
- Differential controller for temperature (TYPE 2). This component monitors and controls the average temperature of the tank, to control the operation of the auxiliary electric heater.
- The general forcing function (TYPE 14) from TRNSYS library, this component describes and characterizes the hourly load profile corresponding to 200 L/day of hot water demand.

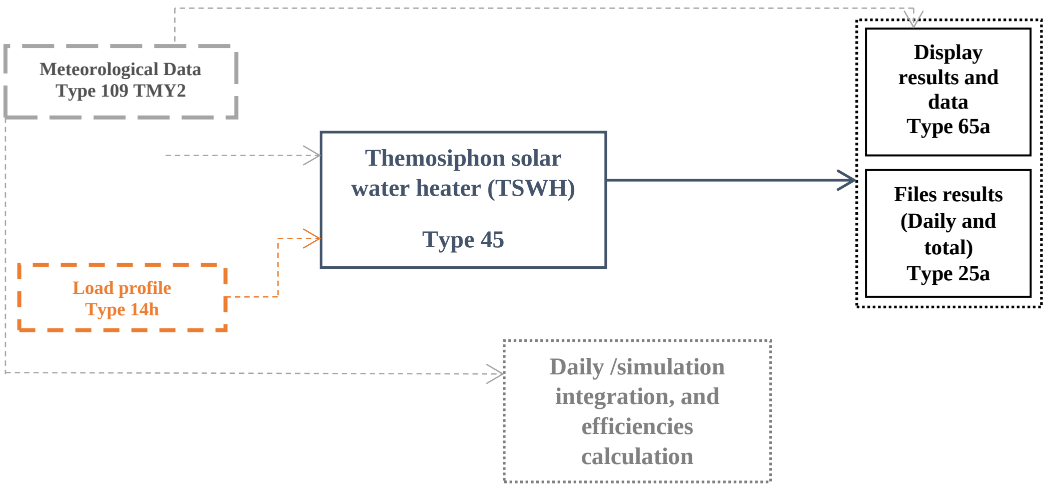


Figure 25: Thermosyphon diagram executed under TRNSYS program.

3.5. Performance indices

3.5.1. Collector efficiency

The collector efficiency describes the ratio of the total useful energy gain to the solar energy absorbed by the collector. It is calculated using the equation below (66):

$$E_{coll} = Q_{ucoll}/(A_c\, I_{coll}) \qquad (66)$$

Qucoll is the energy rate from heat source, and Icoll is the total radiation on the tilted surface.

3.5.2. Solar fraction

The solar fraction Fsol represents the solar energy available to meet the needs. It presents a clear indication about the contribution of the solar system in meeting the thermal load. The solar fraction is calculated using the equation below (67):

$$F_{sol} = 1 - (Q_{aux}/Q_{DHW}) \tag{67}$$

where QDHW is the energy rate delivered to the load describing the necessary energy to meet all domestic hot water needs, and Qaux is the auxiliary energy. It is important to state that the solar fraction is evaluated on a monthly basis.

4. Model validation

The developed model was simulated with firstly the meteorological data of Cyprus in order to carry out a comparison with the study performed by Michaelides et al study [21]. A typical meteorological year (TMY) for Nosica was built for this end.

The system simulation was lunched for similar conditions as indicated in [21]. Table 4 shows the technical specifications of the studied TSWH while Table 5 and Table 6 indicates the general assumptions concerning technical parameters of validation case, the load profile and water consumption.

profile code	daily HW consumption L/person	Temperature (°C)	Pattern
DOM	30	50	Michaelides

Table 5: consumption profile of the validation study.

Parameter	value
Ac	2.72 m^2
FR	0.791
FRUL	24 kJ h-1 m-2 k-1
Gtest	96 kg h-1 m-2
β	40°
NR	20
Dr	15 mm
di,do	22 mm, 22 mm
Hc	1000mm
H_0	1150 mm
Hr	250 mm
Ha	300 mm
Hth	370 mm
Li, Lo	2000 mm, 520 mm
Uapi	5.1 kJ h-1 k-1
UAPo	5.1 KJ.h-1 k-1
V	162 Liters
(UA)s	6.45 kJ h-1 k-1
Qaux	3 kW

Table 6: Technical parameters of the validation study.

Fig. 26 presents a comparison between monthly solar fractions of the TSWH investigated by Michaelides et al study and those predicted by the introduced TRNSYS model.

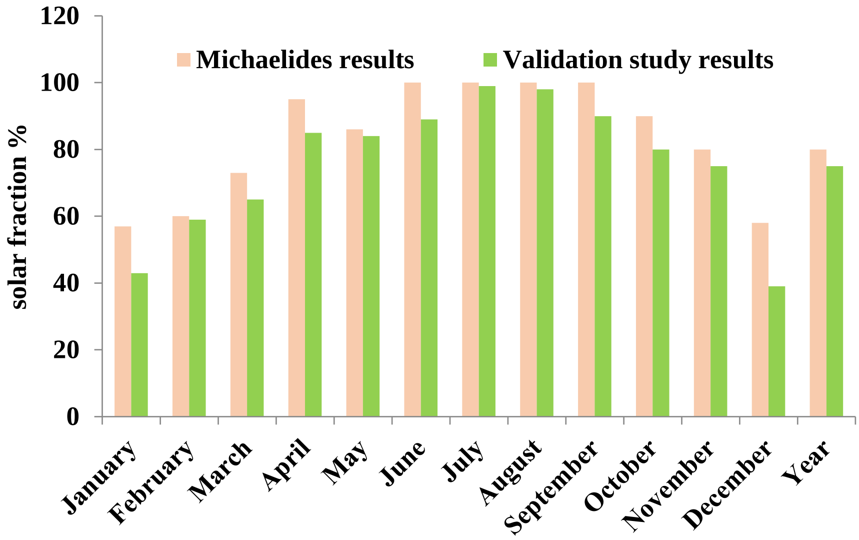


Figure 26: Solar fraction of Michaelides study versus validation study.

The average relative error is about 5%, which is an acceptable value. The deviation between the results can be attributed to the update in climatic conditions caused when using the Meteonorm database that corresponded to the period 1986-1992 for the study of Michaelides et al. while the prepared meteorological data file used in our calculations corresponds to the period 1991-2010.

5. *Results and discussion*

5.1. Energetic evaluation

As presented in Fig. 27(a), the thermosyphon system performs differently in the six cases. The average solar fraction ranges between 46% to 71%, and the maximum solar fraction value was noticed in Errachidia 71%. This result is explained by the importance of solar irradiations in this zone. The annual average solar fraction is about 69% in the first zone represented by Agadir which is a sunny coastal zone. It is in general the most favorable zone for this system especially in winter.

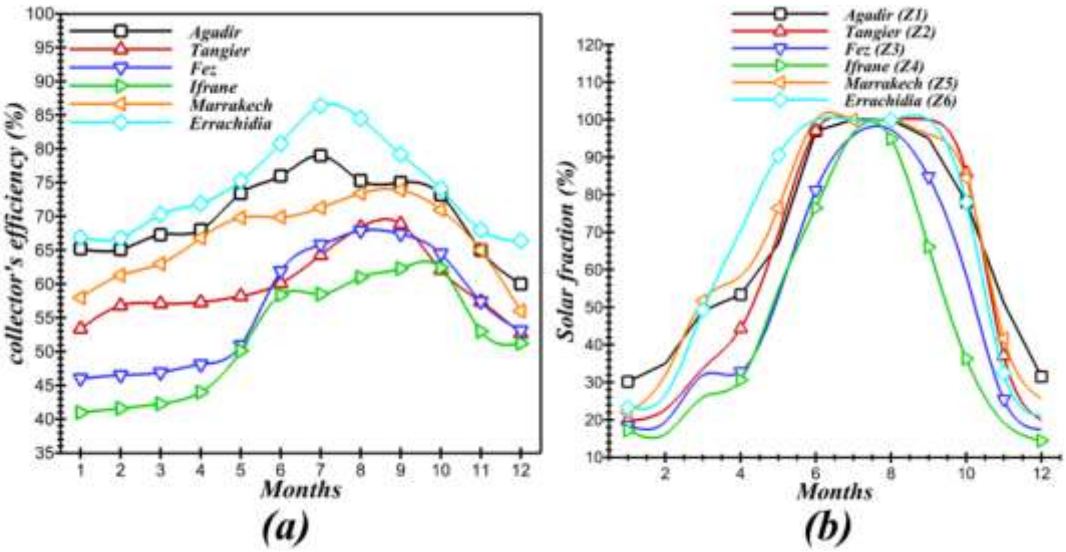


Figure 27: (a)- Collector's efficiency. (b)- Solar fraction.

Tangier (zone 2) and Marrakech (zone 5) exhibit approximately the same solar fraction variation, but (Zone 5) has a higher annual average value of 66% versus 61 % in (Zone 2). This difference is due to the favorable conditions of Marrakech which is considered as one of the sunniest areas in

Morocco. (Zone 3) presents a total annual average solar fraction of 52%, which is lower compared to the previously discussed sites. This result can be explained by the fact that Fez is characterized by a Mediterranean climate, dominated by continental and atlantic effects, which accounts for the remarkable fall of the solar fraction to 17.4% during the coldest month of winter. Finally, the coldest zone, Ifrane has an averaged solar fraction value of only 46%. It is concluded that Ifrane's weather is the most unfavorable climate for installing solar TSWHs because Ifrane remains the coldest zone in Morocco with an average annual temperature of 10.8°C. Also, one can observe that most of the hot water requirements in the Moroccan zones, previously cited, are totally satisfied during the sunniest three months of the year (July, August, and September) with a solar fraction achieving 100%.

Fig. 26(b) presents the dynamic behavior of the collector efficiency for the six zones. The most favorable zone, where the collector performs with high efficiency is zone 6 represented by Errachidia, with a maximum value of 86% in July, and an average annual value of 74%. The collector operates in Agadir with 70% of efficiency, in Marrakech with 66%, Fez and Tangier with 54% and 59% respectively and finally in Ifrane with 51%. These results confirm the explanations previously presented for solar fraction. In fact, when the thermal efficiency of the collector is maximized, the useful thermal energy transmitted to the working fluid is as well maximized and thus less auxiliary energy will be required.

5.2. Economic assessment

This section aims to assess the total financial gains generated by the integration and the generalization of solar water heaters in Morocco into the residential sector, according to the six climatic zones and for different house's types. The solar system will be compared to a reference system which is the conventional gas boiler according to two scenarios:

(i) The first scenario takes into account the state subsidies on gas, which presents a purchasing power support of households. In this case, the consumer benefits on each bottle of gas that purchased a reduction of 67% on its price.

(ii) The second scenario does not consider the subsidies.

The number of thermosyphon systems required to be installed was determined according to the situation of the building in Morocco. The number of houses counted on 2014 is 5.8 million [47], distributed as follow: occupied houses, secondary, vacant and professional use houses as presented in Table 7.

Type	Percentage
Housing occupied (habitat)	79%
Secondary housing	6%
Vacant	9%
Professional use	3%

Table 7:Distribution of houses in Morocco according to the 2014 census.

The number of occupied houses in Morocco is 4.582 million houses: this value is officially distributed over 12 regional zones according to (The High Commissariat of the Moroccan Plan)[47].

A conversion of this distribution according to the climatic zones was investigated as presented in Table 8. It is found that this number of houses per climatic zones can be also fragmented into many types such as: modern Moroccan houses which represent the main construction type in Morocco with a percentage of 63%, followed by apartments (25%), villas 4%, traditional Moroccan houses 4%, and finally anarchic construction 4%.

zone	pourcentage of housses %	number of housses
1	46	2109220
2	12,5	572790
3	29,3	1340970
4	3,1	144960
5	4,1	189740
6	5	224320

Table 8: Distribution of occupied houses per climatic zone in Morocco.

These statistics will enable the determination of the thermosyphon's number to be integrated at a national scale. The study will focus on apartments, modern Moroccan houses, and villas. It should be highlighted that, because of the presence of these variants in the construction sector, it is recommended to consider different capacities related to the type of house for an appropriate analysis. Table 9 presents the system capacity with respect to the construction type. The generalization of this system into the building sector will generate an important total investment of 5876.42 Million USD. This total investment is found to be 1145.5 Million USD, 4144.42 Million USD and 586.50 Million USD for Modern Moroccan houses (150L), apartments (200L) and villas (300L) respectively.

size	150 L		200L		300 L	
zone	number	Area m^2	number	Area m^2	number	Area m^2
zone 1	527400	1160100	1413200	3109000	84400	371300
zone 2	143200	315100	3837800	844300	23000	100800
zone 3	335300	737600	898500	1976600	53700	236000
zone 4	36300	79800	97200	213700	5800	25600
zone 5	47500	104400	127200	279700	7600	33400
zone 6	56000	123400	150300	330700	8900	39500

Table 9: The number of TSWH to be installed.

5.2.1. Total annual gains

The total gains or the life cycle savings of the thermosyphon generalization in Morocco by using the subsidies and non-subsidies gas butane prices is presented in Fig. 28(a). This indicator represents the global cost savings resulting from the integration of the thermosyphon system instead of buying gas butane cylinders.

It is concluded, from the comparison of these two scenarios, that, obviously, the gains generated considering subsidies are less than the second case for the six zones. In fact, the state subsidies (on fuels) policy is representing a barrier towards development solar energy projects in Morocco. Moreover, the first zone represents the most important gains by 197.11 Million USD in the first scenario against only 44.32 Million USD in the second zone. This difference can be explained by the highest solar fraction (68.8%), together with the high intensity of the population concentration with a percentage of 46%. In the zone represented by Agadir, this optimal combination of solar fraction and the number of homes for the first climatic zone gives optimized results and very encouraging gains as it is previously represented. This value becomes significant and would reach 448 Million USD per year by canceling government grants.

The third zone is holding the second place with total gains of 69.34 Million USD per year. It can be improved by removing the state subsidies to reach 214.63 Million USD per year. The other climatic zones achieve lower gains than the previous ones, despite their significant solar fractions which

reach 66% (Errachidia) representing the most favorable climate conditions for the system. This result is explained by the minimal percentage of houses.
The energy gains generated by the generalization of thermosyphon systems are presented in Fig. 28(b). The first zone achieves an energy annual gain of 5943.46 GWh per year, which is distributed according to the different studied configurations: apartment with 1214.60 GWh per year, modern Moroccan houses by 4340.19 GWh annually, and 388.67 GWh generated for the villas type. The integration of solar water heaters in the modern Moroccan houses generates the maximum gains in the six climate zones compared to other types due to the remarkable presence of this type in the typological distribution of housing in the Moroccan territory. In fact, it represents 63% of the total occupied houses, followed by the buildings and finally villas.

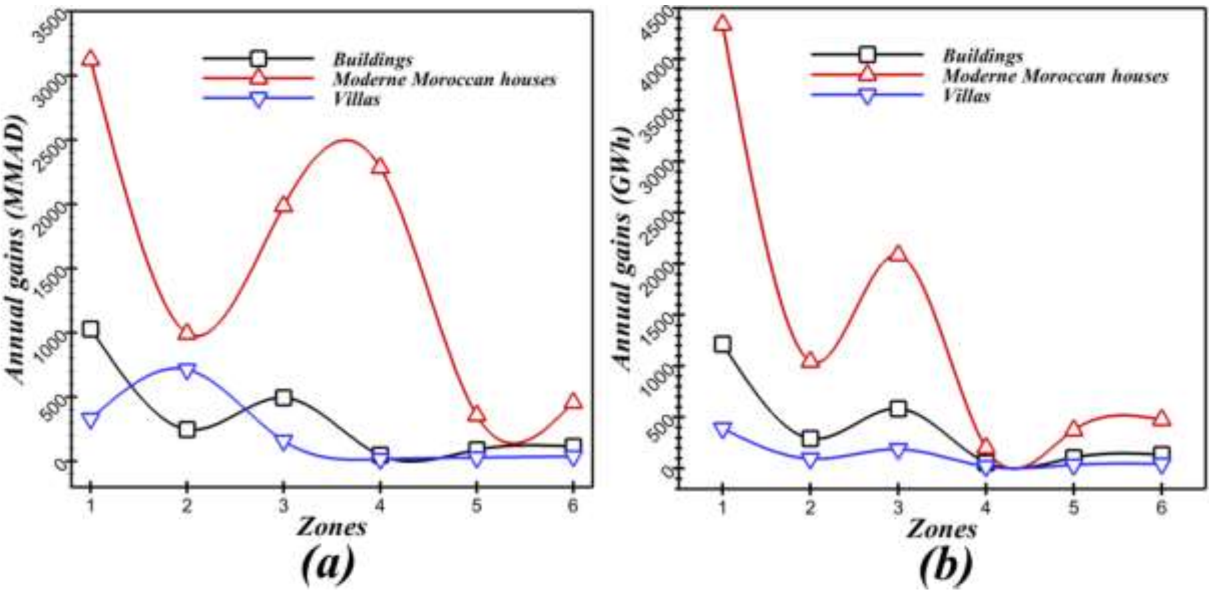


Figure 28: (a)-Total annual gains (with state subsidies). (b)-Total annual gains (without state subsidies).

Fig. 29(a), (b) and (c) present the evolution of the annual gains in an interval of 12 years, and under the condition of (non-subsidies) for several type of houses treated in this paper.

The payback period for the proposed sizes and under the six climatic data condition can be determined based on Fig. 28. The ROI varies between 3 and 6 years according to the performances of the system related to the meteorological context, the investment and the gains generated which are related also to the performance and the total expenditures produced by the traditional gas butane system. In general, after a period of 6 years the thermosyphons installed in the climatic zones will cover the initial investment and in general they will enable 100% of the life cycle savings.

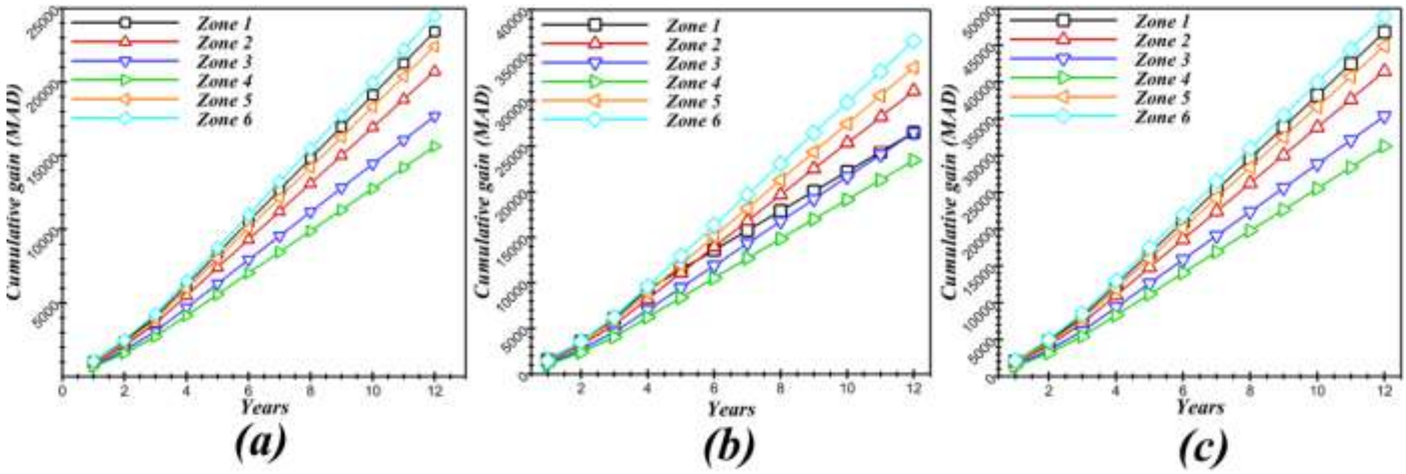


Figure 29: (a)- Cumulative gains for buildings (non-subsidies scenario). (b)- Cumulative gains for Modern Moroccan houses (non-subsidies scenario). (c)- Cumulative gains for villas (non-subsidies scenario).

5.2.2. Global results: cumulative gains for different house's types

The overall average solar fraction presents a national value which is estimated at 62%. Table 10 presents the total gains for different type of house according to the two scenarios (with and without subsidies):

The generalization of solar water heaters has an important role to play in the achievement of the development program's goals of the Moroccan market for solar water heaters by (PROMASOL).

Type of house	Apartments	Modern and traditional Moroccan houses	Villas
Total Investment	1145.5	4144.42	586.4
Subsidies			
Annual expenditure of gas Water heater (USD)	115.47	3009.45	36.95
Gains (USD)	71.59	1865.86	22.91
No subsidies			
Annual expenditure of gas Water heater (USD)	357.40	957.83	114.36
Gains (USD)	221.59	593.86	70.90
The annual gains(the number of gas bottles)	17.05 million	45.68 million	5.46 million

Table 10: The total gains for different type of houses according to the two scenarios (with and without subsidies).

This program aims to provide the evolution continuity of thermosyphon installed capacity since 2000 obtained by the analysis of imports conducted by the (AMEE) which is a result presented in Fig. 30. This figure is presenting the cumulative area of the SWH installed in Morocco since 2000 to the expectations desired to achieve.

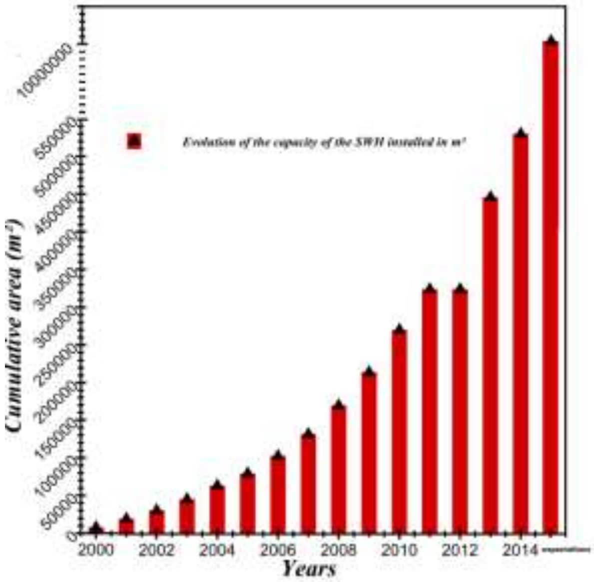


Figure 30: cumulative area of the SWH installed in Morocco since 2000 and expectations.

5.3. Environmental assessment

Using solar water heaters will also make it possible, in contrast to the conventional water heater, to reduce emissions of greenhouse gases. It should be recalled that recently, Morocco announced its engagement to reduce 13% of these gases by 2030, and ratified the Kyoto Protocol, which entered into force in 2005 Table 11 presents the annual CO_2 emissions avoided by the integration and the generalization of the TSWH:

The maximum CO_2 emissions avoided are remarkably visualized on the first climatic zone which presents the highest number of houses, and as a result the highest number of SWH installed, and energy savings.

zone	gains (number of gas cylinder) (million)	Gains (Million m3 of butane gas)	CO_2 emissions avoided (tones /year)
zone1	44610.75	220377	1856000
zone 2	8.36	41.29	446900
zone 3	16.51	81.56	891800
zone 4	1.59	7.86	85300
zone 5	3.1	14.83	160200
zone 6	3.56	1.756	203700

Table 11: The annual CO2 emissions avoided by the integration and the generalization of the TSWH.

Conclusion

In this Chapter the thermosyphon solar water heater was presented, modeled, simulated and assessed according to six Moroccan climatic zones which represent the recent zoning carried out by the Moroccan Agency of Energy Efficiency (AMEE), in order to predict the system performances, and the dynamic behaviors of different parameters which are describing the thermosyphon. The system was modeled and simulations where launched under TRNSYS simulation program.

According to the simulation results the thermosyphon's performances in terms of the annual average solar fraction varies between 50% and 70%. The results confirmed that the climatic conditions are the key of the simulation. They have to be taken into consideration to optimize the overall system efficiency. Moreover, an economic study which is about the generalization of this technology was conducted to analyze the potential benefits offered by this solar solution in different zones in Morocco from a weather point of view, and to predict the total life-cycle savings. In fact, life-cycle savings were optimal in the first zone represented by Agadir, due to the optimal combination of performances and high needs that are concentrated in this zone. To complete this study, an environmental section was developed to exhibit the amount of CO_2 emissions that can be avoided by the implantation of this project. The results confirmed that a considerable amount of greenhouse gas emissions is reduced.

The penetration of large-scale solar water heaters in Morocco is prevented by many barriers, such as the understanding's lack among the population of the financial unattractiveness to poor households and the benefits they provide. However, thermosyphon will be accepted easier when the population understands all these technology advantages. In the case of SWH systems, the benefits are not immediately visible for a payback period of six years: the energy bill will be reduced, but not fast enough in order to justify the cost of installation. Thus, the governmental subsidies will be an important incentive solution for beneficiaries. The generalization of this type of installation will not be possible without the introduction of incentive mechanisms that involves the public authorities, subsidizing the purchase of solar water heaters which will enable citizens to equip themselves at a lower cost.

The advantages linked to the generalization of the thermosyphon in Morocco are multiple, both economically and environmentally. Citizens could save their energy bill in the long term, since after an average of six years they would have profitable purchase price. Moreover, manufacturing the solar water heater in Morocco will lower the import bill cost. Furthermore, it will also help the development of subcontracting and involve SMBs in the manufacture of this product. Hence entrepreneurship in this solar field will grow and be encouraged. Therefore, jobs will be created which is going to absorb unemployment.

Chapter III: *Energy Efficiency of social Buildings Comparative study between active and passive systems Via TRNsys.*

Introduction

This chapter involves comparing active and passive efficiency solutions energy in the building. The results presented in this part focus on the insulation solution and double-glazing application for the building envelope, And water solar heaters for domestic hot water production. To this end, a numerical simulation model of solar water heater installations is created and validated under TRNSYS, to compare different scenarios of the studied solutions. This comparison aims to highlight the potential of solar water heater installations in Morocco. Three scenarios of demand on hot water (Low, Standard, and High) were taken into account for the six thermal zones defined in the Moroccan thermal regulation of constructions (RTCM). The same software (TRNsys) is used to model a pilot building consisting of 16 flats. Energy efficiency actions have been carried out; building simulations are made for the six thermal areas. Comparing the results from the simulations of the energy savings and financial economies achieved shows the influence of subsidized gas prices on solar water heaters' relevance despite significant energy savings.

two types of improvement efficiency actions on the building were carried out, the passive and the active, where a complete comparison was developed. In the literature, several studies have taken the same direction, but a limited number have treated the comparison and the combination of the two action types; they have developed each solution separately from the other. The global aim is to enhance building energy efficiency. Cabeza et al. [51] have tested the active and passive system on an experimental building prototype located in Puigverd de Lleida (Spain). His study aims to evaluate the energy savings resulted from testing, on the one hand, different technologies of actives solutions such as; solar thermal, free cooling, geothermal …Etc.

Furthermore, sustainable materials and phase change materials are a passive solution to designing the green building envelope. Gou et al. [52] combined the two design strategies (active and passive) to develop the first zero energy building in Southeast Asia. This work is based on an existing building and under tropical climate conditions, presenting a cost-effectiveness comparison of passive and active strategies. The results show that passive solutions must be applied on a large scale to have significant economies because of its long payback period compared to the active one. Another work presented by Buonomano et al. [53] converges in the same direction. The passive and active effects on the photovoltaic and thermal system's integration were analyzed by evaluating the performances, energy demands, and electrical production. The numerical model was validated and compared to an experimental model integrated into an office building simulated in several European climates; the results achieved lead between 56.8 and 104.4% of energy consumption reduction.

All works take his direction intending to improve the energy efficiency [54] in different building type and model, the newest and the existing [55] even for the historical ones [56], under several conditions of climate, occupation, construction, and system integration to achieve the optimal thermal comfort.

The renewable energy solutions integrated into the building are massively present in the literature. Yan Wang et al. [57] developed a new energy performance index by studying the integration of renewable energy on school building for heating needs in Germany. The numerical model was developed and simulated; a new performance indicator was developed to evaluate the active solution proposed. The results show that the distribution enhanced can achieve a proper thermal comfort level for the case studied, reduce electricity costs, and reduce CO2 emissions by 5.3 kg per typical winter.

Bougiatioti et al. [58] studied the integration of active solar systems on an existing building in traditional settlements to develop several possibilities of a smart architectural integration in Cyprus and Greece where the constructional conditions make this action advantageous. This work aims to evaluate gains and difficulties to showcase the need to exploit these benefits under the economic crisis. In the same directive of highlighting the role of active solutions in both energy performance and the indoor built environment, Amilios et al. [59] studied the active solar systems integration on southern Europe building envelopes. The studies have been carried out under the inhabitants' comforts requirements, making an energy and environment assessment. This action gives a remarkable reduction of cooling and heating loads in a comprehensive environmental approach proposed.

The active solution proposed is the solar water heater (SWH) in its two configurations; the individual and the collective. There are numerous studies in the literature focused on the performance and design optimization of residential water heaters as a performing solution [60], [61].

The building efficiency studies using passive solutions are presented on a pronounced number in the literature. Whether the optimization is the key of several works, Chen et al. [62], he optimized a typical passively residential building design in China. The optimal model was carried out under the influence of five weather conditions investigating a sensitivity analysis related to the ventilation, the outdoor thermal, and solar radiation, studying the proposed model's applicability. the passively model was studied in several cases in several location and climates conditions such as hot and humid climate [63].

In this part, there are three types of passive solutions proposed. The first solution is to improve the building envelope by the insulation, where several works introduced many innovative insulation materials for optimal building efficiency [64]. Kaushik Biswas et al. [65] integrate composite insulation boards containing foam-encapsulated vacuum insulation panels. The material's thermal characterization was done developing a new process manufacturing technology called modified atmosphere insulation to release a significant cost reduction keeping high performance. Others incorporate the anchors into the insulation in order to strengthen the insulation [66]. The dynamic material was also present as an insulation proposition [67], many other innovative materials were proposed as an excellent cheap alternative such as the bio insulation [68], the wood waste [69].

The insulation studies focused on materials [70] and other parameters such as the thickness [71], It was analyzed by Cemek et al. [72]; they develop a parametric study based on the insulation thickness taking into account several indicators such as energy savings, payback period, and CO2 emissions reduction under the climates conditions of different Turkish cities.

The second passive solution proposed is glazing, which was studied broadly. In the literature, several works detailed this solution focusing on different materials and developed glazing types such as aerogel glazing, PDLC switchable glazing, and simple and double types …Etc.[73], [74] [75] [76] .

The comparison presented was projected on a social building, taking into account different solutions for each type. The study integrated the technological side of active solutions, presenting a comparison between flat plat collectors and the evacuated tube one under two configurations; the individual and the collective, comparing the solar solution with the conventional ones presented in the market.

1. *Passive solutions*

The numerical simulation used in many research and development areas like mechanics, astrophysics, aeronautics, meteorology, is a tool to simulate real nuclear physics phenomena. It is possible to simulate complex physical phenomena such as predicting changes to test an airplane's performance, a car, a boat, or a building. The simulation is used to study the system model's operation and properties and predict its evolution.

This chapter presents the different characteristics of the building studied. Its modeling was carried out with the TRNSYS 16 software and its TRNBUILD module. The final model evaluates the building's load profile according to the composition of the walls, the facades' orientation, the volume of the thermal zones, the occupancy, and the temperatures of record.

This first chapter part aims to compare the energy savings achieved by the requirements of the entire RTCM and separately. The simulations carried out in the following are made for the six thermal zones specified by the RTCM

1.1. The Building case study

The building studied was modeled with the TRNSYS Studio 16 software and TRNBUILD module. The final model makes the energy demand profile valuation possible, taking into account the critical building parameters such as; the walls composition, the facades' orientation, the zones volume, the occupation, and the set point's temperatures. To study the influence of the integration of thermal regulation and passive solutions (insulation, glasses…Etc.), and the active ones (solar water heaters).

- Building architecture

The building studied in this project is social housing with 300 m²; it consists of four levels: a ground floor and three floors. The accommodation is composed of 16 apartments, and the main facade faces west. Fig. 31 shows the global modeling of the building with the Google Sketch UP software.Each floor of the building has four standard apartments of 70m², except the apartments

Figure 31: the building model with the Google Sketch UP software.

on the ground floor, are 60m^2 in size. Fig. 32 shows the architectural plan of the ground floor and a representative floor.

Figure 32: the architectural plan of the ground floor and a representative floor.

- Building construction materials: the composition and materials of the building envelope construction are shown in Table 12.

walls	layers	Thickness (mm)	U (W/m^2.K)
External wall	External plaster	20	0,847
	brick	200	
	Plasterboard	30	
Internal wall	Plasterboard	25	1,183
	Brick	50	
	Plasterboard	25	
Floor	Heavy concrete	200	2,949
	Mortar	50	
	Floor tile	10	
Roof	Plasterboard	13	2,683
	slab	120	
	Lightweight concrete	200	
	Mortar	50	
	Floor tile	10	
glazing	Simple glazing	-	5,8

Table 12: the conventional building envelope

1.2. Simulation model and hypothesis

Fig.33 shows the simulations model flowchart on TRNsys studio software. The building model was created using TRNBUILD connected to TRNsys by the construction model (type 56). It is a non-geometric scale model with one air node per zone, representing the air volume's zone heat capacity and the capacities that are closely related to the air node (furniture, for example). Thus, the node's capacity is a separate entry in addition to the volume of the zone.

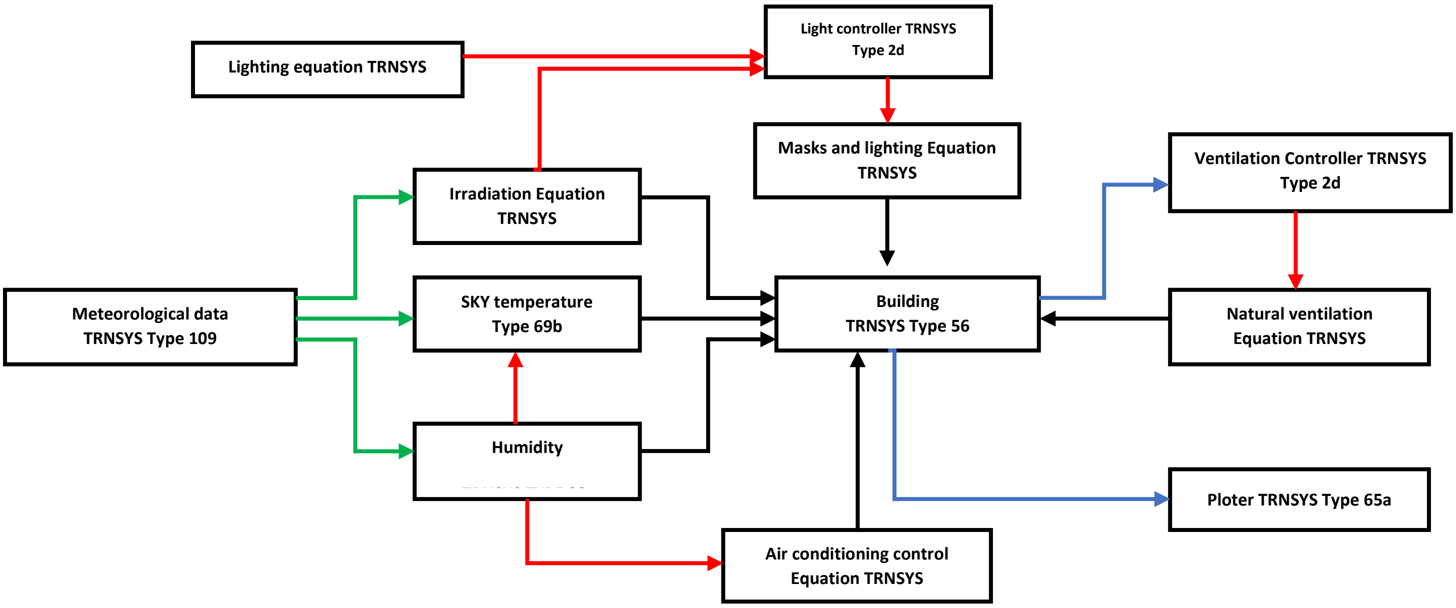


Figure 33: TRNSYS information diagram for multi-zone building

- TRNsys Simulation modules

TYPE 56 is a non-geometric scale construction model with one air node per zone, representing the thermal capacity of the zone volume and capacities that are closely related to the air node (construction and glazing, for example). Thus, the node's capacity is a separate entry in addition to the building zone volume [77].

TYPE 109:is weather data reader at regular time intervals from a data file, transforming it into the desired unit system and generating radiation outputs for surfaces with a different inclination and orientation surfaces. In this mode, Type 109 extracts a meteorological data file in the standard TMY2 format. The TMY2 format is used by the National Solar Radiation Data Base (USA), but TMY2 files can be generated from many programs, such as Meteonorm.

TYPE 33e is the Psychometrics utility subprogram caller on TRNSYS. The psychometrics subprogram calculates humidity, relative humidity (in percentage), wet temperature, density, dry air density, dry temperature, and dew point temperature, enthalpy, and dew point temperature.

TYPE 69b identifies the sky's actual temperature to evaluate the thermal losses towards the sky by convection. The actual emittance of the clear and nuanced sky must be known. Furthermore, the sky is concise, an ideal black surface. sky temperature is calculated by this valve according to air pressure, air humidity, ambient temperature, and sky cloudiness factor.

These components, combined with TYPE 56, make it possible to model with precision the external conditions that the heating and air-conditioning system must remedy to meet the inhabitants' comfort needs. Thus, once the simulation is carried out for an annual period, TYPE 56 provides a file that corresponds to the building's load profile, according to the information contained in the associated TRNBUILD file.

- Simulation hypothesis

Four dynamic thermal simulation scenarios have been made to evaluate the heating and air conditioning capacities. The first conventional scenario concerns the case without any energy efficiency action on the building envelope; this is the reference case. The other scenarios are modeled using insulation and double glazing separately, and then the two combined. For the four scenarios, the simulation hypotheses (internal inputs, masks, thermal zoning, heating, air conditioning instructions, Etc.) are the same.

For an excellent numerical describing the real building conditions and the choice of modeling, hypotheses are essential. The main assumptions that have been made for the modeling of the building are:

The thermal zoning: The selected model was considered with 36 thermal zones, 16 heated and air-conditioned thermal zones. Each zone includes the living rooms and rooms of each apartment and 20 thermal buffer zones, which are the bathrooms, kitchens, and halls of all the apartments. Fig.34.represents the thermal zones considered. Two other hypotheses would have been possible: to model each room by a thermal zone and model each floor as a single zone.

Two other assumptions would have been possible:
– model each room by a thermal zone.
– model each floor as a single area

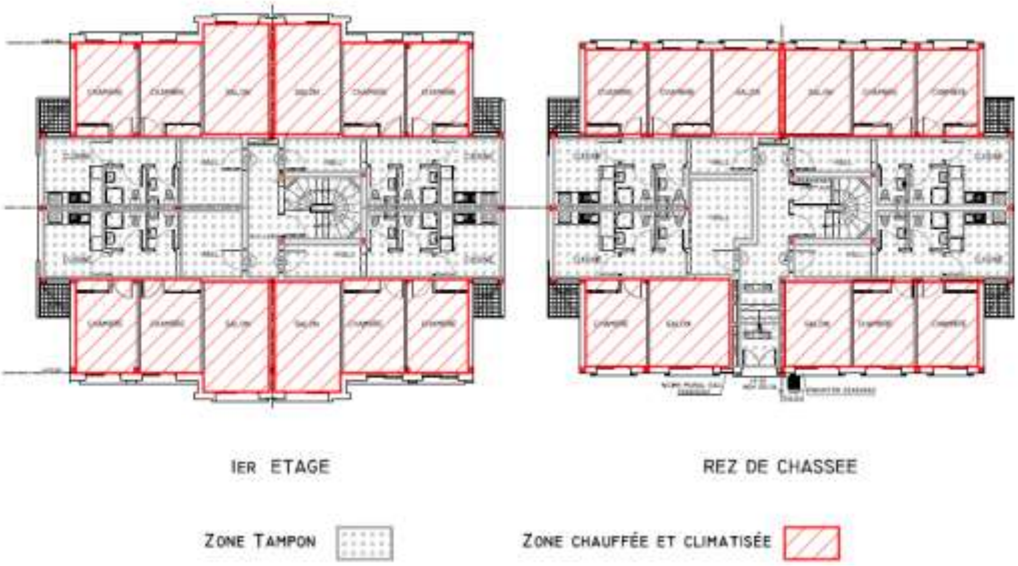


Figure 34: the building zoning.

Masks: the balconies and the progress of the roof were considered. Thermal solar panels are made up of vacuum tubes allowing part of the radiation to penetrate, and flat thermal solar panels create shading. However, it was assumed that this shading was minimal and was not considered. No close mask was considered (trees, buildings).

Internal inputs: TRNSYS offers the possibility to specify the people's thermal load according to ISO 7730 and VDI 2078. The VDI 2078 is a German standard, that is why we used the international standard ISO 7730. This standard specifies people's heat according to their activity types'. Each apartment is supposed to be occupied by four seated people releasing 100 Watts according to the ISO 7730 standard under the schedule showed in Fig. 35 The lighting heat input is about 10W / m^2. besides, the electrical appliance's heat constitutes additional inputs.

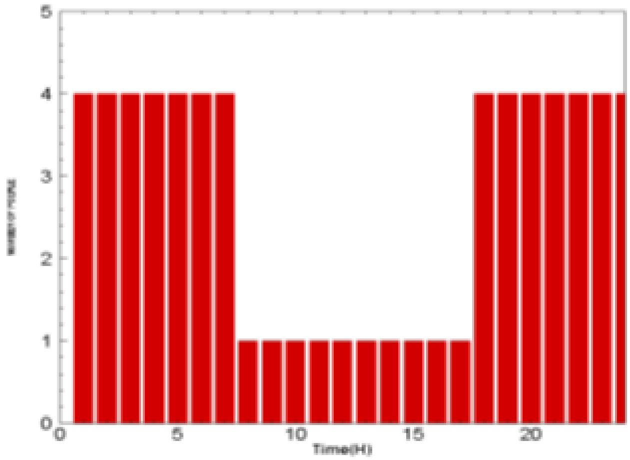


Figure 35: occupation schedule.

Thermal Bridge: The calculation of a thermal equivalent surface must be carried out in order to integrate the bridge thermal. In this case, no thermal bridge was considered. This hypothesis can generate a thermal envelope more efficiently than reality.
Ventilation: The imposed ventilation rates depend on many aspects and differ according to the regulations. Table 13 groups the values imposed by the RT2012 standard.

Number Of Principal Rooms Per Housing	Extracted flow rate (m^3/h)				
	kitchen	Bathroom	Other room water	Wash room	
				Unique	Multiple
1	20/75	15	15	15	15
2	30/90	15	15	15	15
3	45/105	30	15	15	15
4	45/120	30	15	30	15
5 et plus	45/135	30	15	30	15

Table 13: Regulatory ventilation flow rates.

Since the building in question is a social building, the ventilation mode chosen during the simulation is natural. In heated and air-conditioned areas, the air exchange rate and equal to 0.6 volume/hour, for areas not treated by air conditioning and heating- kitchen, bathroom, and shower- the rate of air renewal chosen is equal to 2.6 volume/hour.
Heating and air conditioning: The heating and cooling schedules profile are shown in Fig.36 .according to the time of day, the value of the control is 1 or 0. The set temperature set for the heating is equal to 20 ° C, and that of the air conditioning is equal to 26 ° C.

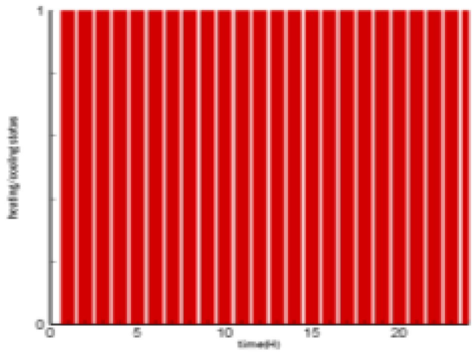


Figure 36: Hourly heating and cooling profile.

Meteorological data: The Moroccan territory has been subdivided into six climatic zones that are homogenous and circumscribed: Zone 1, Zone 2, Zone 3, Zone 4, Zone 5, and Zone 6. this climatic zoning adopted for the thermal regulation in the building in Morocco
The simulations were done for the six climatic Moroccan zones.

The building improvement solutions

- Insulation

The purpose of insulation during this scenario is to respect the thermal transfer coefficient's values specified by the thermal regulation of Moroccan buildings. The insulation type and thickness are not discussed in this work. The building walls thermal characteristics and floors in different Moroccos' thermal zones are shown in Table 14. The windows are single glazing types with a heat transfer coefficient of U = 5.8 W / m²K.

Thermal zones	U (W/m²K)			
	External walls	Internal walls	Low floor	High floor
Z1 Casablanca	0,847	1,813	2,949	0,750
Z2 Tanger	0,847	1,813	2,949	0,636
Z3 Fès	0,847	1,813	2,949	0,657
Z4 Ifrane	0,60	1,813	2,949	0,552
Z5 Marrakech	0,60	1,813	2,949	0,636
Z6 Errachidia	0,60	1,813	2,949	0,636

Table 14: Thermal Characteristics of Insulated Building Walls and Floors

- Glazing

In this scenario, the only action to be taken on the building envelope is to respect the heat transfer coefficient values set by the RTCM for glazing. The building will not be isolated in the six zones' first simulation scenario, using the single glazing.
Table 15 lists the thermal characteristics of the building envelope for the second scenario.

Walls	layers	thickness (mm)	U (W/m²K)
External wall	Exterior plaster	20	0,847
	Brick	200	
	Plaster panel	30	
Internal wall	Plaster panel	25	1,183
	Brick	50	
	Plaster panel	25	
Floor	Heavy concrete	200	2,949
	mortar	50	
	tile	10	
Roof	Plaster panel	13	2,683
	slab	120	
	Light concrete	200	
	mortar	50	
	tile	10	
glazing	Double glazing	-	2,83

Table 15: building envelope action on the glazing.

- RTCM (Moroccan building thermal regulation)

In this scenario, the RTCM requirements are met for all zones. Table 16 illustrates the thermal characteristics of the envelope adopted for the simulations.

envelope	U (W/m².K)					
	Z1	Z2	Z3	Z4	Z5	Z6
External wall	0,847	0,847	0,847	0,60	0,60	0,60
Internal wall	1,813					
Low floor	2,949					
High floor	0,750	0,636		0,552	0,636	0,636
glazing	2,83					

Table 16: Thermal Characteristics of the Building Envelope for the RTCM

1.3. Simulation building results

Table 17 shows the values obtained following simulation of the building modeled in TRNBUILD, for one year with a time step of one hour. The conventional building's thermal simulation results without any energy efficiency action clearly show the significant energy demand for heating and cooling, especially for zones Z6, Z4, which exceeds 200 kWh / m² / year. A decrease between 23% and 39% of total annual needs is achieved with insulation compared to the conventional case. This ratio remains higher than that set by the RTCM. The ratio decrease is vital for the healing power reaching a 44% decline for the Z5 zone (Marrakech), against the annual requirement ratio in air conditioning that does not significantly decline. The decline is zero for the zone Z1 (Casablanca); the maximum recorded is a 27% decrease for zone Z6 (Errachidia).

The conformity of the glazing's thermal characteristics with the RTCM makes it possible to reach a maximum decrease of 25% on the total annual ratio compared to the conventional case. This value is recorded in zone Z5 (Marrakech). The ratio of air conditioning needs is not significantly reduced. This drop does not exceed 8% for zone Z6 (Errachidia).

Zone	Z1 Casablanca				Z2 Tanger				Z3 Fes				Z4 Ifrane				Z5 Marrakech				Z6 Errachidia			
	C	I	G	TR	C	I	G	TR	C	I	G	TR	C	I	G	TR	C	I	G	TR	C	I	G	TR
Heating annual demand	41	25	35	15	56	32	48	14	95	55	81	29	160	92	128	47	48	27	38	13	81	46	65	23
Cooling annual demand	30	29	31	27	40	37	43	34	58	44	56	39	40	30	39	30	93	71	87	61	132	96	121	66
Total annual demand	71	54	66	42	96	69	91	48	153	99	137	68	200	122	167	77	141	98	125	74	213	142	186	89

Table 17: heating and cooling annual demand (kWh/m²/year)

After having carried out the building dynamic thermal simulations for different thermal zones, and under the fourth scenario condition (RTCM) the insulation and glazing. The sum of the heating and cooling power ratios for each zone is greater than the one set by the RTCM; this is justified by the fact that the building is misdirected, which increases solar gain.

On the other hand, compared to the results obtained by the simulations of the conventional, insulated, and glazed scenarios. In Zone 4 of Ifrane, a maximum saving of 62% is achieved between the conventional case and the RTCM scenario. This remark is made for the other three scenarios where maximum savings are achieved in Zone 4 of Ifrane.

It is concluded that the application of a double-glazing solution in buildings, without the application of insulation, does not lead to significant savings in comparison with the cost of investment - A comparative economic study will be presented by the after -. On the other hand, insulation alone makes it possible to reach a savings threshold that is considered reasonable.

From this, the application of the RTCM allows significant energy consumption savings of buildings even if, in this case study, ther results were higher than the values set by the RTCM. This difference is explained by the orientation of the building, which is oriented towards the west. We can also add that the simulation does not recreate the reality without error, given the large number of assumptions made in this study.

2. *Active solutions*

This part aims to develop and validate two TRNSYS models to simulate solar installations for SWH production. The first model is for individual solar systems. The second concerns the Collective solar systems. First, the simulations will be under FES region climatic conditions to validate models and compare some significant characteristics of the configurations and the technologies studied. Second, the simulations will concern the six Moroccan climatic zones to compare these solutions to the passive ones previously studied.

This part will contain a mathematical description of the solar system components. The simulation's hypotheses for each model will be detailed. The Validation of the first model will also be presented referring to LACOUR AYOMPE work "Validated TRNSYS Model for Forced Circulation Solar Water Heating Systems with FPC and Heat Pipe ETC “[78]. Finally, the simulation results will be presented based on the energy performance indices for analysis.

To not overload this part of the study, the energetic results will be presented and analyzed only for the zone 3 represented by Fes city.

2.1. *Daily Hot water needs estimation*

Identifying the quantity of hot water drawn is essential to size the production apparatus, whatever the system was appropriately chosen. There are three methods to determine the volume taken from a building. These methods differ in their degree of approximation of the real situation. It is easier to size the hot water storage needs for a renovation project in an existing building than for a new building making use assumptions [79].

2.1.1. *The typical profiles*

For this method, the Consumption statistics on identical buildings may be used. The use of these typical profiles applies particularly well to apartment buildings.

2.1.2. *The census of consumption points*

Consumption points, their nominal flow rate, and their use period can be listed according to available statistics. This method of enumeration should be carried out with extreme caution. The risk of over-sizing the system is significant if a coherent scenario of the consumption point simultaneous use mode is not carefully established.

2.1.3. *Counting of actual consumption*

The ideal method is to measure the actual hot water consumption. This method will be the most suitable for renovations in the tertiary sector. If the building consumption remains the same, a campaign of measurements using water counter or on the supply of the various consumption points or consumption appliances, or the cold-water supply of the existing production apparatus shields from any on or under-dimensioning of the system. The investment made during the study is then quickly profitable. This method will not be taken into account for this study.

2.1.4. *Case study load profile*

Using the first method of standard profiles in this study and taking into account Moroccan consumers' habits of the social class. The daily needs per person of domestic hot water in 25L/day/person for low demand. 37.5L/day/person for an average SWH demand and 50L/day/person for a high SWH demand and estimating occupancy of 4 people for an apartment.

The Fig. 37,38 and 39 show the monthly energy requirements for the three different demands: low, standard, and high. The energy demand was calculating using the equation 1 bellow:

$$Q_{th} = V\ C_p(T_H - T_C) \tag{13}$$

Qth : the energy demand (kWh).
V: the volume(m^3).
C_P: the specific heat (kJ/kg. K)
T_H,T_C hot and cold temperature (°K).

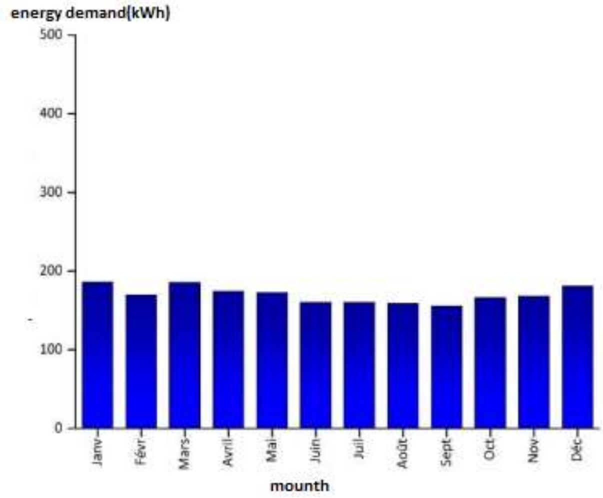


Figure 37: Low demand energy need.

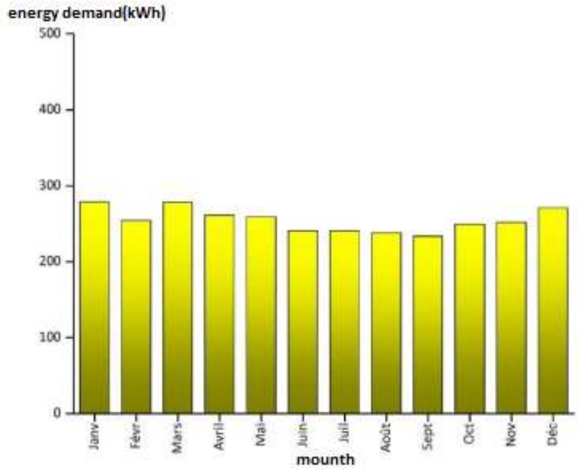


Figure 38: standard demand energy need.

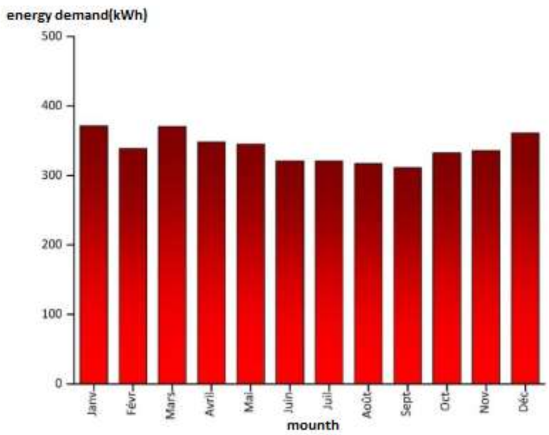


Figure 39: High demand energy need.

2.2. Individual SWH case

2.2.1. Simulation model and hypothesis

- <u>*Models*</u>

For the simulation of the individual solar system Fig. 40, two types of solar water heaters were considered. The first represents the FPC collector and the second an ETC. The two models of the individual solar system are realized under TRNsys.

The TRNsys library has most of the elements we need, and the different collectors types of :
-A flat plate collector for the first model, and a vacuum tube collector for the second.
-A component to define the load profile.
-A storage tank.

-A component for cold water temperature variation.
These components (types) are chosen and interconnected using ''Assembly Panel', then for each type, the input parameters are defined. The other elements necessary for the model can be supplied as an equation via the (Equation type), for example, the daily consumption quantity of domestic hot water.

a) Type 537 models glazed FPC by incorporating a variable speed pump and a control system to adjust the flow of fluid through the collector to maintain the desired output temperature. The model has a minimum and maximum flow rate for the pump. If the values of the parameters obtained by this model are exceeded, the fluid temperature at the outlet of the collector will not be equal to the user's temperature.

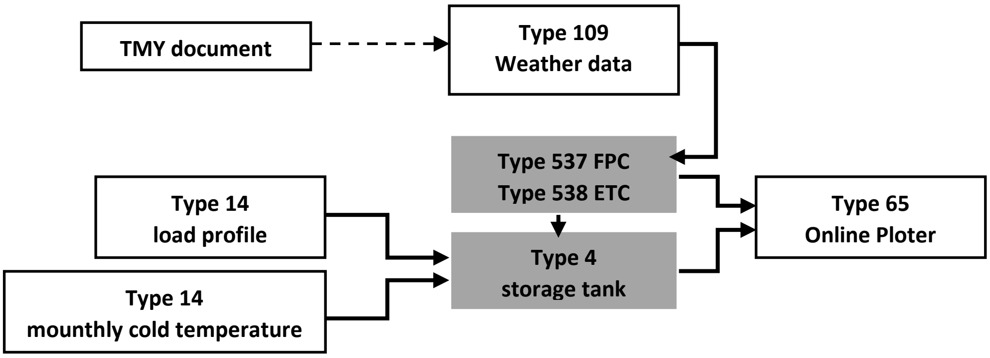


Figure 40: the flowchart of individual solar water heater system.

<u>Mathematical model:</u>

The tests carried out for flat glass collectors are carried out on sunny days and normal solar illumination on the collector surface. However, the angle of incidence of solar radiation varies throughout the day and the year. Because of this, the transmission power of the collector coverage also evolves, this power is measured by a factor called angle factor or even an incidence factor noted IAM (Incident Angle Modifier).

Type537 contains two methods for determining the collector incidence angle modifier (IAM) equation 68. The incidence angle is a dimensionless parameter between 0 and 1 that describes the variation of the collector's transmittance-absorption product (τα) according to the solar incidence angle.

$$IAM = 1 - b_0 \left[\frac{1}{maw(0.5;\cos(\theta)} - \&\right] - [(1 - b_0)\frac{\max(60;\theta)-60}{30}] \quad (68)$$

b_0 : first IAM coefficient.

<u>Collector performance</u>

Type537 The thermal performance is based on theoretical equations described in Solar Engineering of Thermal Processes

The standard collector performance equation is represented on equation 69:

$$Q_u = Q_u[F_R(\tau\alpha)_n I_t - F_R U_L \Delta T] \quad (69)$$

the useful energy gain is determined using equation 70:

$$Q_u = A_C F_R(\tau\alpha)_{n-} F_R U_L \Delta T \quad (70)$$

Equation 70 is based on two different standards. The American standard (ISO 9806-1, -2, -3 according to ANSI/ASHRAE Standard 93-1986) expresses the temperature deviation ΔT at the collector inlet and the ambient temperature, while the European standard (EN 12975-1, -2, -3) expresses the difference between the average collector fluid temperature and the ambient temperature. It should be noted that Type 537 refers to the American standard.

For the values of FR (τα)n and FRUL for particular mass flow and for a single collector integrated into a series chain. Therefore, it is necessary to adjust these values by correction factors R1, R2, and R3 according to the actual flow rate and the actual number of collectors used in the simulation.

Since a control signal for the variable speed pump is included among the model's inputs, type 537 can be used as a single-flow device in which the mass flow of the fluid is taken as the input flow provided by the user. If the collector flow is nonzero, and the pump control signal is 0), $F_R U_L$ factor is determined equation 71.

$$F_R U'_L = F_R U_L + F_R U_L (T_{in} - T_{amb}) \quad (71)$$

This parameter is then used to calculate F'UL.

$$F' U_L = \begin{cases} F_R U'_L if \frac{F_R U'_L}{g_{test} C_p} > 1 \\ g_{test} C_p \ln\left(1 - \frac{F_R U'_L}{g_{test} C_p}\right) if \ \frac{F_R U'_L}{g_{test} C_p} \end{cases} \quad (72)$$

R3 has the value if 1, R1, R2 and R3 are then calculated. R1 includes a term called R_{test}, shown in equation 73.

$$R_{test} = g_{test} C_p (1 - e^{\left(-\frac{F_R U'_L}{g_{test} C_p}\right)}) \quad (73)$$

$$R_1 = \frac{N_{series} \dot{m} C_P}{A_C} \left(\frac{1 - e^{\left(\frac{-F' U_L A_C}{N_{series} \dot{m} C_P}\right)}}{R_{test}}\right) \quad (74)$$

$$R_2 = \frac{1 - (1 - \frac{R_1 A_C F' U_L}{\dot{m} C_p N_{series}})^{N_{series}}}{N_{series} (\frac{R_1 A_C F' U_L}{\dot{m} C_p N_{series}})} \quad (75)$$

Equation 21 it is modified by the inclusion of the incident angle modifying effects, R1 and R2.

$$\dot{Q}_u = R_1 R_2 R_3 A_C [F_R(\tau\alpha)_n IAM I_t - F_R U'_L (T_{in} - T_{amb})] \quad (76)$$

The temperature of the fluid at the outlet of the collector is described by equation 11:

$$T_{out} = T_{in} + \frac{\dot{Q}_u}{\dot{m} C_p} \quad (77)$$

Without any flow condition, if the $F_R U_L$ value is zero, then the fluid output temperature is:

$$T_{out} = T_{amb} + \frac{F_R(\tau\alpha)_n IAM I_t}{F_R U'_L} \quad (78)$$

b) rage tank Type 4: it evaluates the thermal performance of a sensitive water energy storage tank, subject to thermal stratification. This performance can be modeled assuming that the tank consists of segments of equal volume N (N = 15) thoroughly mixed. N's value determines the degree of stratification. If N is equal to 1, the storage tank is modeled as a thoroughly mixed tank, and no stratification effect is possible.

c) Type 538 is a vacuum tube solar collector, where it can be used to model any collector for which energy efficiency can be modeled by a curve linear or quadratic efficiency, and out-of-normal radiation effects can be treated with a bi-axial incident angle modifying (IAM). The model allows flow control through the collector to maintain the desired output temperature. It calculates the efficiency of the collector (F'). Solar radiation outside normal is due to the use of an external data file containing IAM data. IAM bi-axial data are useful for considering optically symmetrical collectors, such as vacuum tubes.

Mathematical model

The differential equation of the first general order of the fluid in a solar collector can be expressed as [50]:

$$C\frac{dT}{dt} = F'\left(S - AU_L(T - T_a)\right) - \dot{m}C_P(T - T_{\dot{m}}) \tag{79}$$

$$S = (\tau\alpha)_n IAMAI_t \tag{80}$$

IAM (Incidence Angle Modifier) the angle modifier, is the ratio of the radiation absorbed at the current angle of incidence to radiation absorbed at incidence normal.

A general equation for solar collector efficiency as a function of input temperature can be obtained from the Hottel-Whillier equation under steady-state conditions as follows:

$$\eta = \frac{Q_u}{AI_t} = \frac{\dot{m}C_p(T_{out}-T_{in})}{AI_t} = F_R(\tau\alpha)_n - F_R U_L\frac{(T_{in}-T_{out})}{I_t} \tag{81}$$

A more precise expression can be obtained by taking into account a quadratic loss term as a function of temperature:

$$\eta = F_R(\tau\alpha)_n - F_R U_L\frac{(T_{in}-T_{out})}{I_t} - F_R U_{L/T}\frac{(T_{in}-T_{amb})|(T_{in}-T_{amb})|}{I_t} \tag{82}$$

Equation 29 can be used to calculate the outlet temperature of the collector under steady-state conditions at normal incidence as follows:

$$T_{out} = T_{in} + \frac{A}{\dot{m}C_p}(F_R(\tau\alpha)_{nI_t - F_R U_L(T_{in}-T_{amb}) - F_R U_{\frac{L}{T}}(T_{in}-T_{amb})|(T_{in}-T_{amb})|} \tag{83}$$

The incidence angle modifier (IAM) is expressed in equation 30.

$$IAM = \frac{(\tau\alpha)}{(\tau\alpha)_n} = \frac{I_{bt}\frac{(\tau\alpha)_b}{(\tau\alpha)_n} + I_{dst}\frac{(\tau\alpha)_{ds}}{(\tau\alpha)_n} + I_{dgt}\frac{(\tau\alpha)_{dg}}{(\tau\alpha)_n}}{I_t} \tag{84}$$

ETC is optically not symmetrical. It contains two directions:

- The longitudinal incidence angle is measured in a plane perpendicular to the collector and contains the collector azimuth. The corresponding IAM is referred to as longitudinal IAM, or altitude modifier.

- The transverse angle of incidence is measured in a perpendicular plane to both the manifold opening and the longitudinal plane. The corresponding IAM is designated as the transverse IAM or azimuthal modifier.

Type 538 requires that bi-axial incidence angle modifiers $(\tau\alpha)_b / (\tau\alpha)_n$ be provided in an external data file, which serves as the IAM required for non-null longitudinal and transverse angles. The IAM for all l and t can be approached by multiplying IAM (θ_l, 0) and IAM (0, θ_t), as explained in McIntire, and Theunissen and Beckman.

- ***<u>Hypothesis</u>***

The total solar water heating system numerical modeling of a is impossible given the large number of parameters involved; for this, several hypotheses are considered inevitable.

Collectors area

Based on the meteorological data related to the global radiation incident and the necessary thermal requirements, the necessary catchment area could be calculated:

$$S = \frac{thermal\ needs}{irradiation} \tag{85}$$

<u>Technical characteristics</u>

The FPC and ETC chosen are of the Chaffoteaux brand. Its offer multi-energy heating and production systems of domestic hot water, integrating the latest technological innovations in terms of environmental protection and energy savings.

Solar storage must meet the needs of domestic hot water; therefore, to have a margin of safety, and moving away from any dissatisfaction, the volume of the storage tank of hot water is worth:

$$Vt = daily\ hot\ water\ needs\ (L).1.5 \tag{86}$$

Vt is the tank volume (L), and 1.5 h is the reserve time.

Table 18 shows the technical characteristics of collectors and tank used in this study scenario.

Collectors		
Technical characteristics	FPC	ETC
Area (m^2)	1.8-3.3	1.5-3
tested flow rate kg/hr.m2	60	60
optical coefficient (%)	0.7	0.7
thermal loss coefficient a1(kJ/hr.m^2 .K)	3.13	1.894
thermal loss coefficient a2(kJ/hr.m^2 .K^2)	0.016	0.0039
mass flow rate (min; max) (kg/hr)	0;90	0;90
optimal inclination (°)	45	45
Tank		
Volume (L)	150-200-300	
Specific heat of the fluid (kJ/kg.K)	4.19	
fluid density (kg/m^2)	1000	
thermal loss coefficient (kJ/hr.m^2.K)	1.4	
height (m)	1	
nodes number	3	
auxiliary heater power (kW)	1-1.5-3	
maximum auxiliary heater temperature (°C)	60	

Table 18: technical characteristic of collectors and tanks (individual SWH)

Load profile

The load profile Fig. 41 is adopted for the present scenario studied.

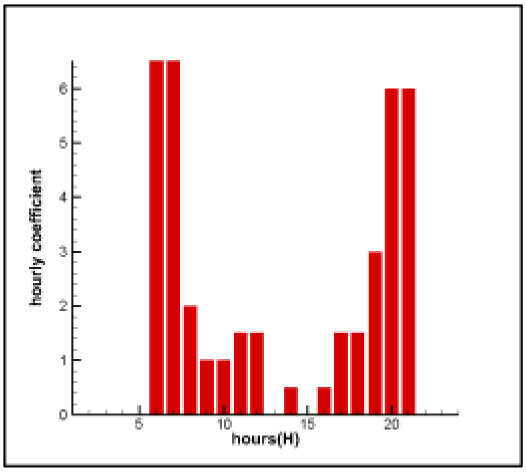


Figure 41: The daily profile of domestic hot water use.

All information related to the additional data such us (Cold water temperature) are in appendices.

- ***Energy performance analysis.***

The energy performance indices evaluated in this study include the energy collected, the useful energy, the solar fraction, and the collector's efficiency.

- The useful energy collected by the collector is:

$$Q_{coll} = \dot{m}C_p(T_{out} - T_{in}) \tag{87}$$

- The produced energy (in tank) is:

$$Q_T = \dot{m}C_p(T_{Tin} - T_{Tout}) \tag{88}$$

- Solar fraction:

$$SF\ (\%) = 1 - \frac{Q_{auxliary}}{Q_T} \tag{89}$$

2.2.2. Model Validation

to validate the simulation models, the validation article is "Validated TRNSYS Model for Forced Circulation Solar Water Heating Systems with Flat Plat and Heat Pipe Evacuated Tube Collectors» published by L. AYOMPE et al. [78] a comparison was made between the results given in the article and the results obtained by applying the data or the hypotheses set out in the article on our simulation model. Three different days are taken into account to compare the collector output temperature for the two different collector types indicated in the article and obtained by our simulation. Fig. 42 and 43 show the temperature variation obtained for the three different days for the two collectors. For the first two days, a difference of 2 ºC to 3 ºC between temperature results. For the third day, a difference of up to 10 ºC. Tables 18 shows the errors, 21%is the ETC average value, and 23% for FPC. The error is explained by the inexactitude of meteorological data used in the simulation.

$$Error(\%) = \frac{T_{REF} - T_{Model}}{T_{REF}} \times 100 \tag{90}$$

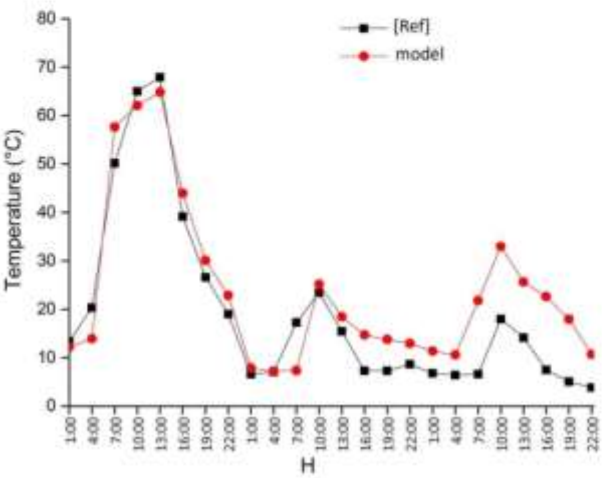


Figure 42: FPC validation results

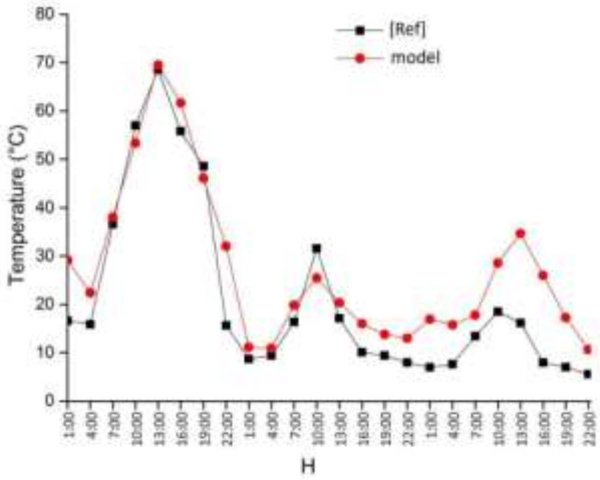


Figure 43: ETC validation results.

DAY	HOUR	Model temperature (°C)		Ref temperature (°C)		Error (%)	
		FPC	ETC	FPC	ETC	FPC	ETC
02-june	10 :00	62.08	53.38	65	57.1	-4	7
	13 :00	64.82	69.51	67.89	68.55	-5	-1
	16 :00	43.95	51.66	39.15	55.80	12	-9
25-november	10 :00	23.40	25.46	25.15	31.56	-7	24
	13 :00	15.45	20.34	18.48	17.10	-16	-16
	16 :00	7.27	15.97	14.69	10.12	-51	-37
20-junary	10 :00	17.97	28.55	32.96	18.50	-45	-35
	13 :00	14.13	34.65	25.62	16.14	-45	-53
	16 :00	7.47	25.95	22.62	7.95	-67	-69

Table 19: Validation results.

2.2.3. Simulation results

Three days representing the typical weather conditions in Fez were chosen to analyze the daily performance for the three different demands (low, standard, and high) of the glass plane collector. That is a cloudy day (November 22), clear sky (September 24), and intermittent cloudy (June 15). Fig. 44 shows the variation of the global radiation during the three different days; the maximum irradiation is equal to 1150 W/m^2 for the day with clear skies, 798 W/m^{2}for the intermittent cloudy day, and 100 W/m^2 for the cloudy day.

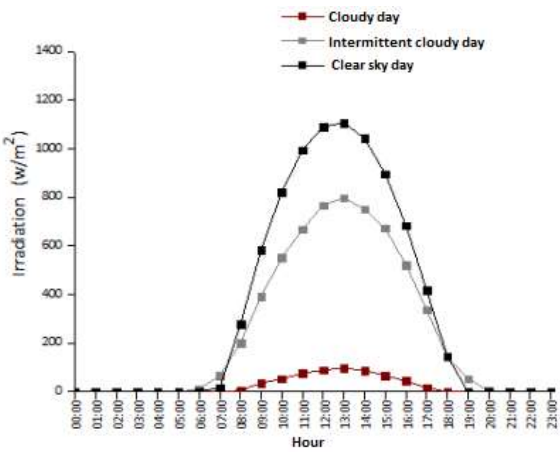
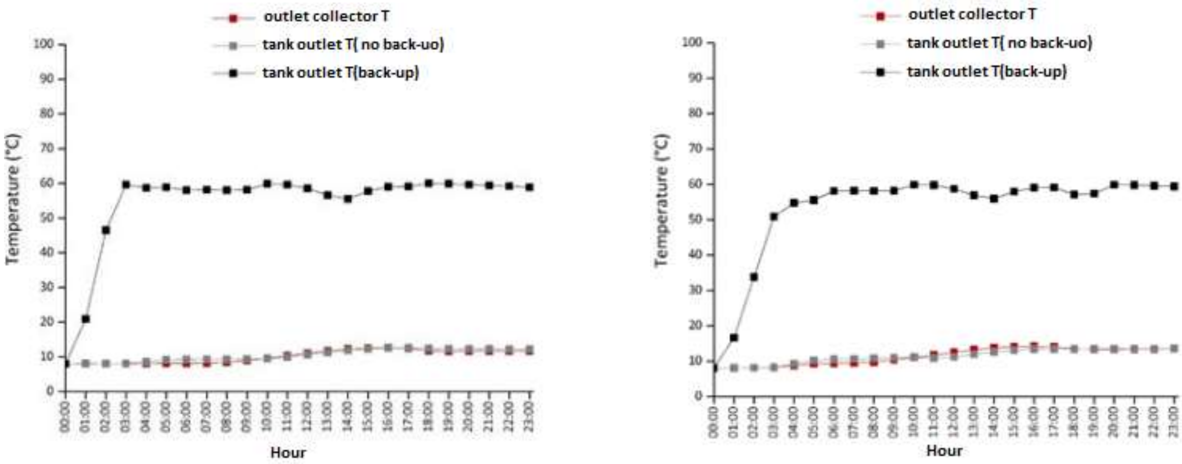


Figure 44: Fes irradiation variation.

a) Cloudy day results

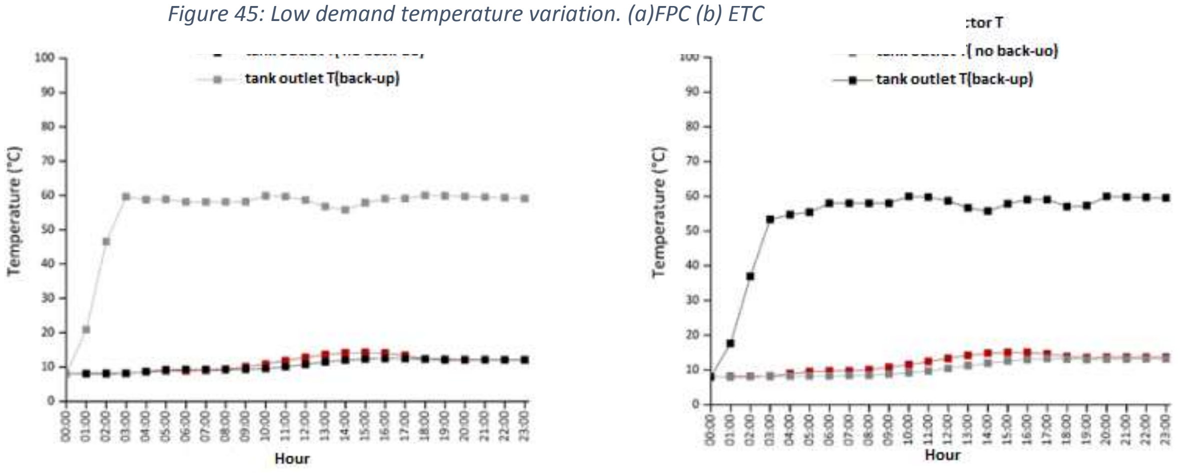
Figures 45a, 46c, and 46e show the variation of the FPC output temperature and the tank output with and without a back-up system for the different hot water demand: low, standard, and high-. It is found that the variation in the demand has no significant influence on the tank temperature (with back-up). The collector outlet temperature and the tank temperature (without back-up) show a slight difference between the low demand and the other two profiles. This difference is 2°C between 12 and 16 o'clock. This variation is due to a difference in the optimal collector area for each demand.

Figure 45b, 46d and 47f show that the variation of the demand does not influence the collector output temperatures and tank one. The variation of these two temperatures during the day is almost identical



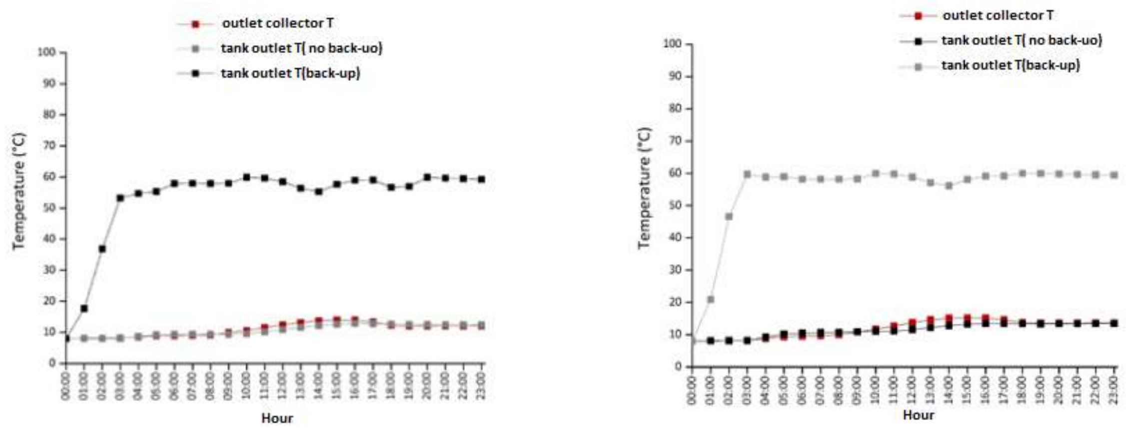
(a) (b)

Figure 45: Low demand temperature variation. (a)FPC (b) ETC



(c) (d)

Figure 46: Standard demand temperature variation. (c)FPC(d) ETC



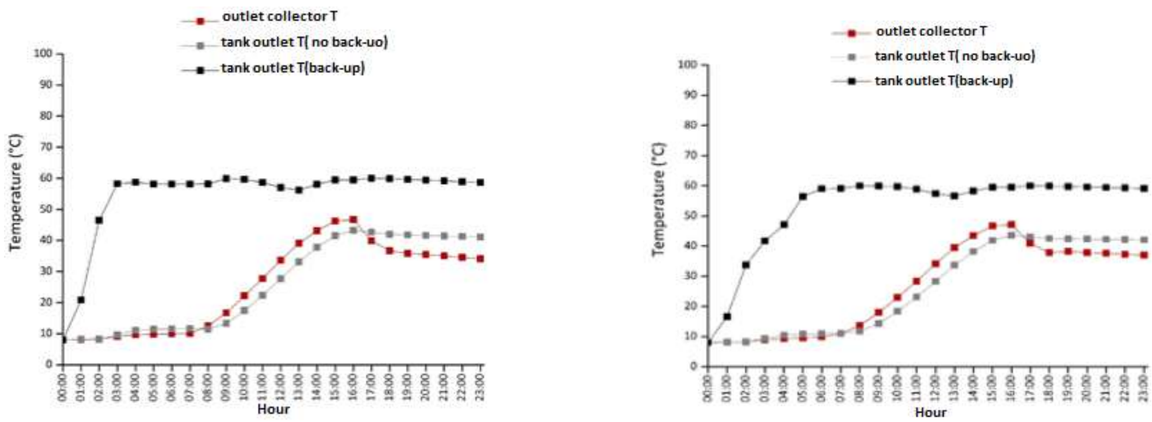
(e) (f)

Figure 47: High demand temperature variation. (e)FPC (f) ETC

b) Intermittent cloudy day results

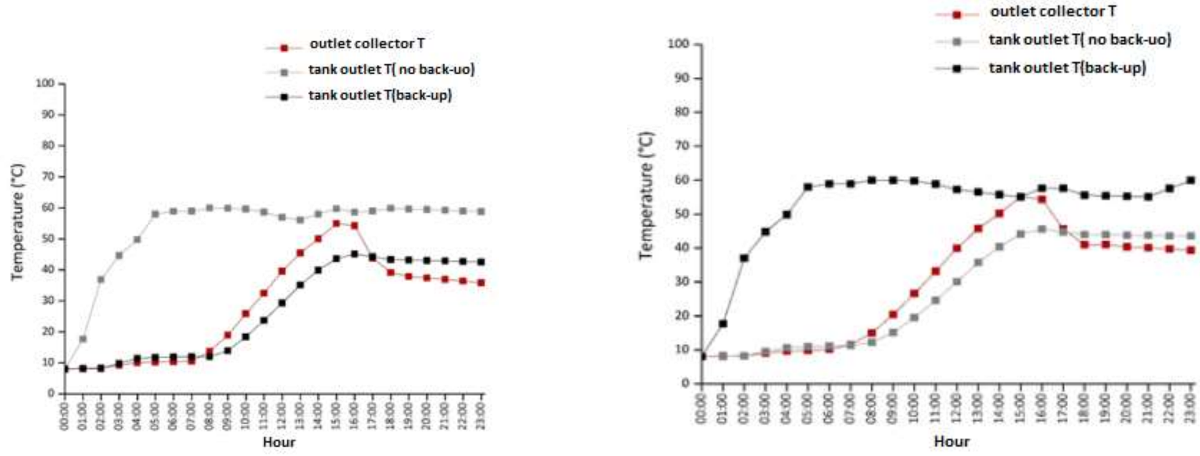
For FPC, the simulation of the solar system's behavior during an intermittent day covered with clouds makes it possible to notice that the solar storage tank reaches 45°C for the three request demands. While the collector outlet temperature evolves with the demand, it reaches a maximum value of 48°C for the low demand figure 48(g), 58°C for a standard demand figure 48(i), and 60°C for the high demand figure 50(k). This variation can be explained by the increased surface area of the collectors according to demand.

For ETC, the variations in collector and tank temperatures for this intermittent cloud-covered day depend on the demand for domestic hot water; the collector area variation explains this according to demand.



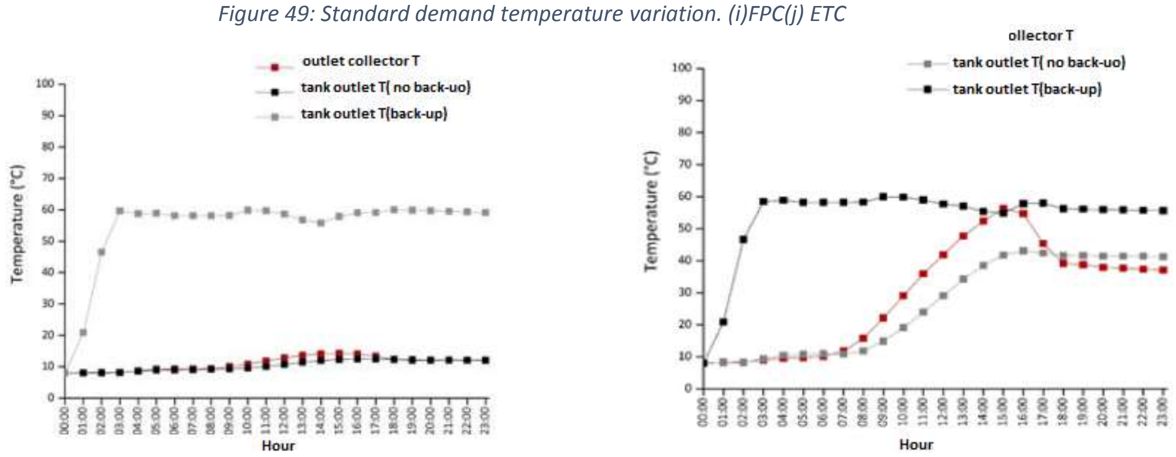
(g) (h)

Figure 48: Low demand temperature variation. (g)FPC(h) ETC



(i) (j)

Figure 49: Standard demand temperature variation. (i)FPC(j) ETC



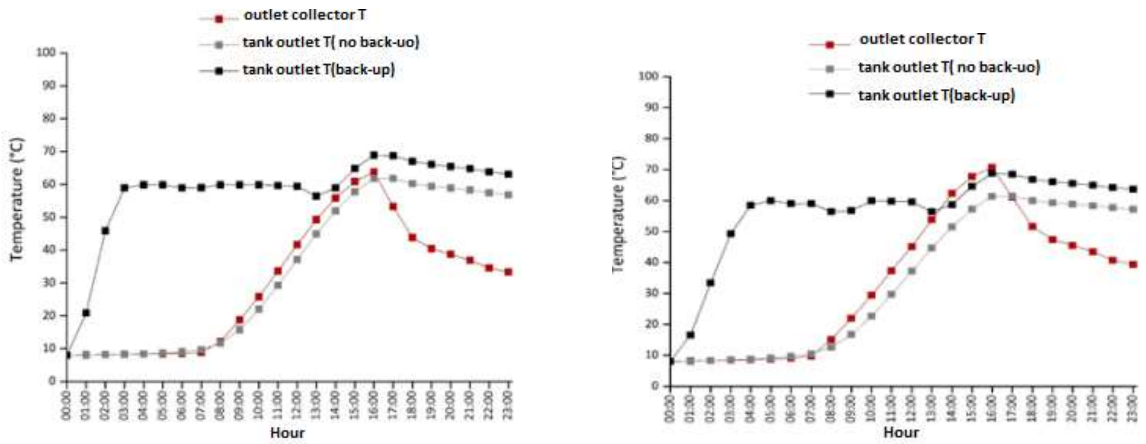
(k) (l)

Figure 50: High demand temperature variation. (k)FPC (l) ETC

c) Clear sky day results

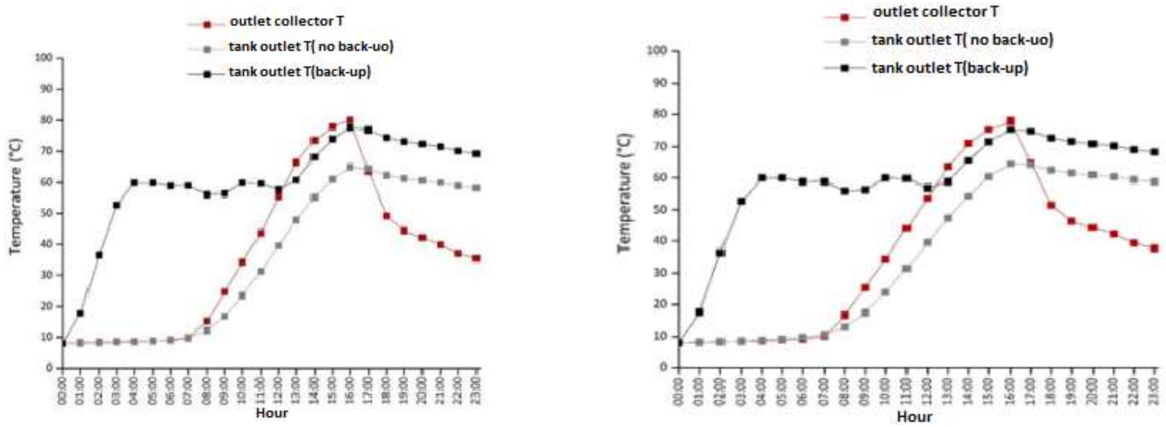
The temperatures recorded during this simulation are used to assess solar radiation's effect on the efficiency of thermal collectors. On the other hand, it is noted that the collector outlet temperature for the three demand profiles scenarios follows the variation of solar radiation during the day Fig. 51(m),52(o), and 53(q). while the temperature of the solar storage tank without a back-up system maintains its values for the three demand profiles, this is explained by the effect of tank thermal insulation.

The temperatures variations in the collector and tank (no back-up) are the same as those observed with the FPC. Temperatures recorded in these simulations with the vacuum tube collector are close to those recorded in the FPC simulations. This is explained by the difference in the collector area used during the two simulations. The FPC area is slightly greater than that of the ETC.



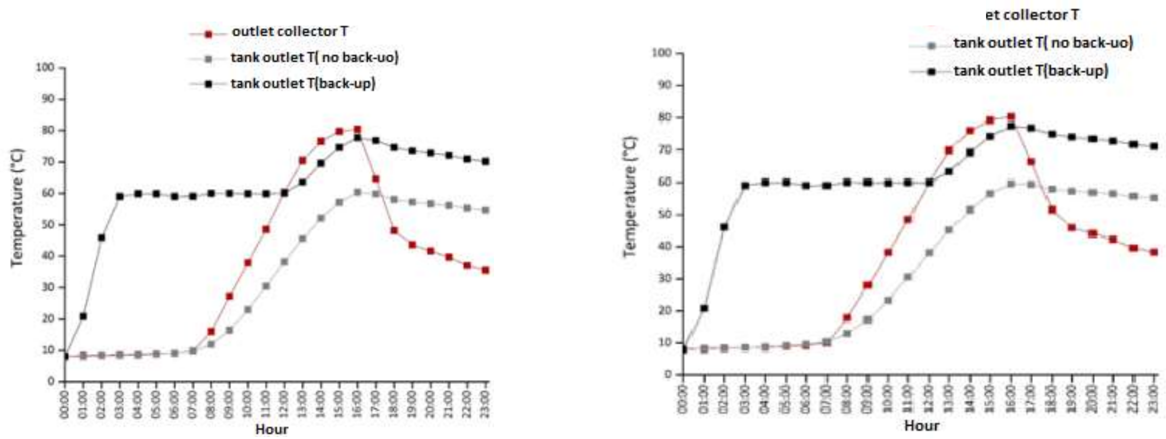
(m) (n) ETC

Figure 51: Low demand temperature variation (m)FPC (n)ETC.



(o) (p)

Figure 52: Standard demand temperature variation. (o)FPC (p) ETC



(q) (r)

Figure 53: High demand temperature variation. (r) ETC q)FPC

d) Monthly performances

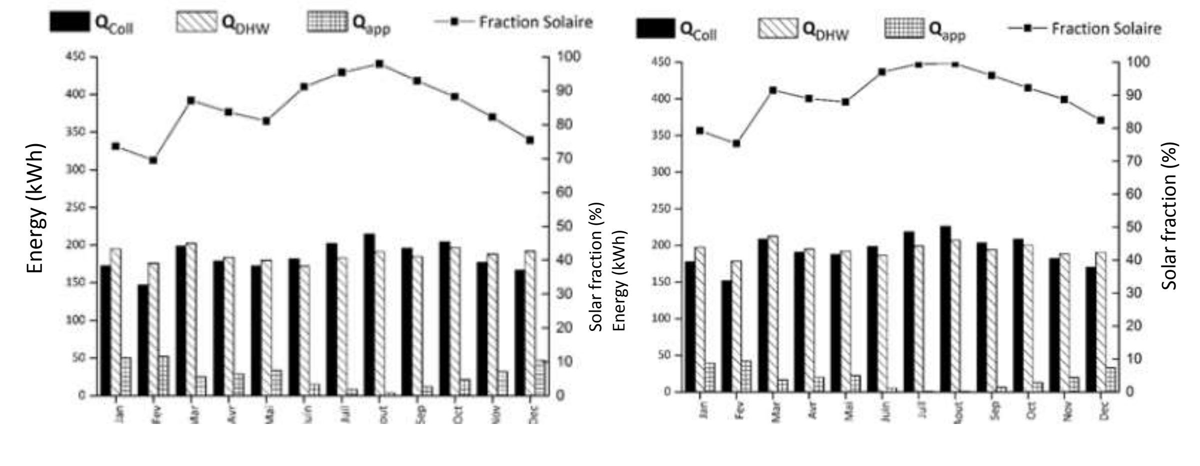
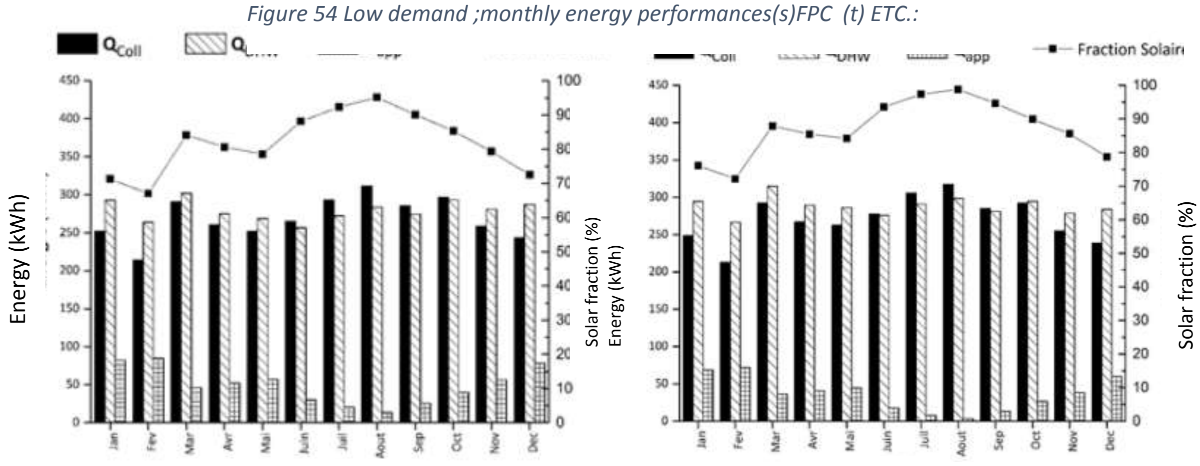


Figure 54 Low demand ;monthly energy performances(s)FPC (t) ETC.:



(u) (v)

Figure 55: Standard demand; monthly energy performances(v) ETC(u)FPC.

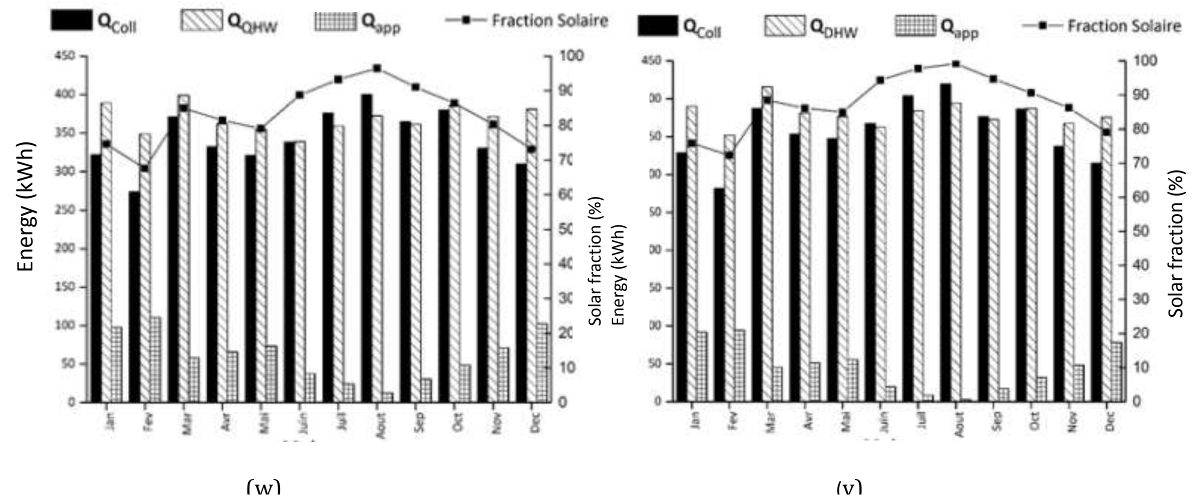


Figure 56: High demand ;monthly energy performances(w)FPC (y) ETC.

Fig. 54, 55 and 56 show the monthly variation of useful energy, extracted from the tank, the extra energy and the solar fraction for the three different demands (low, standard, and high), for the two technology types. The collected energy varies according to the demand; this is due to the catchment surface variation. The collected energy varied between 214kWh and 146kWh in August and February, respectively, for low demand case (150L).and between 311kWh and 214kWh for

standard demand case (200 L). For high demand (300 L) varied energy between 400kWh in August and 274kWh in February.
The energy extracted from the solar flask varied according to the load profile. The solar fraction varies in the same way for the three cases. It varies between 70% in February and 98% in August.
The energy collected by the collector varies in function of the loads' profiles; this is due to the load profile influence on the collector's area. The surface increases with the increase in the amount of water exhausted.
The energy extracted from the tank, which means the energy required to heat the sanitary water, varies during the year, depending on the cold-water temperatures. This energy is higher than the useful energy produced during the year's cold period, and the auxiliary system compensates for this difference. Note that the backup system is requested in the summer. This can be explained by the demand for hot water during the night and the morning's first hours.
The solar fraction varies at the same rate for the three types of use. This fraction reaches a maximum value in the summer of the order of 99%.
The two solar water heater technologies comparison, based on the results presented in this section, makes it possible to conclude that the evacuated tube collectors perform better than the glazed flat plate collectors in the third zone. To analyze the performance of the two technologies in the Moroccan context and draw comparative conclusions. Simulations of solar water heaters are made for all thermal zones of Morocco. The analysis of the simulation results shows that:
Evacuated tube solar water heaters are better than flat glazed flat plate collectors, during cold seasons of the year, in areas with a Mediterranean climate in the North, Oceanic in the West. On the other hand, the two technologies are identical for the warm seasons.
For the fourth zone, we note that the vacuum tubes are more efficient from March. In zones that have a continental climate zone five and a Saharan climate zone 6. The vacuum tube collectors have a better performance than flat glass collectors throughout the year.

2.3. Collective SWH

2.3.1. Estimation of daily needs

Defining domestic hot water requirements is essential to size a solar water heater properly. It is recommended to base on the actual consumption of hot water and, if it is not possible, to base on the ratios of domestic hot water consumption that depend on the temperature. Unlike a conventional installation, a solar installation is dimensioned on average annual consumption and not on the peak. The main difficulty in arriving at the right sizing is the correct estimation of hot water consumption.
In the case of apartment buildings, numerous statistics have made it possible to precisely define the load profile according to the building apartments' standard number. The first step is, therefore, to define the number of standard apartments. This will allow later to refer to the typical load profile.

a) Standard apartment number

Standard housing has the following characteristics:

- Number of occupants: 3,5
- Number of rooms (living room + bedrooms): 4
- Sanitary equipment: 1 ordinary bathtub (160x70)
- One sink

As a first approximation, if we do not know the exact characteristics of the dwellings and if we think they are close to the definition given above, we can say that the number of standard dwellings in the building is equivalent to the actual number of dwellings. If we want to be more precise, we will calculate the number of standard dwellings of the building. It will be noted that if the building's actual housing type differs from the definition of standard housing, the numbers of standard housings and actual apartment may be significantly different.

b) Exact calculation of standard apartment number in the building.

To calculate the number of standard dwellings in a building:

$$N = F_P \sum (F_e F_s) \tag{91}$$

F_P: indicates the average number of persons in a unit dwelling.
F_e: refers to the volume of water drawn from a sanitary appliance.
F_s: represents a factor of simultaneity indicating how much of the consumption of a device must be taken into consideration within a dwelling.
The details values of the coefficient are in Appendices.
The study building has 16 apartments, which have the same dimensions. Each apartment contains two bathrooms with a washbasin and a regular shower, and a kitchen with a single sink. So the unit number for this building will be 8.
Using the standard profile method and taking into account the habits of middle-class Moroccan consumers and the daily needs per person of domestic hot water. A value of 37.5L/day/person for average demand for SWH, also by estimating an occupation of 4 persons per apartment, we will have daily needs of 1320 L to satisfy taking into account the calculations previously unveiled.

Fig. 57 shows the monthly energy demand variation for the entire building.

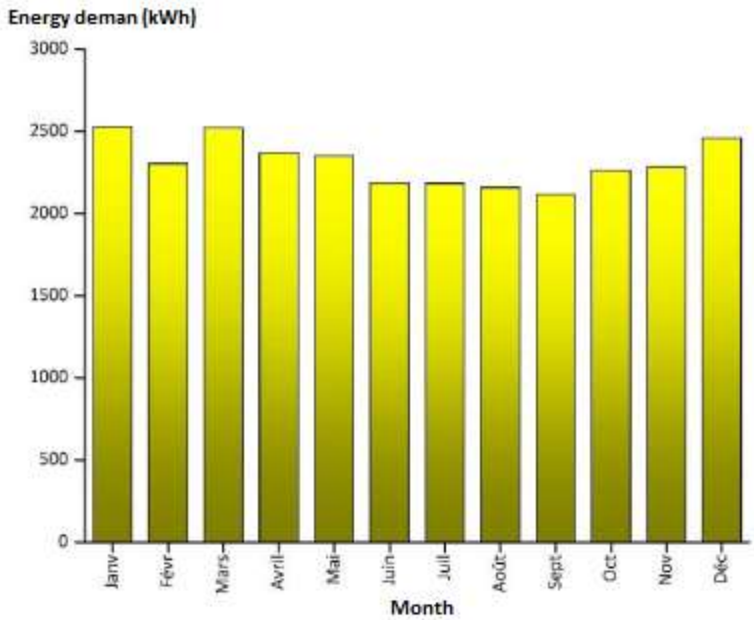


Figure 57: monthly energy demand for collective SWH.

2.3.2. Simulation model and hypothesis

The apartment layout is symmetrical. Eight apartments on each side of the building have a common technical shaft. The collective solar system has been treated in two parts, eight apartments per part that make the entire building (16 apartments). The results obtained will be identical. The configuration of the simulation's solar system model is the "collective solar water heater with collective storage and individualized back-up, which is divided into two circuits.

The primary circuit, which includes the field of collectors and the solar tank with a capacity that covers the eight apartments' needs, this circuit is located in the roof. The second circuit contains the individualized tanks with an integrated back-up, a circulation pump, and a regulator. Fig. 58 illustrates the connection between the primary and secondary circuits of the collective solar water heater system.

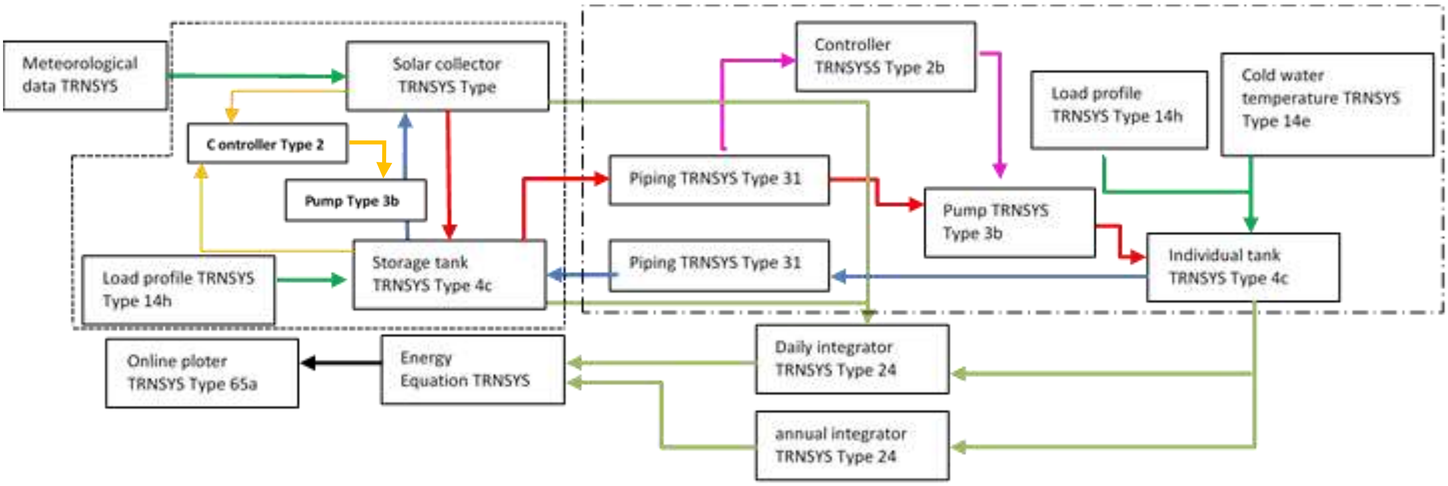


Figure 58: Simulation information flow diagram of the collective solar system.

- **<u>Models</u>**

a) Type 647: Flow diverter

These type models a bypass valve that divides a liquid inlet mass. An inlet flow can be divided into 100 individual flows. The limit of 100 input flows can be changed in the Fortran source code.

Type 647 takes as input, the liquid temperature, and the mass flow. The component also takes a single pressure drop value through the deflection.

Input parameters are fractions of the total input mass flow out of the bypass valve through each given port. The number of ports is also provided as a parameter. The model ensures that the user's fractions are added to 1. The output flow of the outgoing liquid is determined as:

$$m_\iota = \dot{m}_{in} f_\iota \qquad (92)$$

The feed flows temperature at each port is equal to the temperature of the liquid input current. This type does not perform any pressure drop calculations.

b) Type 649: Flow mixer

This type models a mixing valve that combines up to 100 individual liquid streams in a single output mass. The limit of 100 input streams can be changed in the Fortran code source. It models a mixing valve by performing an energy balance on the system of which there may be up to 100 input flows, but a single output stream.

The energy assessment can be written, as shown in the following equation:

$$\dot{m}_{in,1}\, C_p\left(T_{in,1} - T_{mix}\right) + \dot{m}_{in,nPorts} C_p\left(T_{in,nports} - T_{mix}\right) = \dot{m}_{out}\, C_p\left(T_{out} - T_{mix}\right) \qquad (93)$$

The output temperature is shown in the following equation:

$$T_{out} = \frac{\sum_{i=1}^{nPorts} \dot{m}_i T_{in,i}}{\sum_{j=1}^{nPorts} \dot{m}_j} \quad (94)$$

c) Circulation pump

This model of pump calculates a mass flow using a variable control function, which must have a value between 1 and 0 and fixed maximum flow capacity. In this Type 3 instance, the pump power can also be calculated either as a linear function of mass flow or by a defined relationship between mass flow and energy consumption. A specific part of the pump power is converted into thermal energy.

This component defines the flow rate for the remaining components in the flow loop by multiplying the maximum flow rate (Parameter 1) by the control signal (input 3).

The mass flow input of this component is for viewing purposes only. It is not used except for convergence check.

d) Type 2b: Controller

The On/Off differential controller generates a control function with a value of 1 or 0. The signal value is chosen based on the difference between the upper and lower temperatures Th and Tl, compared to two differences in DTI and DTL Deadband temperatures. The new value of the control function depends on the input control function's value at the last moment. The controller is typically used with the input control signal connected to the output control signal, providing a hysteresis effect. However, control signals from different components can be used as input control signals if a more detailed form of hysteresis is desired. For safety reasons, a high limit is included with this controller. if the upper limit is exceeded the control function is set to zero. This controller is not limited to detection temperatures, even if the temperature notation is used. This instance of the type2 controller is intended to be used with the TRNSYS SOLVER 0 standard (Successive replacement).

e) Type 31 piping

This component models the fluid flow's thermal behavior in a pipe or pipe using fluid segments of variable size. The incoming fluid moves the position of the existing segments. In the simulation, the flow rate multiplied, and the new segment mass is equal. The temperature of the new segment is that of the incoming fluid. This pipe's output is a collection of elements that are "pushed" by the input stream. The "plug-flow" considers that between adjacent elements, there is no mixing or conduction.

- <u>**Hypothesis**</u>

Table 20 shows the technical characteristics of the solar tank used in this scenario. For collectors the same technologies type using on the individual case are adopted.

tank		
	common	Individual auxiliary tank
volume (L)	1600	200
Specific heat of the fluid (kJ/kg.k)	4.19	
fluid density (kg/m2)	1000	
thermal loss coefficient (kJ/hr.m2.K)	1.4	
height (m)	1.8	1
nodes number	6	3
auxiliary heater power (kW)	0	1.5
maximum auxiliary heater temperature (°C)	60	

Table 20: technical characteristic of collectors and tanks (collective SWH).

Collectors field

The simulations were carried out with two types of collectors: a flat plate collector with forced circulation and vacuum tube collectors.

The collector field's surface needed to cover domestic hot water's thermal requirements is 18m^2, six-coupled collectors, two in series, and three in parallel (3m^2 each). They are facing due south at an angle of 45° from the horizontal.

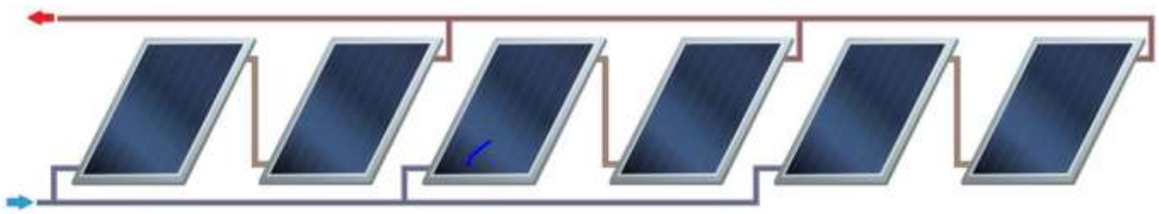


Figure 59: panel assembly.

Piping

In piping, there are thermal losses. The pipes used are PPR (polypropylene) with an internal diameter of 13.2 mm, an external diameter of 20 mm, and thermal conductivity of 0.24W/m^2. ARMAFLEX is the insulation with a thermal conductivity of 0,04W/m^2 and a thickness of 7mm. Below is the detailed calculation of the thermal loss coefficient:

$$U = \frac{1}{\frac{D_{ext-Insulation}}{h_{int} D_{int-pipe}} + \frac{\ln(\frac{D_{ext-pipe}}{D_{int-pipe}}) D_{ext-insulation}}{2\lambda_{pipe}} + \frac{\ln(\frac{D_{ext-insulation}}{D_{int-insulation}}) D_{ext-insulation}}{2\lambda_{insulation}} + \frac{1}{h_{ext}}} \quad (95)$$

Internal convection coefficient :

$$h_{int} = \frac{Nu\lambda}{L} \quad (96)$$

Nusselt number $$Nu = 0.023\ Re^{0.8} Pr^{\frac{1}{3}} \quad (97)$$

Reynolds number $$Re = \frac{\rho v L}{\mu}$$ (98)

Prandtl numer $$Pr = \frac{\mu C_p}{\lambda}$$ (99)

Fluid mass flow $$\dot{Q} = Sv$$ (100)

Piping area $$Sp = \pi d^2$$ (101)

		Piping length (m)	Thermal loss coefficient (W/m².K)
RDC	Apartment 1	25.86	3.81
	Apartment 2	30.41	3.81
R+1	Apartment 5	22.44	3.82
	Apartment 6	26.99	3.81
R+2	Apartment 9	19.79	3.82
	Apartment 10	24.34	3.82
R+3	Apartment 13	16.66	3.83
	Apartment 14	21.21	3.82

Table 21: piping technical characteristics.

- ***Energy performance analysis.***

The energy performance indices evaluated in this study include energy collected, energy extracted from the tank, supply pipe losses, the collector's efficiency, and the system.

Pipe losses,

$$Q_{loss} = \dot{m} C_p (T_{Tout} - T_T) \quad (102)$$

the collector's efficiency,

$$\eta_C = \frac{Q_{coll}}{I_r A_c} \quad (103)$$

the system efficiency

$$\eta_{sys} = \frac{Q_T}{I_r A_c} \quad (104)$$

2.3.3. Simulation results

a) Cloudy day

As for the last part concerning the individual solar water heater, three days were chosen to evaluate the daily performance for the two collectors' types FPC, ETC that are: a cloudy day (22 November), with clear skies (24 September) and intermittent cloud cover (15 June).

Simulation results for a cloudy day show in Fig. 60 that outlet collector temperature does not exceed 25°C, which is less than half the temperature requirement of 60°C.

We also note that the individual tanks and the solar tank are at a higher temperature than the collector; this is explained by thermal inertia's effect – heat stored since the previous day. The representative curves of these temperatures show a significant decrease during the day; this is due to the tank and piping thermal losses and the low temperature from collectors.

Fig. 61 shows that ETC behaves the same way on a cloudy day as the FPC with a slight increase of +3°C in field temperature; this is explained by the losses of almost zero (ETC advantages). FPC has the same absorption capabilities, but losses are much greater.

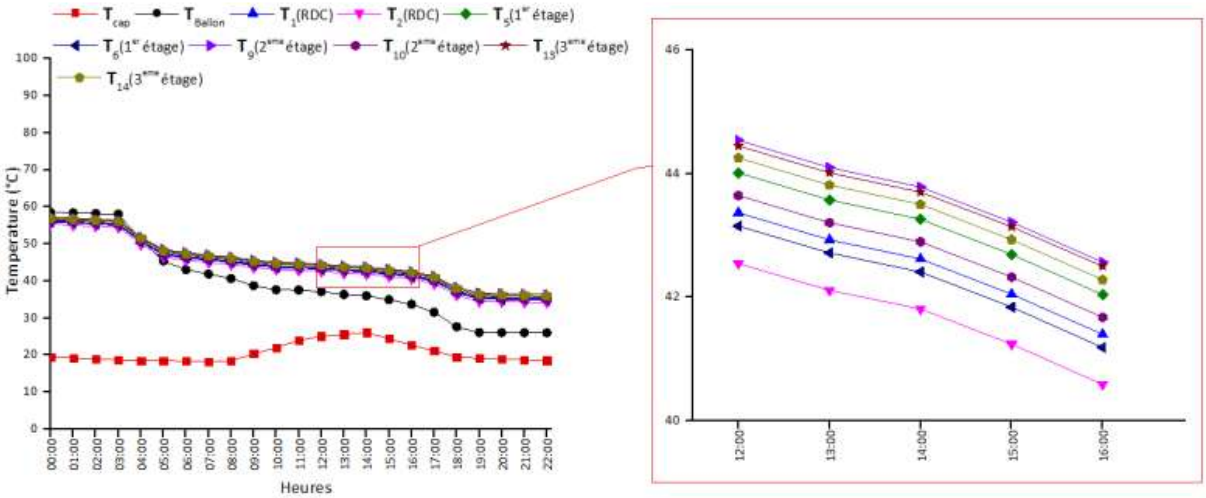


Figure 60: System temperature variation (FPC) in cloudy day.

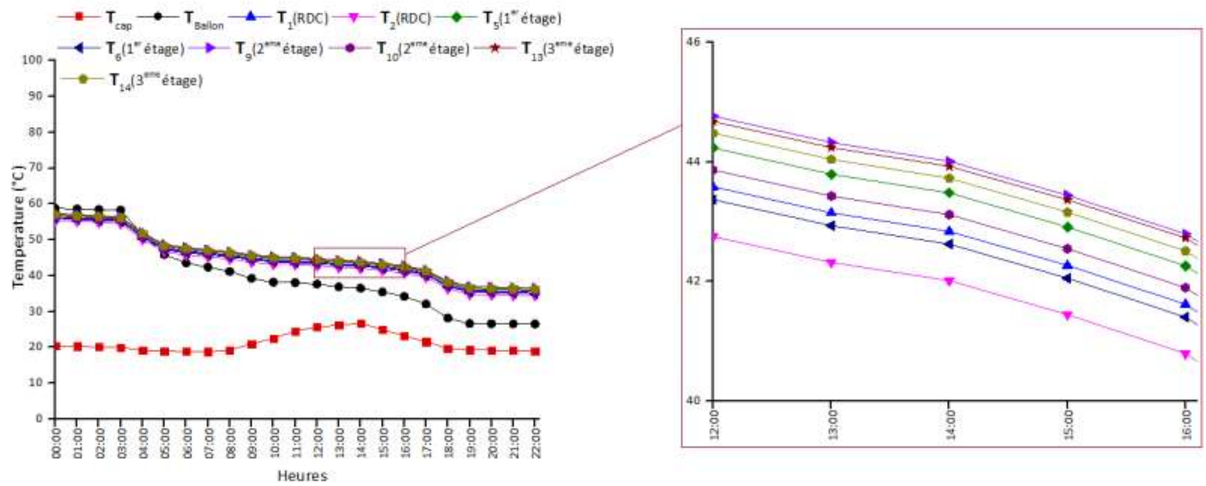


Figure 61: System temperature variation (ETC) in cloudy day.

b) Clear sky day results

On a clear day, the FPC field reaches a maximum of 90°C, while the ETC field reaches 100°C simultaneously. The storage tank temperatures in both configurations (FPC, ETC) exceed 60°C. The flat plate collector system starts to gain temperature from the first hours of sunshine and reaches a temperature of 38°C at 08:00. In contrast, ETC reaches 30°C at the same time. The storage tank related to ETC reaches 100°C at noon. the temperatures of the individual tanks for the ETC system are higher than those of the FPC system

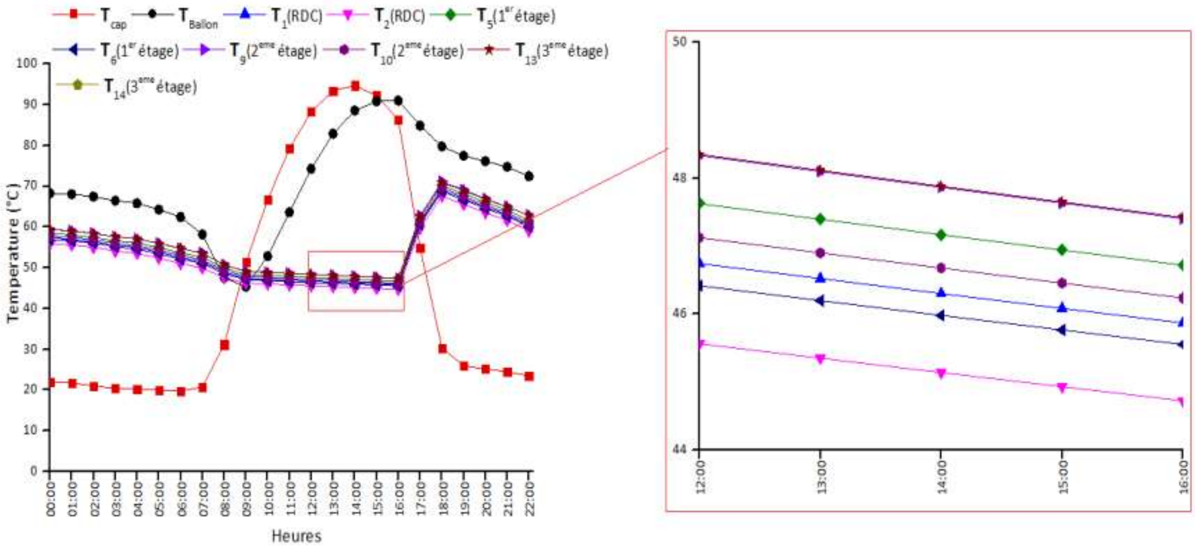


Figure 62: System temperature variation (FPC) in clear day.

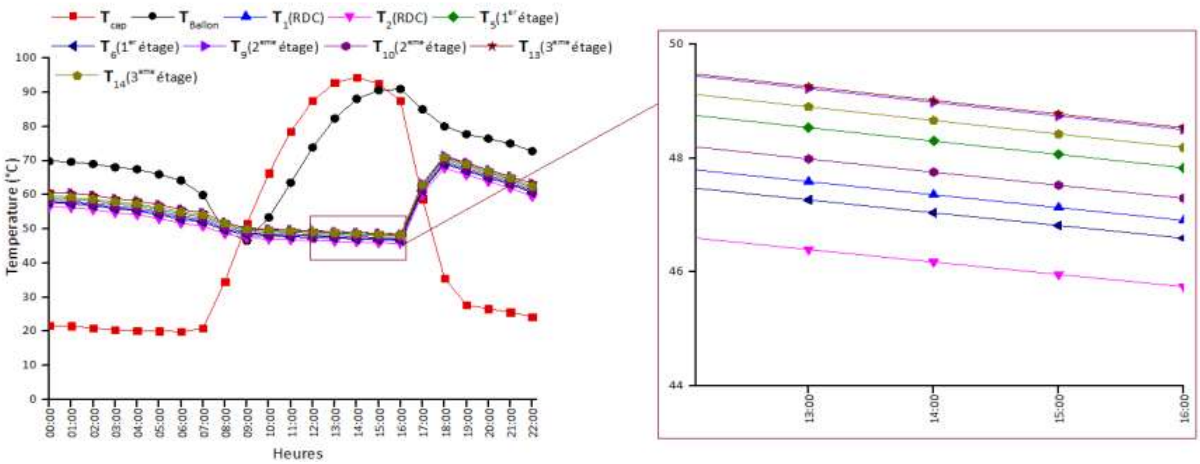


Figure 63: System temperature variation (ETC) in clear day.

c) *Intermittent cloudy day*

During an intermittent cloud-covered day, the two configurations' simulation results show a slight increase in the temperature of the vacuum tube collector outlet compared to FPC. The temperature rate increase is faster for the ETC field than that of the FPC field because solar absorption is not affected by the sun's incident angle as the tubes are round. The vacuum collectors are, therefore, useful from morning to night. FPC is advantageous when the sun is in line with the glazing, but this is only a few hours a day. It is noted that the temperatures of the individual tanks in the vacuum tube system are higher than those of the glass plane collector system—Fig. 64 and 65.

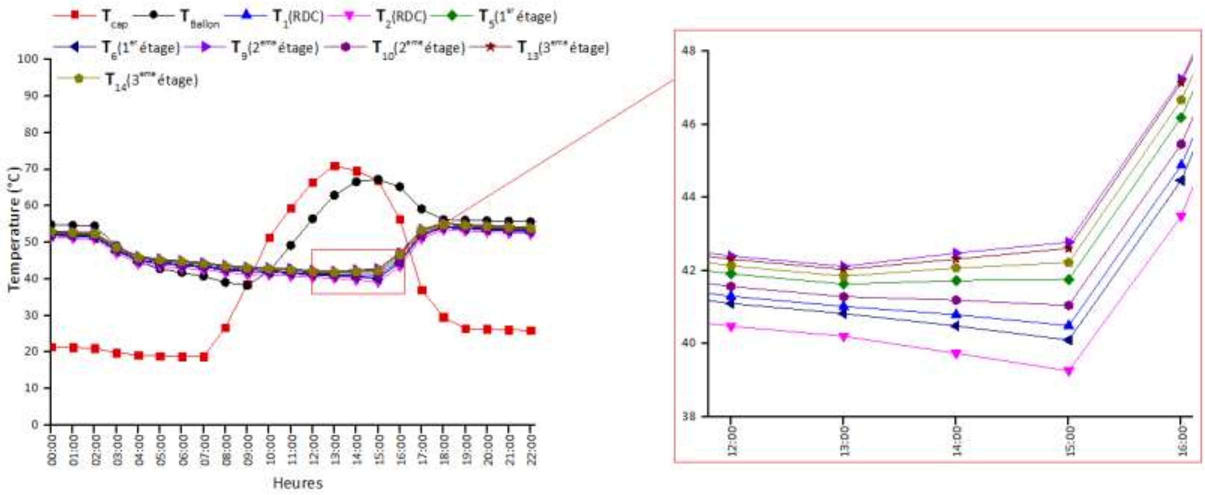


Figure 64: System temperature variation (FPC) in intermittent cloudy day.

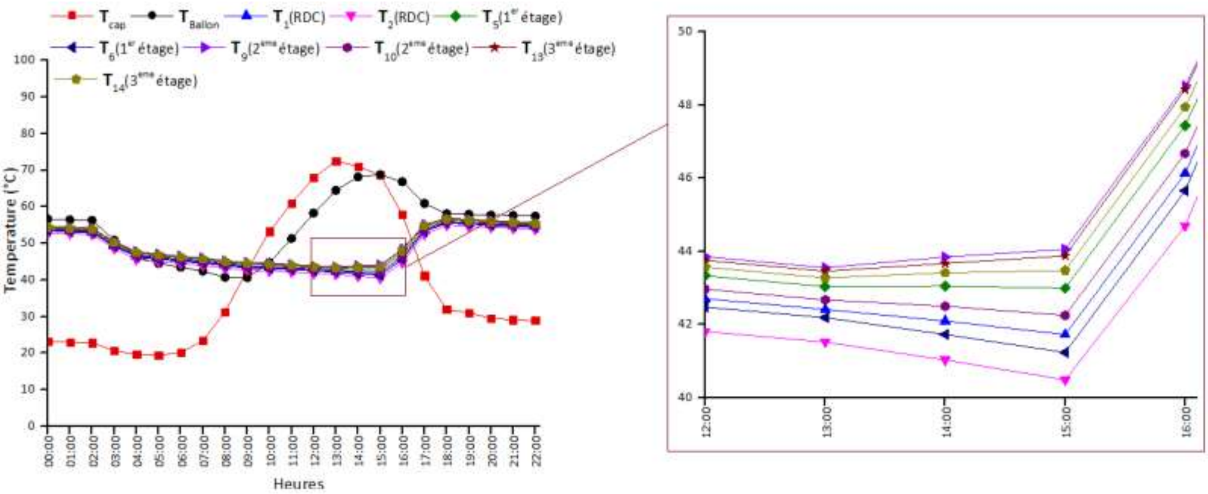
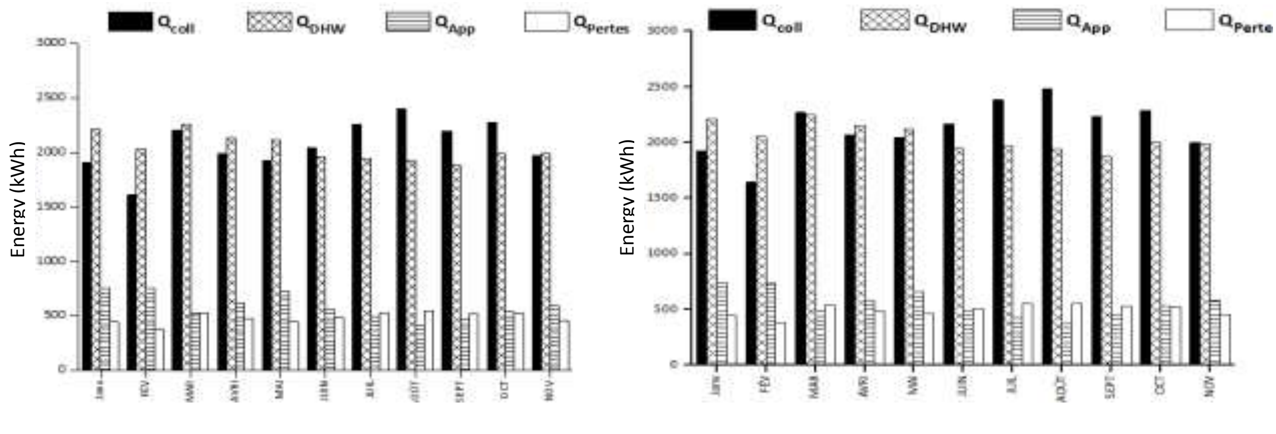


Figure 65: System temperature variation (ETC) in intermittent cloudy day.

d) Monthly performances

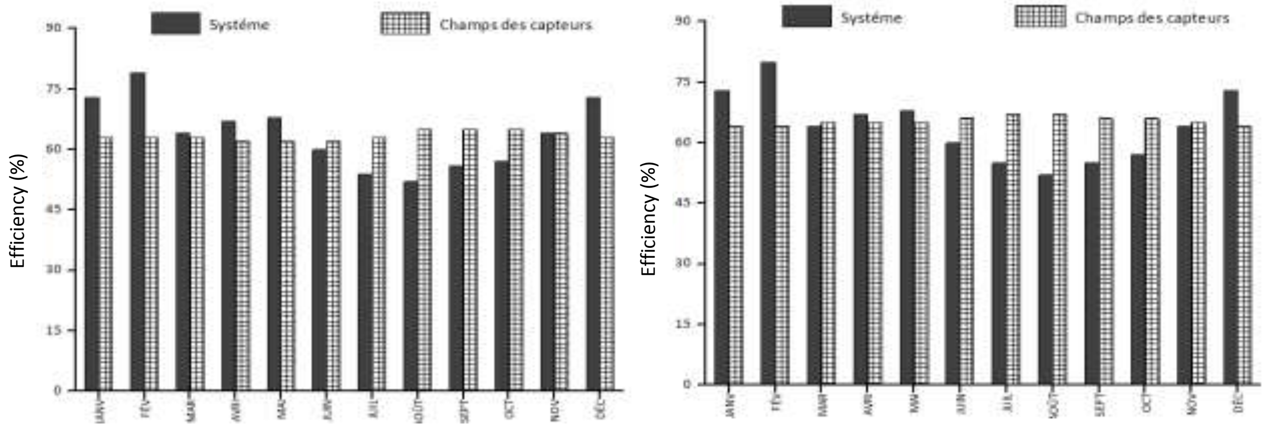
Simulations of solar systems for domestic hot water production make it possible to evaluate collectors and production systems' performance. Figure 66(a) and Figure 67(c) summarize the simulation results for flat plate and vacuum tube collectors. It can be seen that the useful energy produced by the vacuum tube collectors is more significant than that resulted using the glazing flat plate collectors during the cold months; this is explained by the round shape of the tubes, which enables them to capture the irradiations. Along the day, thermal losses at the pipe and solar tank level are almost constant throughout the year, which causes the auxiliary heater's operation all year round, with a decrease during the hot months.

The efficiency of the domestic hot water production system based on the simulations carried out shows that the vacuum tube system's performances are higher than the flat plate collector. During the cold months, the efficiency of the vacuum tube system reaches 80% in February. However, the efficiency of both systems is identical during the summer months. The vacuum tube collectors' field efficiency is always greater than that of the FPC, as shown in Figure 66(b) and Figure 67(d).



(g) (h)

Figure 66: (a) flat plat collector, (b) evacuated tube collector



(i) (j)

Figure 67: (c) flat plat collector, (d) evacuated tube collector (efficiencies).

The results of collective solar systems simulations related to the domestic hot water production show that the solar water heaters with ETC are more efficient than FPC, whatever the demand profile.

An analysis of the solar fractions and energies provided concludes that the evacuated tubes are more efficient than the glazed flat plate technology on all Morocco's cold zones (zones 4, 5, and 6). For zones 1 and 2, characterized by their moderate climates, we note that the two technologies are identical during all the year except for the winter months, where ETC systems deliver more energy than the FPC collectors.

3. *Economic study*

The simulations results carried out in the previous parts allow us to study the energy savings achieved and subsequently conclude the estimated financial savings.

We will first present the energy requirements for domestic heating water by various conventional means, namely electric water heaters and gas water heaters. The savings evaluation will be presented following the transition to solar energy; in this step, the evaluation will be made for individual systems, with two scenarios: ETC and FPC. In the second part of this study, the savings made on domestic hot water will be compared to the building envelope's action savings. Moreover, at the end of the studies, the return on investment time of the two solutions (active and passive) will be presented as a comparative index.

3.1. *Active solution savings*

The hot water production is ensured in the Moroccan context in general by instantaneous gas water heaters in the first place, or by instantaneous electric water heaters. There are also storage water heaters. Table 22 summarizes the overall yields of the various domestic hot water systems considered in this study.

The energy comparison focused only on the individual DHW systems. The comparison of the collective case requires a study of the conventional collective systems of hot water production.

	System	Global efficiency
Electrical DHW	Night accumulation	0,7
	Instanoeus	0,95
Gas accumulation DHW		0,5
Instant gas water heater	With light pilot	0,6
	Without light pilot	0,8

Table 22: Efficiency of DHW production systems.

The power required to produce domestic hot water varies according to the thermal zone demand and old water temperature (variation of cold-water temperature during the year). Fig. 68, 69 and 70 represent the annual energy demand variation for domestic hot water production for the various conventional systems in the different Moroccan thermal zones, according to the demand for domestic hot water.

It is found that the gas storage water heater is the most energy-consuming of all systems, followed by the gas instantaneous water heater. The instantaneous electric water heater is the most economical technology. The required annual energy thresholds vary according to the thermal zones; This is due to the variation of each zone's cold-water temperatures.

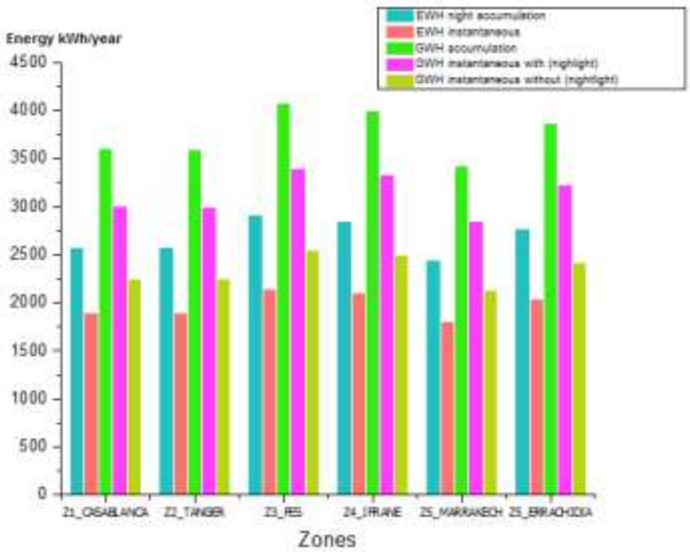


Figure 68: SWH production energy for low demand

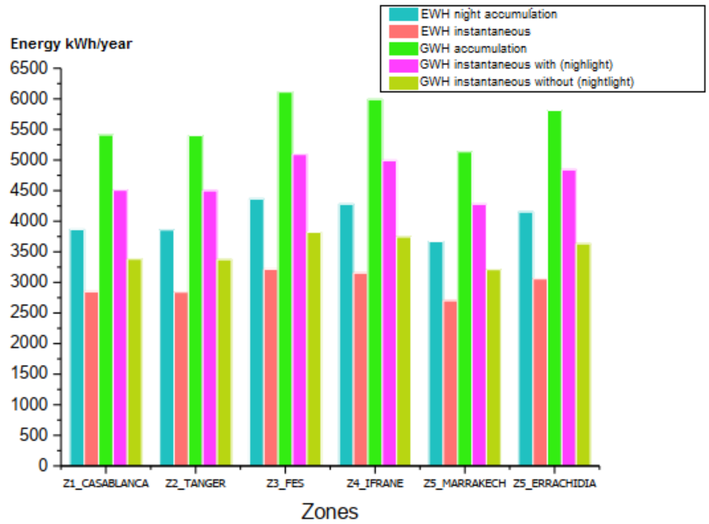


Figure 69: SWH production energy for standard demand

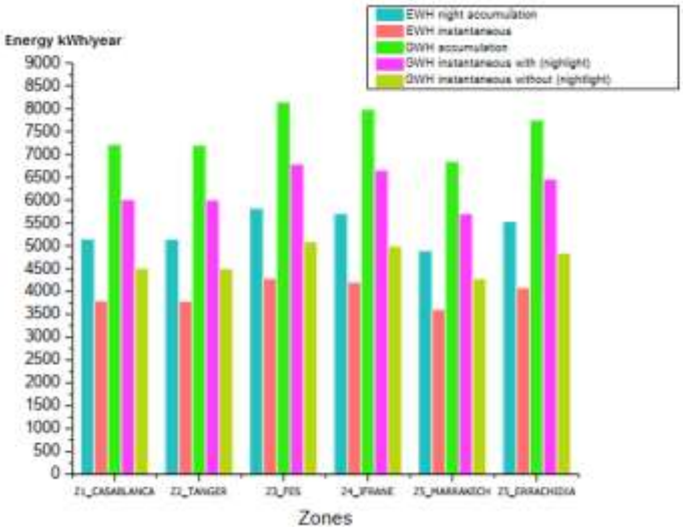


Figure 70: SWH production energy for high demand.

The Solar Domestic Hot Water System requires an auxiliary (i.e., conventional. In the following auxiliary energy (gas and electricity) will be presented. The simulations results presented previously, plots of variations in the auxiliary heating energy required by solar water heaters were plotted according to the thermal zones, the demand for domestic hot water, and the type of conventional energy source Fig.71, 72 and 73. Energy demand is high in Zone 4 (Ifrane) for all hot water demand scenarios.

This part concerned the savings evaluation of domestic hot water's energy production and consumption by conventional systems and solar production systems. We can see a maximum energy saving of 97% replacing a gas storage water heater in zone 5 Marrakech by a solar water heater ETC system with an electric auxiliary heater. Besides, the minimum savings obtained is about 58%, replacing an instantaneous electric water heater in zone 4 -Ifrane- by a solar water heater with FPC technology with gas back-up.

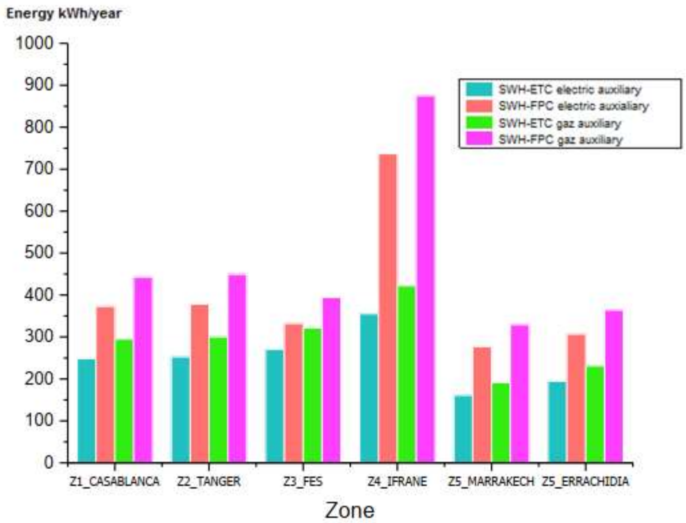


Figure 71: : Annual energy of the back-up system for a low demand for DHW.

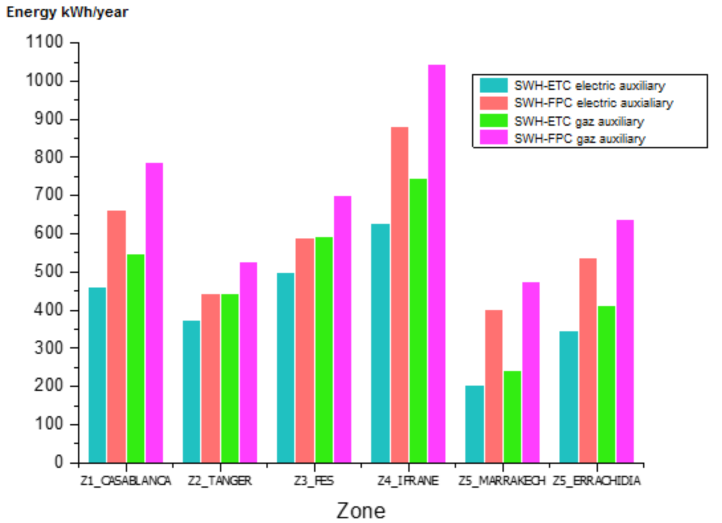


Figure 72: Annual energy of the back-up system for a standard demand for DHW.

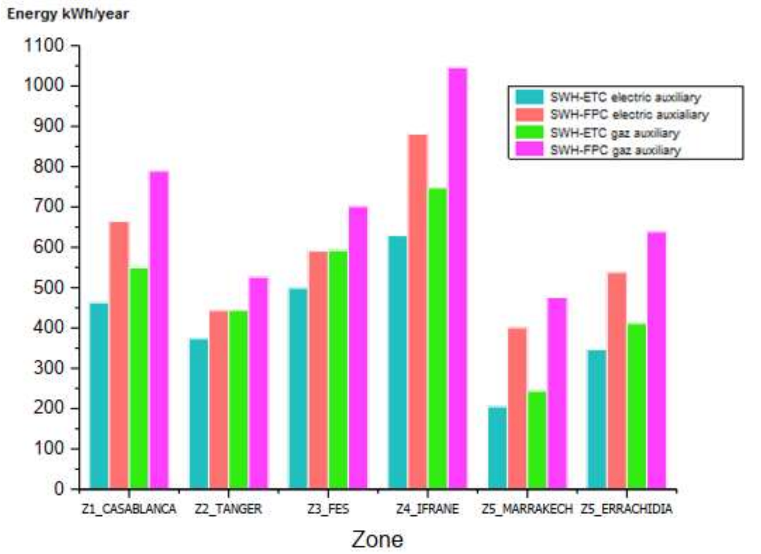


Figure 73: Annual energy of the back-up system for a Hight demand for DHW.

Energy savings achieved for different scenarios of DHW production (kWh / year)

	A→1	A→2	A→3	A→4	B→1	B→2	B→3	B→4	C→1	C→2	C→3	C→4	D→1	D→2	D→3	D→4	E→1	E→2	E→3	E→4
Z1	2328	2204	2282	2134	1650	1526	1604	1456	3359	3234	3312	3164	2758	2633	2711	2563	2006	1882	1959	1812
Z2	2319	2193	2271	2122	1642	1516	1595	1445	3347	3221	3300	3150	2747	2621	2700	2550	1997	1871	1950	1800
Z3	2639	2578	2588	2516	1873	1812	1823	1750	3803	3742	3752	3680	3124	3063	3073	3001	2275	2214	2225	2152
Z4	2498	2116	2431	1978	1747	1365	1680	1227	3639	3257	3572	3119	2973	2591	2906	2453	2141	1759	2074	1621
Z5	2284	2168	2254	2116	1641	1524	1610	1472	3262	3146	3232	3094	2692	2575	2661	2523	1978	1862	1948	1810
Z6	2573	2461	2537	2404	1845	1733	1808	1675	3681	3568	3644	3511	3035	2923	2998	2865	2227	2115	2191	2058
Z1	3477	3316	3404	3213	2460	2299	2387	2196	5023	4862	4950	4759	4121	3960	4049	3857	2994	2833	2921	2730
Z2	3561	3292	3506	3186	2546	2277	2491	2171	5104	4834	5049	4729	4204	3935	4149	3829	3079	2810	3024	2704
Z3	3830	3776	3730	3665	2681	2627	2581	2517	5576	5522	5476	5411	4558	4503	4457	4393	3284	3230	3184	3120
Z4	3737	3542	3636	3404	2611	2416	2510	2278	5449	5254	5348	5116	4451	4256	4349	4117	3203	3008	3101	2869
Z5	3412	3299	3364	3230	2447	2334	2399	2265	4879	4766	4831	4697	4023	3910	3975	3841	2954	2840	2906	2771
Z6	3845	3699	3788	3614	2753	2606	2695	2521	5506	5360	5449	5275	4537	4391	4480	4306	3326	3180	3269	3095
Z1	4690	4489	4603	4364	3334	3133	3247	3008	6751	6550	6665	6425	5549	5348	5462	5223	4046	3845	3959	3720
Z2	4769	4699	4699	4616	3415	3346	3345	3263	6826	6756	6756	6673	5626	5556	5556	5473	4126	4056	4056	3973
Z3	5321	5229	5228	5118	3790	3698	3696	3587	7649	7557	7556	7446	6291	6199	6198	6088	4594	4502	4500	4391
Z4	5076	4825	4958	4660	3575	3323	3457	3158	7359	7107	7241	6942	6027	5776	5909	5611	4363	4112	4245	3946
Z5	4685	4489	4646	4414	3398	3202	3359	3127	6641	6445	6602	6370	5500	5304	5461	5229	4073	3878	4035	3803
Z6	5189	4998	5124	4897	3733	3541	3668	3441	7404	7213	7339	7112	6112	5921	6047	5820	4497	4306	4433	4205

Table 23: Energy savings achieved for the different scenarios of DHW production.

Legend:

A: electric DWH night storage

B: Instant electric DWH

C: Gas storage water heater

D: Instant gas water heater with pilot light

E: Instant gas water heater without pilot light

1: Evacuated tube SW with electric auxiliary heater

2: Flat plat SWH with electric auxiliary heater.

3: Evacuated tube SW with gas auxiliary heater

4: Flat plat SWH with electric auxiliary heater.

Low hot water demand

Standard hot wtaer demand

Hight hot water demand

3.2. *Passive solutions savings*

The total energy demand for the building is represented per m^2 heated per year. Dynamic thermal simulations have evaluated three solutions:

- Building with insulation respecting the RTCM requirements.
- The glass building respecting the RTCM requirements.
- Building respecting all RTCM requirements.

The three solutions are compared with the conventional case. Fig. 74 shows the ratios obtained for each thermal zone.

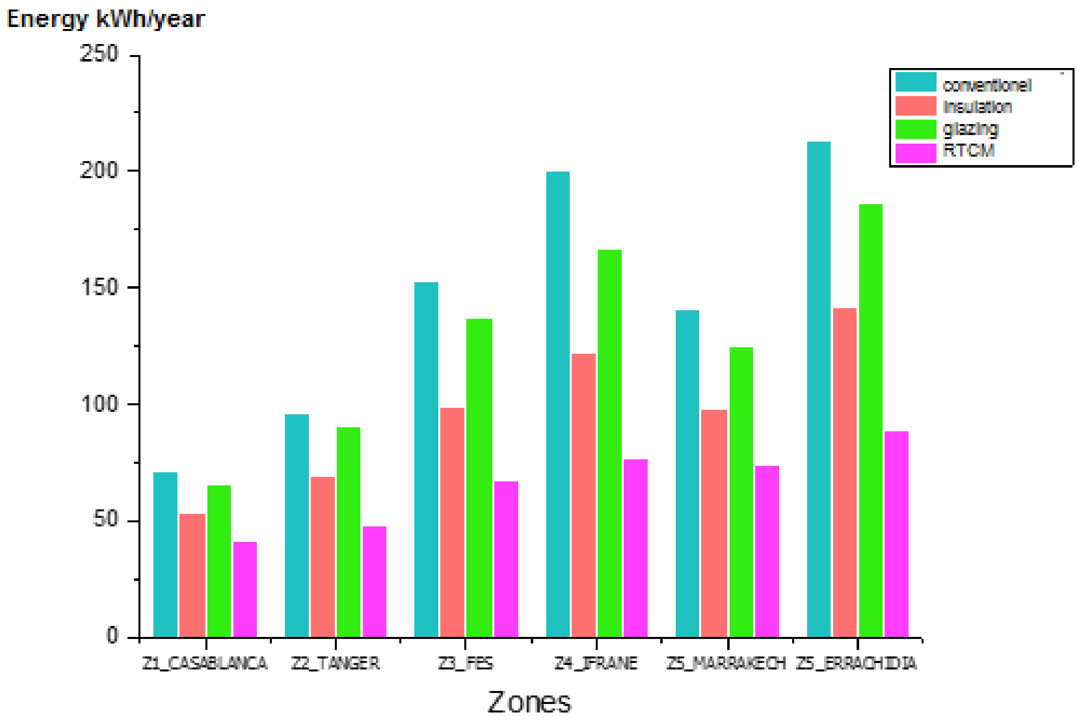


Figure 74: Air conditioning and heating consumption ratio.

The RTCM allows a significant reduction of energy heating demand compared to the conventional case. It is found that the glazing solution (double glazing for most areas) does not give a significant saving compared to the insulation solution. It is remarkably shown on table 24.

Zones	Insulation	Glazing	RTCM
Zone 1	680	200	1160
Zone 2	1080	200	1920
Zone 3	2160	640	3400
Zone 4	3120	1320	4920
Zone 5	1720	640	2680
Zone 6	2840	1080	4960

Table 24: Savings of passive solutions kWh/year.

This work aims to compare the savings generated by active and passive energy efficiency actions. Table 23 groups the energy-saving quantities using the solar water heater system compared to the conventional hot water system.

Table 23 and 24 analysis shows that the solar water heater solution saves up to 7649kWh / year, and in the worst case, it is possible to reach 1227 kWh / year, which is higher than 44% of the savings generated by passive solutions. Financial analysis is presented to complete this energy analysis, considering the savings and investments for different actions.

3.3. Financial analysis

The fundamental economic problem is to compare an initially known investment with estimated future operating costs. Most solar energy processes require an auxiliary (i.e., conventional) energy source. Solar equipment is being purchased today to reduce the fuel bill of the future.

The economic problem in solar process design is to find the lowest cost system. In principle, the problem is multi-variable, with all system components and system configuration having some effect on thermal performance and, therefore, on cost. Several economic criteria have been proposed and used to evaluate and optimize solar energy systems, and there is no universal agreement on which used.

The most commonly used methods. Lower-cost solar energy is a reasonable merit figure for systems where solar energy is the only energy source.

The lowest cost system can be defined as showing the minimum cost of ownership and operation over the system's life, taking into account solar energy only. However, the optimal design of a complementary solar energy system based on the minimum total cost of energy delivery will generally be different from that based on solar energy at a lower cost. The use of solar energy at a lower cost as a criterion is not recommended for systems using solar energy combined with other energy sources.

Life-cycle cost is the sum of all costs associated with an energy delivery system over its lifetime or during a selected analysis period in today's dirham. It considers the time value of the money. The basic idea of life cycle costs is that projected future costs are reduced to the current (discounted) cost by calculating how much should be invested at a market discount rate in order for funds to be available when they are needed. Life-cycle cost analysis includes inflation when estimating future expenditures. This method can only include significant cost elements or as many details that may be significant.

The life-cycle economy (net present value) is defined as the difference between a single conventional system's life-cycle costs and the life-cycle cost of a more cohesive solar energy system.

The annualized life-cycle cost is the average annual cash outflow (cash flow). The actual debit varies depending on the year. However, the sum throughout an economic analysis can be converted into a series of payments equal to today's dirham equivalent to the variable series.

Return on investment time (ROI) is defined in several ways:

A. The time required for annual cash flows to become positive.
B. The time required for the cumulative savings of fossil or electric energy to correspond to the total initial investment, i.e., how long it takes to recover the investment through fossil or electric energy savings. The typical way to calculate this recovery time is without discounting fossil or electric energy savings. It can also be calculated using updated fossil or electric energy savings.
C. The time required for cumulative savings to reach zero.

D. The time required for cumulative solar energy savings to correspond to the principal of the remaining debt on the installed system.
The most common definition of return on investment time is B. Each of these returns on investment times can have significance given the economic objectives of various users. The calculation of recovery periods can be done, including only major elements or including many details.

The return on investment time is calculated for all the scenarios presented in this study based on definition B, without considering the discount rates of electricity prices and butane gas. The degradation of the solar collector was not taken into account in the calculations. The price of butane gas during this analysis is considered with and without state subsidy to get an idea of the future situation of energy bills for hot water production

The price is considered with and without state subsidy to get an idea of the future energy bills for hot water production. Table 25 shows the kWh prices derived from butane gas calculated based on the prices announced by the government. [41].

Gas butane Price	MAD/ kg	PCI butane (kWh/kg)	Kwh Butane price MAD
with subsidies	3.33	12.66	0.26
without subsidies	10.41		0.86

Table 25: kWh butane price.

Since the electricity price for residential buildings on the consumption band system, Table 26 shows the prices per kWh per band.

Consomption level (kWh)	unit Price HT MAD	Tva ratio	TVA amount	Unit price HT MAD
0-100	0.7904	14	0.110656	0.901056
101-150	0.9414	14	0.131796	1.073196
151-210	0.9415	14	0.131797	1.073197
211-310	1.0242	14	0.143388	1.167588
311-510	1.212	14	0.16968	1.38168
>= 511	1.3998	14	0.195972	1.595772

Table 26: electricity kWh price.

It is not enough to determine the electricity bill based on the difference between the conventional case energy demand and after applying energy efficiency actions to evaluate the savings achieved. The increments billing system influences the results.
The electricity bill savings require evaluating the conventional case bill and the new one after applying the energy efficiency actions.
Table 27 summarizes the annual energy bill for conventional domestic hot water systems, presented previously in this paper.
Table 28 shows the annual energy bill for the auxiliary system consumptions of the solar water heaters, based on the simulations' results.

SWH	Zones	Amount MAD / year							
		A	B	C1	C2	D1	D2	E1	E2
LOW HOT WATER DEMAND	Z1	2553	1818	949	2966	791	2472	593	1854
	Z2	2547	1814	947	2960	789	2467	592	1850
	Z3	2939	2082	1072	3350	893	2792	670	2094
	Z4	2873	2037	1051	3284	875	2737	657	2053
	Z5	2408	1714	900	2815	750	2345	563	1759
	Z6	2773	1969	1019	3186	849	2655	637	1992
STANDARD HOT WATER DEMAND	Z1	4087	2867	1423	4449	1186	3708	890	2781
	Z2	4077	2860	1420	4440	1184	3700	888	2775
	Z3	4773	3297	1607	5025	1339	4187	1005	3140
	Z4	4655	3223	1576	4926	1313	4105	985	3079
	Z5	3840	2699	1351	4222	1125	3518	844	2639
	Z6	4479	3114	1529	4780	1274	3983	956	2987
HIGHT HOT WATER DEMAND	Z1	5862	3998	1898	5932	1581	4943	1186	3708
	Z2	5848	3989	1894	5920	1578	4933	1184	3700
	Z3	6798	4668	2143	6700	1786	5583	1339	4187
	Z4	6636	4551	2101	6568	1751	5474	1313	4105
	Z5	5499	3760	1801	5629	1501	4691	1125	3518
	Z6	6391	4379	2039	6373	1699	5311	1274	3983

Table 27: Annual invoice for production of DHW by conventional systems.

Legend
A: Night accumulation electric water heater
B: Instantaneous electric water heater
C1: Gas Water Heater with Subsidy
D1: Instantaneous gas water heater with pilot light with subsidy
E1: Instantaneous gas water heater without pilot light with subsidy
C2: Gas water heater without subsidy
D2: Instantaneous gas water heater with pilot light without subsidy
E2: Instantaneous gas water heater without pilot light without subsidy

Table 29 summarizes the maximum and minimum savings achieved after replacing the conventional system (gas water heater) by the solar one. The next step in this comparative study is calculating the annual savings achieved by passive energy efficiency solutions. It is assumed that the heating and cooling systems are electric, so it is necessary to initially calculate the energy bills of the various scenarios presented previously, which was devoted to the building's simulations. It is to deduce the maximum and minimum values of the savings generated, comparing it with the solar water heaters saving results. The saving was calculated taking into account two scenarios based on Moroccan government gas subsidies.

Table 27 Legend
ETC_A: Instantaneous electrical auxiliary heater for ETC.
FPC_A: Instantaneous electrical auxiliary heater for FPC.
ETC_E1: Instantaneous Gas auxiliary heater without Pilot Light for ETC – Gas Price with Subsidy.
FPC_E1: Instantaneous Gas auxiliary heater without Pilot Light for FPC– Gas Price with Subsidy.
ETC_E2: Instantaneous Gas auxiliary heater without Pilot Light for ETC – No Subsidy Gas Price.
FPC_E2: Instantaneous Gas auxiliary heater without Pilot Light for FPC – No Subsidy Gas Price.

SWH	Zones	Amount MAD / year					
		ETC_A	FPC_A	ETC_E1	FPC _E1	ETC_E2	FPC _E2
LOW HOT WATER DEMAND	Z1	224	336	78	116	243	364
	Z2	228	341	79	118	247	370
	Z3	244	299	85	104	264	324
	Z4	320	664	111	230	347	720
	Z5	145	250	50	87	157	271
	Z6	175	276	61	96	190	300
STANDARD HOT WATER DEMAND	Z1	349	495	121	172	379	536
	Z2	266	509	92	177	289	552
	Z3	482	531	167	184	522	575
	Z4	488	664	169	230	529	720
	Z5	230	332	80	115	249	360
	Z6	276	408	96	142	299	442
HIGHT HOT WATER DEMAND	Z1	417	600	145	208	452	649
	Z2	337	399	117	138	365	433
	Z3	449	532	156	185	487	577
	Z4	566	803	197	275	615	860
	Z5	185	361	64	125	200	391
	Z6	312	484	108	168	338	525

Table 28: Energy bill of auxiliary systems.

SWH	Zones	Amount MAD / year			
		Max with subsidies	Min with subsidies	Max without subsidies	Min without subsidies
LOW HOT WATER DEMAND	Z1	2888	229	2475	257
	Z2	2881	222	2468	251
	Z3	3265	346	2854	371
	Z4	3173	155	2762	211
	Z5	2765	292	2358	313
	Z6	3125	337	2712	361
STANDARD HOT WATER DEMAND	Z1	4328	354	3966	395
	Z2	4348	336	3985	379
	Z3	4858	430	4606	474
	Z4	4757	265	4486	321
	Z5	4142	484	3760	512
	Z6	4684	514	4383	548
HIGHT HOT WATER DEMAND	Z1	5787	537	5717	586
	Z2	5803	751	5731	785
	Z3	6642	762	6642	807
	Z4	6439	453	6439	510
	Z5	5565	734	5435	764
	Z6	6283	749	6283	790

Table 29: Amount saved by installing a solar water heater for an individual building.

Tables 30 and 31 show the heating and cooling energy bill—the same energy reductions generated by energy efficiency actions reflected the energy bills. Glazing does not realize significant gains. However, insulation or both solutions combined are more significant. The glazing solution does not exceed 18% savings compared to the insulation. On the other hand, the insulation reaches 44%, the combination of the two solutions, which represent the RTCM, reaches a reduction of 66% compared to the conventional case.

Zones	Energetic bills MAD			
	Conventional	insulation	glazing	RTCM
Z1	808	575	737	445
Z2	1131	756	1030	552
Z3	1870	1118	1640	735
Z4	2388	1342	1952	821
Z5	1640	1079	1440	799
Z6	2824	1753	2439	1088

Table 30: Annual energy bill for heating and cooling for an individual building.

Zones	Percentage of savings		
	Insulation	Glazing	RTCM
Z1	29%	9%	45%
Z2	33%	9%	51%
Z3	40%	12%	61%
Z4	44%	18%	66%
Z5	34%	12%	51%
Z6	38%	14%	61%

Table 31: Savings rate achieved.

The generated savings comparison of the solar water heaters production and the passive energy efficiency actions result in the maximum solar water heaters savings being more significant than passive actions. The most unfortunate cases of solar water heaters savings are close to those reached by passive actions, sometimes even lower.

3.4. Economies comparative ratios ; active VS passive

In this part, the rate represented by the economy reached by each solution proposed during this work is presented. Given a large number of possibilities of conventional domestic hot water systems and the replacing action by solar water heaters. The following cases are treated:
Passive configurations:
Configuration 1: electric heating and cooling, electric SWH.
Configuration 2: electric heating and cooling, gas SWH.
Active configurations:
A: Instantaneous electric water heater.
B: Instantaneous gas water heater without pilot light.
1: SWH-ETC with electric auxiliary heater.
2: SWH-ETC with gas auxiliary heater.
3: SWH-FPC with electric auxiliary heater.
4: SWH-FPC with gas auxiliary heater.

All results are for a standard domestic hot water application (volume of 200L).
According to Table 32 and table 33 results, the solar water heater for configuration 1, where the domestic hot water production system is electric, achieves savings rates on the building energy bill, higher than that achieved by applying passive actions in all Moroccan thermal zones.
Under the second configuration conditions, the active solution is more interesting for all thermal zones than the insulation and the double-glazing actions. However, the RTCM saves more than the solar water heaters in the second configurations in the hottest areas.

The solar water heater solution with FPC in the case of configuration 1, where the domestic hot water production system is electric, allows saving rates on the building energy bill, almost identical to the second configuration in case of subsidies. In contrast, the SWH-ETC, compared to the conventional solution, generates considerable savings without subsidies.
In both configurations, it can be seen that solar water heater solutions deliver significant savings on buildings' energy bills compared to passive energy efficiency solutions.

	Savings ratio Configuration 1								**Savings ratio Configuration 2**							
	subsidies															
	yes	**No**	**yes**	**No**	**yes**	**No**	**yes**	**No**	**yes**	**No**	**yes**	**No**	**yes**	**No**	**yes**	**No**
	A→1		**A→2**		**A→3**		**A→4**		**B→1**		**B→2**		**B→3**		**B→4**	
Z1	69%	69%	75%	68%	65%	65%	65%	65%	32%	68%	45%	67%	23%	64%	42%	63%
Z2	65%	65%	69%	64%	59%	59%	59%	59%	31%	64%	39%	64%	19%	58%	35%	57%
Z3	54%	54%	61%	54%	54%	54%	54%	54%	18%	53%	29%	52%	16%	52%	29%	51%
Z4	49%	49%	54%	48%	46%	46%	46%	46%	15%	47%	24%	47%	10%	44%	22%	43%
Z5	57%	57%	60%	56%	55%	55%	55%	55%	25%	56%	31%	56%	21%	54%	29%	53%
Z6	48%	48%	51%	47%	46%	46%	46%	46%	18%	47%	23%	46%	14%	44%	22%	44%

Table 32: Savings using the active system SWH.

Zones	**Savings ratio**					
	insulation		**Glazing**		**MTRC**	
	config 1	**config 2**	**config 1**	**config 2**	**config 1**	**config 2**
Z1	6,34%	13,72%	1,93%	4,18%	9,88%	21,38%
Z2	9,40%	18,57%	2,53%	5,00%	14,51%	28,68%
Z3	14,55%	26,16%	4,45%	8,00%	21,97%	39,48%
Z4	18,64%	31,01%	7,77%	12,93%	27,93%	46,46%
Z5	12,93%	22,58%	4,61%	8,05%	19,38%	33,86%
Z6	18,04%	28,33%	6,48%	10,19%	29,24%	45,93%

Table 33: Savings using the passive system SWH.

3.5. Payback time

Another critical factor in helping to make investment decisions in energy efficiency actions is the time to return on investment. The actions investments and the time of return on investment are evaluated.

3.5.1. Active system

<u>Individual SWH</u>

The study treats two cases; individual and collective. The amounts given in results, including the prices of the various installation components and accessories, the maintenance costs, and the replacement estimates of the defective parts, are not considered.
It can be seen in Table 34 that the payback time for a solar water heater project in the current case of subsidized butane gas prices is not attractive, the payback time in this case is more than 18 years which makes the project excessively uninteresting. On the other hand, for electric systems and unsubsidized butane gas, the payback times are almost identical depending on the demand; more the demand higher more the ROI is lower, and the project becomes interesting.

<u>Collective SWH</u>

RIO's collective installations are calculated according to ETC and FPC systems and under the conditions of a standard demand (200 L) for domestic hot water. In a collective building, the demand for water hot sanitary is not identical. These investments for this case was calculated without including maintenance charge prices and replacement estimates for defective parts. The assess system consists of

- 12 solar collectors,
- 2 solar tanks of 1600 liters,
- 16 Tanks of 200 L
- 400 m of piping,
- 16 Electronic Controllers,
- 16 Circulation pumps,
- 2 copper tube collectors.

Following the same methodology of the individual part, the time of return on investment was calculated under two scenarios:

- Replace a conventional electric system with the solar water heater.
- Replace a conventional gas system with the solar water heater.

A is the electric solar water heater, E1: Gas is an instantaneous water heater without a pilot light and with subsidies. E2 is a gas instantaneous water heater without a pilot without subsidies.

Table 35 shows that the payback time for subsidized butane gas prices is relatively high, making collective solar projects unattractive in the current economic context. On the other hand, in the case of an electric system or unsubsidized butane gas, the return on investment does not exceed the 8 years in most Moroccan zones. Moreover, in the zone of Fez, the time of return on investment on a collective solar project using FPC technology does not exceed the 7.5 years.

SWH	**Zones**	**ROI (year)**					
		ETC			FPC		
		A	E1	E2	A	E1	E2
Low demand	Z1	8,6	37,3	8,4	6,9	39,9	6,8
	Z2	8,7	37,8	8,5	7,0	40,8	6,8
	Z3	7,5	32,3	7,4	5,7	27,6	5,7
	Z4	8,0	40,8	7,9	7,5	36,4	7,4
	Z5	8,8	32,9	8,5	7,0	32,7	6,8
	Z6	7,7	29,8	7,6	6,1	28,4	6,0
Standard demand	Z1	6,3	29,1	6,5	5,4	32,3	5,6
	Z2	6,1	25,3	6,3	5,4	33,6	5,6
	Z3	5,6	30,1	5,9	4,6	26,9	4,9
	Z4	5,8	31,7	6,1	5,0	39,7	5,3
	Z5	6,4	25,7	6,5	5,4	24,9	5,5
	Z6	5,5	23,2	5,8	4,7	23,3	4,9
High demand	Z1	4,8	22,4	5,2	4,2	24,3	4,6
	Z2	4,7	20,4	5,1	4,0	18,2	4,3
	Z3	4,1	19,4	4,6	3,4	17,7	3,9
	Z4	4,3	23,1	4,9	3,8	27,9	4,3
	Z5	4,8	18,4	5,2	4,2	18,7	4,5
	Z6	4,2	17,9	4,7	3,7	18,0	4,1

Table 34: Return on investment time of individual solar water heaters.

Zones	ROI (year)					
	ETC			FPC		
	A	E1	E2	A	E1	E2
Z1	8,7	40,4	9,0	8,6	51,6	8,9
Z2	8,4	35,2	8,7	8,7	53,8	9,0
Z3	7,8	41,8	8,2	7,4	43,0	7,8
Z4	8,0	44,0	8,4	8,0	63,5	8,4
Z5	8,9	35,6	9,1	8,6	39,8	8,8
Z6	7,7	32,2	8,1	7,5	37,2	7,9

Table 35: Return on investment time of collective solar water heaters.

3.3.1. Passive solutions

Zones	Investment MAD			Payback time (year)		
	Insulation	Glazing	RTCM	Insulation	Glazing	RTCM
Z1	13209	81000	94209	1,2	25,3	5,1
Z2	17850	81000	98850	1	25,3	3,2
Z3	23205	81000	104205	0,7	7,9	1,9
Z4	53360	81000	134360	1,1	3,8	1,7
Z5	48005	81000	129005	1,7	7,9	3
Z6	48005	81000	129005	1,1	4,7	1,6

Table 36: payback time of passive actions.

this, the economic study data prices represent the average of the current prices on the market. Table 36 summarizes the insulation prices and the calculated return on investment time. It is noted that the time of return on investment is relatively short for insulation projects, not more than a year except for zone 5, where it reaches two years. Furthermore, the double-glazing solution for zones 2 and 3 is not attractive, the investment payback time exceeds 25 years. On the other hand, in zones 4 and 6 the double-glazing solution is fascinating; the ROI varies between 4 and 5 years, which is considered reasonable. This solution's payback time in zones 3 and 5 is 8 years, which makes this solution moderately interesting. The application of Moroccan thermal building regulations (RTCM) consists of combining the two previous solutions (Insulation and Double Glazing), The high payback time of the double-glazing projects shown in Table 20 is reduced by the combination of insulation and double glazing (RTCM). It is found that the ROI for zones 1 and 2, which was 25 years for glazing and one year for insulation, is reduced to 5 years for zone 1 and 3 years for zone 2 after applying RTCM, Table 18. Investment in the RTCM scenario is considered attractive, given the reduced ROI observed for all Moroccan thermal zones. The results obtained show that, despite the energy savings achieved with collective solar hot water production systems, low butane gas costs in Morocco and initial installation costs are detrimental to the project's profitability.

Passive energy efficiency solutions deliver significant savings in zones with a cold winter and a hot summer season.

In summary, it is difficult to make a clear and definitive judgment on comparing the savings made by solar solutions to produce domestic hot water and the actions on the enveloped building, but still the active solution are more attractive than the passive one.

Conclusion

In this chapter Four building simulation scenarios under TRNsys have been adopted (Conventional, Insulated, double glazing, and applying the RTCM requirements). The glazing solution does not exceed the 6% savings on the total energy demand (including the electrical

demand for domestic hot water), while the insulation reaches 17% savings in zone 4. RTCM is the best solution. This solution allows for saving 27% of energy consumption.
The study's active solutions were under various domestic hot water production scenarios using solar systems, introducing different types of solar collectors, and the variables of the backup systems.

The energy demand comparison of the different conventional domestic hot water production systems and the new actions showed that solar solutions are remarkably efficient. In the same context, ETC and FPC's comparison shows that vacuum tube collectors perform better in all Moroccan thermal zones during the winter. While during the summer season, both technologies have solar fraction thresholds close to 90%.

The study of the collective solar water heating system on TRNsys reinforces the findings made in individual scenarios: the vacuum tube collector is significantly efficient.
The savings made due to the various solutions was on two-part: energy and financial. A comparison of energy savings shows that solar water heater solutions are superior to those achieved by building envelope actions. The financial analysis of the savings on the calculated bills shows that solar water heater solutions are attractive in non-subsidized butane gas prices.

This comparative study opens the possibilities of integrating collective solar water heaters in the building, considering the possible savings. From another point of view of this study's results, we push to seek the financing solutions of the collective solar projects possible, by green funds proposed by some non-governmental organizations or state organizations.

Part *II*: The solution: solar water heater SOL'R SHEMSY/ development SHEMSY Network (experimental platform, controllers and management system)

Chapter IV: *Solar water heaters Technologies, standards and manufacturing materials*

Introduction

This chapter present the most used and available technologies of domestic solar water heaters, shedding light on their operation and possible applications, to subsequently detail all of their main components. All SWH technologies are several rules subject to managing this throughout the world, presenting in the form of standards in the second part of this paper. The European standardization of the solar water heater systems is shown by presenting different European standards, there applicability, and the various requirements and tests for each standard, followed by a presentation of the different certification bodies and the certificate s types which respect the European standards. Therefore, it is necessary to design the solar water heating system as per manufacturing materials, an overview of various materials used on the SWHs worldwide in the international market and characterizing them is presented to give a complete SWH guide from technologies to best materials going through the essential technical rules to respect, giving an efficient and safe product.

1. History vs. current solar thermal technology

The technology of solar thermal panels being relatively simple, its history is quite succinct. The history of low-temperature thermal collectors Vishwakarma et al [80] dates back to the 1780s when H. B. de Saussure demonstrated the greenhouse effect of glazing over an absorber in an insulated box. However, it was not until 1910 that the first solar water heaters appeared in California. Like many renewable energy sectors, solar thermal energy experienced a significant growth phase between 1973 and 1985 in response to the oil shock. Nevertheless, this rapid development, with deficient technologies or installers, has resulted in many underperformances [81].
The first traces of parabolic mirrors date back to antiquity when the Greeks lit the Olympic flame with the sun's rays alone and with such a mirror. In 1615, Salomon de Gaus [82] built a solar pump, using heated air with solar radiation. In 1747, M. de Buffon experimented with a mirror whose numerous mirrors concentrated sunlight towards the same point: he thus managed to melt a silver (whose melting temperature was 1044°C)[83]. At the end of the 18th century, Lavoisier built a solar oven that reached 1800°C [84]. To do this, he concentrated the sun's rays using a liquid lens. In 1816, Robert Stirling invented the "hot air engine" (now called the "Stirling engine"), a 4-stroke engine [85]. During the 19th century, Augustin Mouchot developed many inventions: solar pasteurization, solar distillation, solar cooking, solar pumping, parabolic concentrator feeding thermal machines [86]. He won the gold medal at the 1878 World's Fair with a 5-meter diameter reflector combined with a steam engine that operated a printing press [87]. In 1910, the American Franck Shuman built an industrial-scale thermosolar power plant in Egypt [88]. In 1949, Félix Trombe built-in Mont Louis, a large parabolic mirror that allows us to reach 3000°C at its concentration point [89]. At the end of the 20th century, various power plants and concentrated solar furnaces were launched:

after various prototypes, EDF inaugurated in 1983 Thémis, the first French tower electro solar power plant. Since France had chosen to develop only the nuclear industry, this power plant closed in 1986 and opened again in 2007.

Similarly, from 1984 to 1991, many cylindro-parabolic mirror plants were created in the United States. Since the end of the 1990s, some countries have relaunched programs to support the development of solar thermal energy: Austria, Germany, China…etc. Other countries have joined them in recent years (United States, Spain, Israel, Australia, Morocco, Egypt, etc.), particularly the realization of solar power plants allowing more extended storage of heat and powers increasingly large. For example, by 2013, the PS10 power plant in Spain, should supply the entire city of Seville with electricity [90].

Nowadays On a global scale, the new 9/10 solar thermal installations. The total installed capacity was 37.2 GWth (53.1 million m^2 of solar collectors), a 14% decrease over 2014, This is according to a recent study by the international association REN21[91], which states that, on the segment of individual housing, the decrease is explained, in particular, by the low price of oil and the low cost of photovoltaic systems. Vacuum tube collectors accounted for 76% of the new installations, compared to 20% for flat panel collectors and 4% for glass-free water collectors (mainly used for pool water heating). These new facilities increased the global fleet to 435 GWth by the end of 2016, compared to 409 GWth a year earlier. There was enough installed capacity at the end of 2017 to provide 357 TWh of heat annually, the study notes, which adds that solar thermal accounted for 8% of the renewable heat produced last year around the world. Over the past few years, global sales of solar thermal systems, which in 2014 accounted for 50% of new installations. A remarkable growth in the integration of this technology is progressing [81].

2. Domestic solar water heaters technologies and types

The classification of water heating systems is based on the heat transfer method, giving rise to two solar water heating system types: passive and active systems, Direct (open loop) and Indirect (closed-loop) water heating. The technologies are investigated in several works in the literature, such as Taylor et al.[92]. And kylili et al. [93].

Indirect systems require an intermediary fluid that conveys heat to water, which is the heat carrier fluid. This operation is done through a heat exchanger between the collector and the hot water tank. Active and passive systems are differentiated by the circulation pump's intervention for the active ones, unlike the passive ones whose circulation is done by the note of the convection and the thermodynamic properties' changes.

2.1. Active solar water heating systems

There are described as active Based on the water circulation type between solar tank and collectors; therefore, there are two types of circulation solar water heater system [92]:

- Direct circulation systems

Pumps circulate household water through the collectors and into the home. They work well in climates where it rarely freezes.

- Indirect circulation systems

Pumps circulate a non-freezing, heat-transfer fluid through the collectors and a heat exchanger. That heats the water that then flows into the home. They are popular in climates prone to freezing temperatures.

2.1.1. Forced-circulation water heaters

The liquid that circulates in the solar panels is a non-frost-free fluid (usually glycol water). It is the same principle as the cooling system of cars; it mixes glycol (alcohol) antifreeze to lower the point of solidification by the cold.

As this liquid, called heat transfer fluid (which carries heat), is unsuitable for consumption and should not be mixed with domestic hot water, heat is recovered in the flask through an exchange. An exchanger is a coil, inside the tank which isolates the heat transfer fluid from the sanitary water [94]. There are thus two circuits:

- a circuit that warms the fluid in the panels.
- a circuit that transports sanitary water to the taps.

The exchange of calories becomes the solar tank, the central reservoir.

A pump ensures the transfer of fluid between the panels and the exchanger.

In this system, the position of the tank to the panels does not matter.

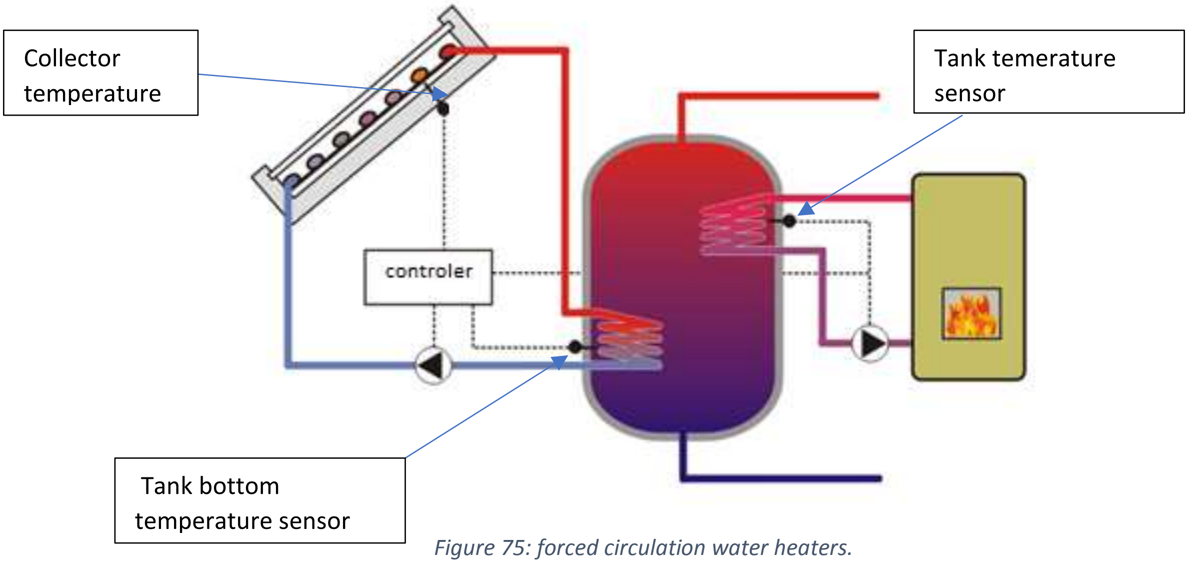


Figure 75: forced circulation water heaters.

2.1.2. Separate water heaters

These solar thermal systems have a regulation which activates the circulator as soon as the solar energy is sufficient. The performances of these systems are thus much better than those of thermosiphons. When those thermal collectors are integrated into the building architecture, the tank is located separately, even below the collectors. Extra energy can be integrated into the solar tank. This system's plumbing and ordinary heating system correspond to that of a conventional production system, and maintenance is similar[95].

2.1.3. The monobloc water heaters

These are the most straightforward water heaters: the tank and the solar panel form a single compact unit. In general, the tank is attached to the top of the solar panel. In a monobloc system, it is directly the domestic hot water that circulates in the panels. Heated by the solar radiation, the water becomes less dense and rises in the tank.

There is, therefore, no need for a pump. The disadvantage is that the tank's proximity with the panel makes a little aesthetic on the roof. Moreover, it is a water heater reserved for a warm country, such as overseas countries or Greece[96].

2.2. Passive solar water heating systems

Passive solar water heating systems are typically less expensive than active systems, but they are usually not as efficient. However, passive systems can be more reliable and may last longer. There are two basic types of passive systems [96]:

2.2.1. Integral collector-storage passive systems

It works best in areas where temperatures rarely fall below freezing. They also work well in households with significant daytime and evening hot-water needs.

2.2.2. Thermosyphon systems

Water flows through the system when warm water rises as cooler water sinks. The collector must be installed below the storage tank so that warm water will rise into the tank. These systems are reliable, but contractors must pay careful attention to the roof design because of the heavy storage tank. They are usually more expensive than integral collector-storage passive systems. To avoid the one-piece system's weak, the panels can be separated from the hot water tank [95].
As long as the panels remain lower than the storage tank, the water will circulate naturally by the "thermosiphon" effect.

The "thermosiphon" principle operates on the heated water's characteristic, which becomes lighter than the cold water, ascends to the tank, replaces the cold water, which, heavier, descends downwards and passes through the solar panel.

The loop is thus looped. Again, the disadvantage arises from the fact that the liquid is the direct sanitary water, and therefore sensitive to frost. This type of solar water heater cannot be used in all countries. It is reserved for hot countries that do not know the freeze [97].

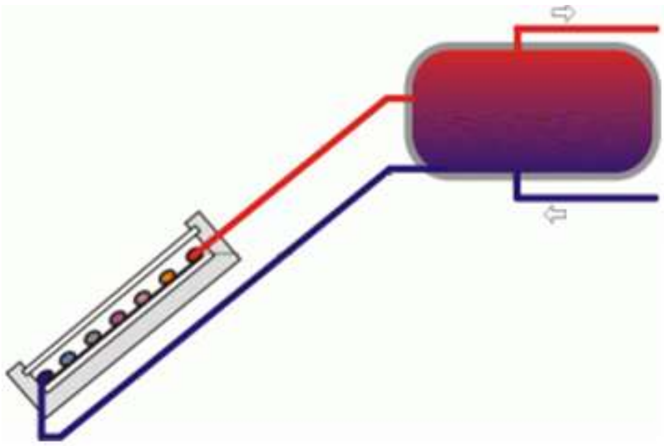


Figure 76: thermosyphon solar water heater.

3. The main components of a solar water heater.

3.1. The solar thermal panel

There are different technologies of solar thermal collectors. Today the two main technologies are plane collectors and vacuum tube technology.

3.1.1. Flat-plate collector

This technology represents the first solar thermal collector technology. The flat collectors are composed of a plate and copper metal tubes that constitute the absorber. The absorber receives solar radiation and heats up. Sealed in a rigid chest, its upper part allows the heat to penetrate and holds it. Inside the metal tubes, a coolant (water or coolant) heats up and moves to a storage tank. From there, the water is redistributed in the sanitary and / or heating water circuits [98].
Advantages disadvantages:

- Easy to implement
- Heating temperature: 50 to 80 °
- Good performance in summer or warm areas.

3.1.2. vacuum tube solar collector

A vacuum tube solar collector consists of two glass tubes into which passes a heat collecting tube. Like a thermos bottle, and a vacuum is created between the two tubes. The inner tube is covered with a substance that absorbs the sun's rays. The heat effect obtained makes it possible to avoid heat losses due to the outside temperature. Indeed, the vacuum being a perfect insulator, there is no heat loss between the inside and the outside of the tube. This makes it possible to obtain very high heating temperatures even in winter in cold and temperate regions. The heat transfer fluid is then conveyed to the storage tank from which the sanitary water is redistributed [99].

Advantages disadvantages:
- Heating temperature above 120 ° C.
- Better performance in temperate and cold zones, the vacuum allowing to obtain very high yields.
- Less sensitive to imperfect exposure: reflectors capture light under non-optimal impacts.
- Slightly more expensive to purchase than FPC collector.
- Technology is also used for solar cooling (air conditioning).

3.2. storage tank

The simplest collector is a water-filled metal tank in a sunny place. The sun heats the tank; this was how the first systems worked. This setup would be inefficient due to the equilibrium effect. As soon as heating of the tank and water begins, the heat gained is lost to the environment, and this continues until the water in the tank reaches ambient temperature. The challenge is to limit heat loss [100].

• The storage tank can be situated lower than the collectors, allowing increased freedom in system design and allowing pre-existing storage tanks to be used.
• The storage tank can be hidden from view.
• The storage tank can be placed in conditioned or semi-conditioned space, reducing heat loss.
• Drain back tanks can be used.

3.3. *The heat transfer fluid*

The primary circuit relating to the installation under pressure is wholly filled with a coolant resistant to frost. Propylene glycol is generally used. There are also complete mixtures that contain a corrosion-inhibiting agent, an anti-foaming agent, an anti-algae agent, and a colorant [101].

Theoretically, one could also work with pure non-glycol water in the case of a drainage system. At present, even in this case, more and more antifreeze is used for safety reasons.
Essential characteristics of a solar fluid Stable to maximum stagnation temperature; Protected against frost.
Non-corrosive.
High thermal capacity.
Reduced viscosity.
Price and availability.

In practice, a mixture of water and glycol is generally used, for example [102]:
Ethylene glycol ($C_2H_6O_2$)
Thermal capacity: 2,410 J.kg-1.K-1
Melting point: - 13 ° C
Boiling temperature: 198 ° C

Polypropylene glycol ($C_3H_8O_2$)
Thermal capacity: 2,500 J.kg-1.K-1
Melting point: -59 ° C
Boiling temperature: 188 ° C

3.4. The circuits and pipes

<u>circuits</u>

There are two circuits inside a solar thermal installation:

• The "primary" circuit: sealed and insulated, contains the heat transfer fluid circulating in the collectors, and heats up in the absorber. It then transmits its heat to the secondary circuit via a heat exchanger.

• The "secondary" circuit consists of a reserve of hot water supplying either the domestic hot water circuit or the heating network [103].

<u>The pipes</u>

Thermal conductor, much more efficient than metals, is used to transport heat through the phase change of fluids. It works by fluid circulation in equilibrium with its vapor between a heated region, the evaporator, and a cooled region, the condenser, all in the absence of air. Ones the pressure difference between the evaporator and the condenser is attempt vapor moves, the condensate then returns to the evaporator under the forces' effect. The circulation of this liquid is induced either by gravitation or by capillary effect. According to these effects, two types of heat pipes are distinguished: diphasic heat pipes and capillary HP [104].
The materials used for the solar circuit pipes must withstand the possible mechanical stresses in the circuit (pressure and operating temperature range (-20 to 150 ° C)) and must be compatible with the fluid and other materials of the installation. Copper, simple steel, or stainless-steel tubes are used mainly. Plastic pipes are more than advised since they are generally not wholly sealed (especially at high temperatures) with oxygen, penetrating by diffusion into the circuit. The risk of corrosion is then increased. Galvanized steel is strictly forbidden because it reacts with the glycol present in the primary circuit [105].
Because of the high temperatures to which these pipes are subjected, their insulation can, in no case, be carried out through any insulation used for the usual sanitary applications. Resistant only to temperatures of the order of 110 - 120 ° C, polyurethane is to be avoided. A synthetic foam rubber capable of withstanding the order of 150 ° C. will generally be used.
The insulation used for the solar loop must also:

- Resist (or be protected from) the U.V.
- Resist moisture.
- Resist attacks by rodents and birds.
- Be waterproof (wind and rain).

have sufficient thickness! (At least equal to the diameter of the pipe).

3.5. The heat exchanger

The heat exchanger is very important, though invisible, part of the solar water heater system. It acts as an interface between two fluids of different temperatures, such as between hot air and cold air, between coolant liquid and cold water. Let us try to grasp the crucial role of this element and explain its functioning [106].

Typically, for large solar systems (beyond 30 m^2 of collectors), external heat exchangers are often used considering the considerable powers that come into play.

The heat exchangers arrangement and their connection shall always promote the correct stratification of the temperatures inside the tanks and the charging circuit: the highest temperatures must be closest to the make-up.

Ensure optimal efficiency of the collectors:

Since the collectors' thermal losses depend on the temperature difference between the fluid inside the collectors and the outside temperature, it will be advantageous to work with a heat-transfer fluid at the lowest possible temperature.

Allow the exchanger to heat a sufficiently large volume of water.

As a result, the solar heat exchanger integrated into small systems' storage will be placed in the lower part of the tank. Then, return to the collectors will be located as low as possible in the tank.

- In a thermosyphon or forced circulation solar water heater, the "hot" fluid is a heat-transfer liquid (antifreeze-water mixture that has just circulated in the solar thermal panels), which will heat the cold water stored in the solar tank. The exchanger is in the form of a metal coil (located in the tank). The coolant will heat the water around the coil by conduction, and come out almost cold. The hot water is then ready to irrigate the house. This type of exchangers is widespread, although more and more water heaters use plate heat exchangers, a little more efficient and compact [92].
- In single-block solar water heaters with thermo-tubes, heat exchangers are vacuum tubes that run from the solar panels (where they act as solar thermal collectors absorbing heat) to the solar tank (where they act as an exchanger). These exchangers are quite rare.
- In solar shower systems, solar carpeting, or above ground swimming pool heating, all of which are very rudimentary, the solar collector transmits its heat directly to the water to be warmed up. The solar collector then merges with the exchanger, no fluid makes the "intermediate [107].

3.6. An expansion vessel or safety valve

An expansion vessel is an installation for absorbing changes in the volume of water of a water heater, depending on the temperature.

The expansion vessel ensures the safety of the installation to avoid excessive pressures due to the water temperature.

This component's role, which consists of an envelope separated at its center by a flexible membrane, is to act as a shock absorber for the water circuit. In the case of excessive pressures, the valve will let the excess pressure escape.

When the water heats up, the pressure increases in the tank. In this situation, the expansion tank absorbs the excess pressure while avoiding any installation deterioration and keeping it tight.

The expansion tank performs the same pressure management function in the water heater as a safety valve except that the safety valve only relieves the circuit pressure (with the release of pressure under Form of vapor) [108].

3.7. pump and accessories

When the system disposes of a circulation pump, it will no longer be necessary to install the hot water tank below the solar collectors since it will direct the heat transfer fluid. It can then be installed in the cellar, in the laundry room, or the bathroom.

However, in order for the system to be effective, it is advisable to supply the pump with a powerful energy source, which suggests it less autonomy but does not make it difficult to install it [109].
Besides, the installations can dispose of additional accessories others then pumps, such as:

- 3-way or 4-way valves
- Purge systems for evacuating the air from the circuit. There are manual or automatic steam traps.
- Manometer, flowmeter, flow regulator.
- Non-return valves to force direction of fluid flow (spring or flap valves).
- Thermostatic valves to maintain a constant operating temperature by mixing hot and cold water.
- Safety groups protecting the installation from overpressure, generally set at 6 bar and installed at the inlet of the hot water storage tank

4. European standardization

4.1. *What are European standards?*

A standard is a guideline about the structure of rules containing several exigences and methodologies to follow as a technical document. This set of rules consists of the management of the areas and the alignment of the agreements to respect particular technical spacing by the interested parties, which must go through national or international standardization bodies, and it was possible to carry out the checks and tests necessary to issue certificates before compliance with the standard.
International standardization aims to develop standards (for products and services) that can be adopted in many countries. Standardization is also implemented at the sub-international level (e.g., through European Standards) and nationally. Standardization is the process of establishing criteria and methods by joint agreement, which are then transposed into a technical document designed to be used as a rule, guideline, or parameter. International standards need to meet specific criteria. According to WTO (World Trade Organization), the criteria that define globally relevant standards are:

- Summarize national and regulatory market parameters to meet needs Effectively meet needs
- Generate and drive technology development
- benefit from and benefit from the market policy
- Do not engage or react negatively to fair competition;
- encourage technological development and innovation
- not to give interest to some countries to the detriment of others in terms of needs and interests
- Leave performance a priority, not prescriptive design

4.2. Standards types

There are two main types of standard:
Technical standards: In principle, the technical standards focus on ensuring the quality of a certain number of criteria and fixed technical specifications. This set of requirements is applied to products, services, and manufacturing processes.

Management and leadership standards: focus on the management and quality of management in companies to ensure the smooth running of processes and activities according to standard regulations.
The bodies may apply standards voluntarily to elect their images on the national and international markets. However, others are obligatory to rig harmonization of the markets according to European standards.
The harmonized European standards set out the Directives' requirements to be applied under the detailed technical information to be provided to enable manufacturers and undertakings to achieve conformity [110].

4.3. European standardization and tests of solar thermal system

Solar thermal is the leading technology exploiting the renewable heat source for domestic use.
is an advanced technology and It has reached maturity, although with improved performance and lower costs. Besides, with this increased evolution, it is essential to monitor markets and age so that Equipment and facilities meet the necessary performance and quality standards [111].

Standardization and certification systems differ around the world. Several countries still lack standards for thermal solar technologies. Worldwide solar thermal standards are mainly standards that are based on tests and tests. However, product standards specify the methodology and manufacturing process for the products (e.g., specific minimum sizes, certain materials to be used, etc.) that manage other sectors. In the case of solar thermal energy, this is not currently the case, and the standards specify how the test methods should be applied to these products in order to test their limits under certain conditions.

4.3.1. Solar thermal collectors

About solar thermal collectors, there are currently several international standards. The first to be widely used and applied is the American standard of ASHRAE (93-77). Then, a series of ISO 9806 standards was launched, and subsequently, the European standard EN 12975 was developed for solar thermal technologies. Recently, the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO) jointly developed a new standard, which is the combination of ISO 9806 and EN 12975. This new international standard, EN ISO 9806: 2013, has replaced EN 12975-2 in CEN countries and is applicable in several other regions. Several national standards are also available, most often based on EN ISO 9806[112].

The standard EN 12975

The standard EN 12975-1 describes the requirements for durability, safety, and performance of collectors, mostly material and design, by presenting the necessary documents that the collector shall be accompanied, informative documents, and the required tests [113].

- Internal pressure for absorber
- High temperature resistance
- Exposure
- External thermal shock. May be combined with the high temperature resistance or exposure test
- Internal thermal shock. May be combined with the high temperature resistance or exposure test
- Rain penetration, only for glazed collectors
- Mechanical load
- Thermal performance

- Freeze resistance, only in the cases specified in 5.8 of EN 12975-2:2006;
- Stagnation temperature. May be combined with the high temperature resistance or exposure test.
- Final inspection
- The optional test for impact shall be carried out if requested.

All tests must be carried out regarding EN12975-2 2006. Document title Thermal solar systems and components - Solar collectors - Part 2: Test methods. CEN publication date 2006-03-29, which present the tests methods, and the specific requirements to respect in every test[114].
The EN12975-2 is replaced by the ISO 9806 which completes the first standard with more specific details, and relevant methods
The standard ISO 9806 describes the different tests to be carried out: mechanical tests and Safety (resistance of the glazing to pulling forces, resistance to pressure and high temperatures, aging of the collectors) and thermal performance tests (efficiency, thermal losses, and yield curves).
It also includes test methods for characterizing the thermal performance of fluid flow collectors, namely the thermal performance of liquid, glazed and non-glazed solar collectors in the stationary and quasi-stationary state, and Thermal performance of solar panels with air, glazed and without glazing, in the stationary state (both in closed loop and open to the atmosphere).
ISO 9806: 2013 also applies to hybrid collectors producing thermal and electrical energy. However, it does not deal with electrical safety or other specific properties related to the production of electrical energy. It also applies to collectors using external power sources for their normal operation and
/ or for safety purposes.

ISO 9806: 2013 does not apply to collectors in which the thermal storage device is an integral part of the collector insofar as the energy capture and storage operations cannot be separated in order to perform Measurements of these two processes [115].
The tests presented on ISO 9806 are:
- Instrumentation for solar water heat characteristics measurements and climatic conditions.
- General measurements and tests (temperature and heat transfer fluid).
- Outdoor steady-state efficiency test.
- solar irradiance simulator for Steady-state efficiency test.
- the effective thermal capacity and the time constant of a collector (test and measurement).
- Optimal incident angle Collector test.
- collector pressure drops (test and precision).

<u>The standards Summary: efficiencies</u>
The standards are essentially based on all thermodynamic and mechanical parameters and resistance to extreme external conditions (climatic or forced). All of these parameters intervene for better energy performance. It is one of the critical parameters to be assessed by the standards (efficiencies, performances, loss factors) ; table 37 presents the ranges of efficiencies and factors characterizing high-performance adapted to European standards of several solar thermal collectors such as evacuated tube collectors, flat plat collectors and the CPC.
This table represents a summary of the reading and analysis of all the standards in force and the international market for solar thermal collectors. the complimentary tables 5,6,7 in Appendices give an overview of the standardized products on the market and which formed part of this analysis basis.

optical conversion coefficient		heat loss coefficient by conduction		heat loss coefficient by convection	
η_0 (%)		$a_1(\frac{W}{K^2.m^2})$		$a_2(\frac{W}{K^2.m^2})$	
min	***max***	***min***	***max***	***min***	***max***
Flat plat collector					
0.683	2.36	1.76	5.1	0	0.0436
Evacuated tube collector (Fin Absorber)					
0.72	0.824	0.55	2.15	0.0044	0.0175
Evacuated tube collector (absorber without fins)					
0.577	0.816	1.24	3.055	0.002	0.0175
CPC					
0.55	0.66	0.7	0.92	0	0.036

Table 37: optical efficiency and loss coefficients of solar thermal collectors.

4.3.2. Solar thermal systems and components

Systems and system components, other than collectors, are at very different stages in the standardization process. There is progress for systems in Europe, with European standards series covering Factory-Built Systems (EN12976) and Custom-Built Systems (EN 12977), where the latest standards (e.g., 12977-3/4/5) also include components, such as stores and controllers [116]. The European standards are well established inside Europe and in some countries beyond (e.g., Tunisia), but it is still unclear how the international.

Harmonization of standards applicable to systems will evolve. THE latest ISO developments show a common will to increase efforts towards enhanced international cooperation; this is reflected in the latest ISO 9459-4:2013, aiming to harmonize the EN 12977 series.

Standard EN-12976

Standard EN-12976, The standard for prefabricated factory-built ISWH parts (1 and 2) is ready-to-install complete assemblies. CEN TC 312 / WG2 has prepared this standard. It concerns self-storage collectors, thermosiphon water heaters, and solar water heaters with forced circulation of the heat transfer fluid. Part 1 of this standard describes the requirements for durability, safety, and performance. Part 2 describes the various tests to be carried out: mechanical, safety, DHW, and thermal performance Production of solar- covered hot water systems. For the latter, two test methods are mentioned in EN 12976: for CESI without supplement, this is the CSTG method, described in International Standard ISO 9459-2. For CESI with backup, this is the DST (Dynamic System Testing) method, described in the international standard ISO 9459-5. The various tests mentioned in the standard EN 12976-2 requiring a solar source are carried out in natural sunlight. Although indicating the possibility of making them indoors in artificial sunlight, the standard does not give any precision as to the corresponding test means. Moreover, no European laboratory tests the CESI in artificial sunlight, according to EN 12976 [117].

The tests required by this standard are:
- Internal pressure for absorber
- High temperature resistance for collector and tank.
- Exposure
- External thermal shock. May be combined with the high temperature resistance or exposure test
- Internal thermal shock. May be combined with the high temperature resistance or exposure test
- Rain penetration, only for glazed collectors
- Mechanical load
- Thermal performance
- Freeze resistance

- Stagnation temperature. May be combined with the high temperature resistance or exposure test.
- Final inspection
- The optional test for impact shall be carried out if requested.
- External choc
- Internal choc
- Test of corrosion

All standards tests related to EN 12976 are presented in Appendices, and particularly the second part about tests, procedures, and methods to apply it [66].

Standard EN-12977

Standard EN-12977, the test standard for CESIs "assembled as required" EN 12977: CESI assembled at the factory but directly on the place of installation of the system. This standard, prepared by CEN TC 312 / WG3, which had long remained an experimental standard, initially consisted of five parts. Only part EN 12977-3, "performance testing method for solar storage tanks," has recently been validated as a standard. The other four parts of the standard have been degraded in Technical Specification (TS) [118]:

- CEN / TS 12977-1: General requirements for water heaters and SSCs (Combined solar systems coupling a DHW and heating water production function).
- CEN / TS 12977-2: Test method for water heaters and SSCs.
- CEN / TS 12977-4: performance testing method for combined solar storage tanks.
- CEN / TS 12977-5: performance testing method for control equipment.

Only European standards can be used as a basis for European Keymark certification. Therefore, the EN 12977 standard with 4 technical specifications cannot be used for a European SolarKeymark CESI certification.

4.4. Certifications types for solar thermal systems; SWH

4.4.1. *The NF CESI mark*

The NF CESI mark has been in existence since May 2010 and concerns pre-fabricated forced circulation water heaters under EN 12976 and ISO 9459-5 standards.

The NF-CESI national certification is structured in two stages: the first is for the thermal performance of ISWH determination by simulations using the European standard(EN 15316-4-3) calculation methods. The second consists in determining these performances for ISWH per product range and extrapolate performance to other ISWHs in the range [119].

4.4.2. The SolarKeymark

The SolarKeymark was developed by ESTIF (European Solar Thermal Industry Federation) and CEN, with the European Commission's support. It complies with the Keymark rules introduced by the CEN to attest to the conformity of products with European standards. These rules are those of voluntary certification by a third party. The SolarKeymark certification for solar collectors is based on ISO 9806, CESI "factory prefabricated" on EN 12976, and CESI assembled according to EN 12977. SSCs are not covered by the SolarKeymark [120].

Solar Kaymark certification is based on [121]:

- Test according to the European standard: EN 12975 for collectors, EN 12976 for compact systems.
- Manufacturer's quality guarantee: An independent inspector must verify the ISO 9001 certification of the quality management system and production.

- Sample collection: the product tested (the collector and the solar system) is a random sample taken on the production line or in the stock by an independent inspector.
- Regular monitoring of the product and the producer's quality management: both the production process and the products are checked regularly by the test laboratory. Changes to the product must be communicated.
Solar Kaymark certification provided for manufacturers:
- Simpler test procedure
- A test valid for all European countries
- Freedom of choice among accredited testing laboratories
- Facilitate the introduction of new products in different European countries
- Simplified procedures for the replacement of components of certified products
Solar Kaymark certification provided to consumers:
- High-quality products
- Guarantee that the product sold is identical to the product tested
- Confirmation that the products are tested according to the standards in force
- Eligibility for grants

Solar Keymark certification requires:
- Initial product testing in an accredited testing laboratory.
- Annual Production Audit: Quality Management System Documentation.
- Every two years, a physical inspection of Solar Keymark certified products from the production line or stock by an inspector.
- Payment of annual certification fee.
- Reporting of product changes to certifying bodies.

The Solar Keymark certification process must start by contacting one or more certifying bodies; this will inform the client about the procedure to follow. The first step is usually to complete an application package. Some certifying bodies only work with specific test laboratories. [121]
The Solar Keymark website www.solarkeymark.org contains the latest updates and news, and lists of accredited certification bodies and testing laboratories. To obtain the Solar Keymark certification, the company must contact a certifying body in Europe. The various Solar keymark certifying bodies, co-ordinates, and testing laboratories recognized by this body in Europe are presented in Appendices .

4.4.3. The technical advice

Technical advice: in France, solar thermal systems are affected by the technical advice procedure. The technical opinion attests to the technical and regulatory performance of the product or system. Without being compulsory, a Technical Opinion remains a guarantee of quality concerning the product, which thus has verification of its performance. For the granting of subsidies in certain regions for collectors and CESI and the ten-year guarantee of insurers, a valid technical opinion is usually required. The CSTB technical advice procedure for solar systems differs in some respects from the requirements of the Solar-Keymark. An example: for aging collectors, EN 12975 requires a 30-day exposure, whereas the technical opinions of collectors require one year of exposure [122].

4.4.4. The CSTBat

The CSTBat mark: it concerns the products holding a technical opinion. It shall verify the product's conformity with the definition given in the technical opinion and certify that the technical opinion's performances are regularly reached by the products concerned. Only solar collectors and CESI thermosiphons can currently benefit from a CSTBat certificate. There is no CSTbat for forced circulation CESIs [123].

5. The materials

5.1. Storage tank

In the literature, the subject of thermal storage is remarkably present, given the critical development that this area knows about used materials and storage technology. (M.E Ezayd et al) interested in his review on the development of PCMs and CTSPCM, and the ratification of this materials types in solar storage and various technologies, namely, packed bed storage units, multi-storage tank with cascaded PCM, the heat exchanger storage units with its different configurations, and other innovative storage tank designs [124].another review presented by (F.S. Javadi), he gives a detailed overview of the progress made in the field of phase change materials (PCM) integrated into solar thermal storage, the overview also encompassed the scientific novelties in terms of publication related to the PCM integrated in solar thermal as well as the problems to the solutions possible for the adoption of this material while presenting efficient systems taking advantage of the high latent heat of PCM[125]. Phase-change materials are currently a significant topic in other scientific research on thermal storage tanks such as (Haotian Huang et al) who proposed a study on a thermal storage tank integrating a cascade PCM storage unit. The PCM used was well studied and chosen to propose the best suitable materials since the phase change materials can significantly increase and improve thermal storage capacity [126]. responds to the seasonal thermal energy storage demand of solar thermal systems, introducing a new phase-change composite material that features two-phase transition temperatures (PTT). The study is carried out on a solar water heater with a vacuum tube collector, which was presented in a three-dimensional digital model. an experimental study is done to validate the numerical model. The study concluded that the single PCM component with high PTT could remarkably affect the composite's PTT and enthalpy. Besides, combining paraffin and capric acid can achieve two different PPTs suitable for better seasonal thermal storage [127]. Seasonal thermal energy storage is also the paper's subject of (Dahash, A., Ochs et al), which presented the different storage technologies for urban heating applications suitable and feasible for a seasonal context. It is mainly focused on (pits and reservoirs) as thermal energy storage on a large scale [128].

Also (Işık, S et al) worked on a solar thermal system coupled with a phase change equipment based on latent heating to make solar energy more efficient. They replaced the conventional solar heating system with a new developed finned-type cell structure type for hot water collector tank [129]. The three-PCM cascade tank system also appears in the work of (O.Mao et al), the transfer of heat (fluid) in the system is done through Air and molten salt and the phase change material (PCM), respectively. The proposed system increases the total stored energy; however, there is no effect on the storage capacity by shape [130]. MAO Qianjun also studied the effect of PCMs and its heat storage characteristics on the solar thermal system's overall performance. The study was carried out through numerical modeling via MATLAB, evaluating the computation of the heat storage by PCM dynamics. It reveals that the system's thermal storage performance is related to the PCM's initial temperature and the flow rate. They must be optimized to increase total heat storage and sensible heat storage [131]. Besides, several recent journal works have come out attacking the subject of energy storage, more particularly, thermal energy using efficient materials such as PCMs. (Koohi-Fayegh et al) presents a complete work on the different energy storage technologies or dealt in part with the importance and characteristics of PCMs, representing the strong point of this choice to strengthen and improve storage in solar thermal systems [132]. (H. Asghariana , E. Baniasadi) also focused on PCMs, which represent the most promising materials for thermal storage. Its review focused on all the PCM simulations and modeling used in various solar systems applications; it mainly focused on studied the comparison and accuracy of different thermodynamic analyzes, numerical methods, and mathematical models of the PCMs integration in solar systems [133].

5.1.1. Internal reservoir

The type and quality of the material used for the manufacture of a domestic hot water cylinder (DHW cylinder, electric water heater, boiler integrated) significantly impact the boiler's corrosion resistance, its lifespan.
Today, hot-water tanks of enameled steel (enamel), stainless steel, and (less and less) are made of copper-clad steel [134].
In particular, depending on the quality of the water to be stored, it is necessary to choose a type of tank with appropriate corrosion protection. Water quality is an essential factor in the longevity of a tank. However, according to the regions, catchment wells, water supply, treatments..., etc. The composition and the corrosive properties of the water vary from one place to another, leading to a choice between one Of the three types of corrosion protection - copper, enamel, or stainless steel used in a hot water tank [135].
The primary criterion for selecting material from the tank is its resistance to corrosion. Tanks made of stainless steel or enameled steel or copper with protective anode are generally used. Galvanized steel tanks are not recommended because of their low resistance to corrosion.
For dead water tanks, which are not under pressure, it is possible to envisage reservoirs made of synthetic material, which is more durable since they are not subjected to corrosion.

The solar water storage tank must not only meet all the requirements of a conventional sanitary water tank. However, it must also be able to withstand the high temperatures to which it could be subjected. The flask temperature may rise to 95 ° C, hence the need to provide a thermostatic mixing valve on the distribution loop [136].
The tanks can be manufactured by various materials such as:
Stainless steel
It is the most upmarket type of tank for the highest hygiene and durability standards, thanks to the unrivaled properties of stainless steel. The stainless-steel hot water tanks guarantee a remarkable corrosion resistance and guarantee perfect hygiene, even in the most demanding environments. Even if it can be used for residential use, Stainless steel is also particularly suitable for kitchens, laboratories, hospitals, and the agri-food industry. Its state of surface is very homogeneous and remains effective even after many years of use, requiring no maintenance, unlike enameled steel tanks, which require a regular replacement of the anode magnesium [137].
The quality of the stainless steel used has a significant impact on the corrosion resistance of a hot water tank. It is preferable to choose austenitic stainless steel (21% chromium and 7% nickel), a steels family to which chromium is added. Over 11% of the solution causes the formation of a protective layer of chromium oxide, which steels its stainless properties. There are also ferritic steel grades which contain 18% chromium and 2% molybdenum, but almost no nickel. Because steel is ferritic, it is not sensitive to mechanical corrosion, which means it is resistant to high chloride concentrations [138].
The high chromium content and, more particularly, the molybdenum concentration improves the resistance to pitting corrosion. The shallow concentration of nickel is a health and environmental advantage because no nickel ion is dissolved could otherwise be the case during the hot water tank's first operating phase.

In addition to the choice of stainless steel, the different stages of the ball's production are essential. After welding a hot water tank, it is essential that the surface, which will be in contact with the water, have a homogeneous composition. For this purpose, a surface-passing etching is carried out, which recreates a uniform film of oxide over the entire internal surface of the hot-water tank. Therefore, it is advisable to choose stainless steel hot water tanks from well-known and renowned manufacturers [139].

However, even with a stainless-steel flask, pitting corrosion may occur. Pitting corrosion is generally not due to heterogeneity of the material but to the accidental presence of metallic dust, which forms an electric cell in a humid environment. The surface of the steel then forms the cathode and corrodes [140].

Finally, with a very high chloride concentration, pitting corrosion may also occur, especially if the water is very hard and calcareous deposits are formed. In this case, the natural oxygen in the water cannot reach the steel's surface, and corrosion may form under the deposit.

Enameled steel

Hot water cylinders in enameled steel are very present on the market because they are less expensive than the stainless-steel tanks. Enamel is a smooth, vitreous material applied to the interior of the hot water tank by heating. The vitreous enamel coating provides a "hygienic surface," studies have shown that enamel does not constitute a brooding place for bacteria.

The enamel takes its form and spreads over the steel surface through a heating process at 860 ° C. However, after treatment, the enameling surface [141].

It always comprises microscopic pores that can leave the tank's steel surface in contact with the water and cause corrosion points. To prevent corrosion, a protective anode is placed inside the enameled steel hot water tanks. The anode is generally composed of a magnesium-based alloy. Since magnesium is a less noble metal than steel, the anode is "sacrificed" (hence the term sacrificial anode) to prevent the steel electrochemically corrosion. The pores of the enamel layer are thus filled with calcium and magnesium compounds [142].

The magnesium anode is consumed at a rate that depends mainly on the quality of the water. Therefore, it is necessary to regularly check the anode to evaluate its lifetime and replace it if necessary.

Alternatively, choose a tank equipped with a titanium anode permanently connected to a generator that imposes an electric current of a few volts to capture certain minerals naturally present in the water (magnesium and calcium) precipitate them on the walls of the tank and thus protect it. This system is often referred to as "ACI" (Anode to Current Imposed - Atlantic Patent) or "AEP" (Electronic Protection Anode). This protection offers the enormous advantage of lasting in time, but also requires water rich in magnesium and calcium to be effective[143] [144].

Finally, there is dynamic protection, which combines the advantages of the anode made of magnesium and the titanium anode to overcome the water quality depending on the region where the hot water tank is installed. It Is the "hybrid" anode. It is a titanium anode coated with magnesium. Even if the water contains very little magnesium, as soon as the tank is put into service, the current emitted by the anode projects the protective magnesium contained on the anode onto the micro porosities of the enamel covering the tank. This protective barrier is then maintained throughout the tank's life, thanks to the current imposed by the anode made of titanium. This dynamic protection extends water heaters' lives up to twice as long when the water is aggressive [145].

vitreous enamel-lined carbon steel

Copper

Finally, there are a few hot water tanks on the market, the steel tank of which is completely covered with a layer of 0.4 to 0.7 mm thick copper welded with argon as a protective gas. The steel tank is resistant to water pressure, while the copper sheet covering it prevents corrosion [146].
As a semi-noble and natural metal, copper is resistant to most drinking water types, including most distribution waters with minimum pH value. Hot water tanks are protected.
Against corrosion by copper, such as stainless-steel hot water tanks do not require maintenance since they do not require a protective anode. Copper also has other advantages. Copper an ideal recycling material, and it can be regenerated many times. Copper is the best choice of material to reduce legionella risk, its anti-microbial effect keeping the water healthy. Finally, the ingestion of copper in small quantities is, in principle, essential to all living beings.
A copper hot water tank may be used without restriction with potable water if the pH is greater than or equal to 7.4, or if the pH is between 7.0 and 7.4 and the Total Organic Carbon TOC does not exceed 1.5mg / l. At low pH (acid water) or in the presence of high concentrations of chloride (brackish water, for example), copper tends to dissolve. Problems of aesthetic orders can then occur, causing a discoloration of the porcelain of the toilets and a greenish coloring of the blond hair in the shower. In the case of a high chloride concentration, pitting corrosion may occur, but the risk is inversely proportional to the calcium concentration (hardness).

Tank lining:

With hot or cold water, the main pressure vessels made of carbon steel rust quickly. A variety of successful and failed tank coatings were used. The types of tank linings hold in some cases and in other cases not, which is revealed by periods of user testing to validate the success of the introduction and the continuity of tank coatings in the market [147].

Galvanizing.

A galvanized steel tank is made by dipping the steel tank into the molten zinc. The zinc solidifies. Zinc acts as a sacrifice to steel and prevents corrosion of the water tank. The zinc life is considerable, but the tank quickly breaks down as rusty water is apparent [148].

Glass lining

Porcelain is used as a coating in the form of an email for steel tanks. A porcelain enamel frit is sprayed inside the container and then baked (heated to a temperature between 1400 and 1600ºF), which binds the frit to the fondue steel tank. And then proceed to the cooling of the container [149].
The integration of the magnesium anode is necessary for all glass-coated tanks because of tiny pinholes in each porcelain enamel. The magnesium anode acts by preventing corrosion and sacrificing these pinholes in the coating; this explains the tank submission to corrosion when the magnesium anode dissolves; this makes periodic replacement of anodes a necessity. Anodes can be replaced periodically, but this is usually a maintenance item undetected and not done.

Copper lining.

Steel tanks contain welded copper plates inside. Moreover, because of the dilatation that copper and steel experience expand and contract over different rates, expansion joints' integration is necessary. For the lined tank, a vacuum circuit breaker is essential to prevent the tripping of the copper coating wall during the tank's emptying. Copper-lined reservoirs are generally little used because of their high costs [145].

Coating of nickel phosphate.

This coating is a chemical deposit of phosphate compounds and nickel salts.
This type of tank coated with this method is generally three mm thick with a nickel phosphate coating. This type of coating can also have small pinholes as for the glass coating, and this is

because of the porous character of the materials used, which cannot be produced without pores. A coating of the amine-cured epoxy coatings is then applied to this type of reservoirs coated with nickel phosphate [150].

There are few manufacturers of hot water tanks lined with nickel phosphate around the world. Most international markets have refrained from offering this type of liner as they believe that other coatings are much more suitable for hot water.

Epoxy coating.

The application of catalytic amine is essential to harden epoxy coated tanks with a need for surface preparation in applying the epoxy liner.

Cracks in the coating are widespread in this type of tank because of the epoxy's physical characteristics: it is hard to have very different expansion rates than the steel tank, which makes it very sensitive to temperature changes brittle. Then the liner tends to fall If water seeps into or behind the liner once it cracks [151].

Finally, stainless steels (sufficiently alloyed) and copper offer incomparable resistance to corrosion. They are, unfortunately, expensive, which suggests considering alternative solutions more economical.

Usually, the tank's internal surface (of type St 37 type) is coated with a protective shield (enamel, ceramic, copper foil, or others), supplemented by galvanic protection by sacrificial anode made of magnesium or titanium. Imposed current systems offer the best protection.

5.1.2. tank insulation

In general, the heat loss reduction in standby mode is the key criterion of thermal insulation evaluation. On the market, there is a variety of insulation characteristics of heaters-water availability. However, this criterion can be improved for existing products that are generally not insulated or poorly insulated to reduce heat loss, and c is with the addition of additional insulation layers in the form of an "envelope" or a roof outside the water heater tank. The water heater can be completely enclosed in a specially constructed and very well insulated space to increase energy efficiency and ensure better operation in extreme conditions.

Fiberglass with a vinyl film on the outside is the most commonly available type as water heater cover and insulation. Fastening the tank in place with tape or belts is essential for developing the insulating cover around the tank. The size of the roof is an essential element for this roofing operation. It must not cover the drainage and safety valves and the controls or block the airflow and airflow through an exhaust vent. Adding insulation to an already well-insulated storage tank can lead to rust caused by condensation, mold especially in too wet places. Alternatively, create other operational severe problems, so maintaining a specific area is necessary and usually ensures by convection caused by waste heat. On the other hand, in these extreme wet conditions, an assistant of a fan ensuring this convection is necessary [152].

The most popular insulation for most modern water heaters is polyurethane foam (PUF)insulation. In the case of oxygen levels in the local water supply or particularly agreeable minerals or the access to the interior scourer is a priority, the application of polyurethane foam in encapsulated form is highly recommended, they allow the removal of the insulating layer for regular integrity checks and, if necessary, repairs to the properties of the water reservoir.

polyurethane foams

The thermal conductivity of the polyurethane foam is between 0.023 and 0.028 W · m-1·K-1.

In the form of expanded foam, polyurethane foams are widely used for their thermal insulation quality, their adhesion to any support, their flotation power, their capacity to fill voids whatever they may be and to allow packaging on Light and strong. Their use is also significant to fill a void of car sill and prevent rust from spreading there as a barrier to rainwater. The caisson is filled, and the foam is propagated in the interstices filling the "perforations".

Foams sold in bombs have an expansion capacity of 50 liters of foam per liter of product. The density of the foam obtained is of the order of 40 kg · m-3 [153].

The mineral wool

The mineral wool mattresses encircled by an aluminum foil and covered with an aluman coat. The insulation industry uses the mineral wool designation to designate a range of different products, including glass wool, slag wool, and rock wool.

Rockwool

Rock wool is a natural mineral fiber that looks like light beige cotton material.

In terms of thermal performance, the lambda (or thermal conductivity) of Rockwool varies from 0.042W / (m.k) to 0.033W / (m.k.). Therefore, the current thermal resistances can vary for a product thickness of 100 mm R = 2.35 m^2 K / W for the most conventional at R = 3 m^2K / W for the most efficient. In monolayer, thicknesses up to 260 mm are available (maximum thermal resistance in monolayer R = 7.2 m^2K / W). These thermal insulation products make it possible to insulate roofs, walls, floors and partitions, winter and summer, and limit the noise nuisance in the habitat [154]. The reaction to fire of unfaced rock wool (without vapor barrier) or glass or aluminum foil surfacing is classified as A1 by the European classification Euro classes (non-combustible product). When a Rockwool is coated with kraft paper, its fire reaction class is F (unclassified or untested). By its nature and its constituents, rock wool responds to the characteristics of dimensional stability at temperature and humidity. Like glass wool, Rockwool is non-hydrophilic insulation; this means that when a Rockwool is accidentally wetted by rainwater or snow, it is sufficient to let it dry without manipulating it, or compress it. When it regains its thickness, it covers its characteristics of thermal conductivity, and therefore its performance.

Wool of slag

Slag wool is a gray product from residues in the iron and steel industry. It is sometimes used for the flocking of car parks, for example, but it can also enter Rockwool's composition.

Glass wool

Glass wool is yellow material, resulting from the fusion and stretching of glass to transform it into fibers. Like Rockwool in its production process, glass wool is manufactured by heating the constituents before spinning them into fine fibers. Various additives can be used during production to coat the fibers and modify their properties.

In terms of thermal performance, the lambda (or thermal conductivity) of glass wool ranges from 0.030W / (m.k.) To 0.040W / (m.k). The current thermal resistances can thus vary for the same product thickness, from R = 2.50 m^2 K / W to R = 3.30 m^2 K / W in 100 mm and, for example, in monolayer R = 6.85 m^2. K / W in 240mm for a lambda wool of 0.035W / (mK) or 7.50m^2K / W in 300mm for a lambda wool of 0.040W / (mK). These recognized thermal insulation products equip more than 75% of French households and are also the most widely used insulation materials globally. They make it possible to effectively insulate roofs, walls, floors, and partitions, against the cold of winter, the heat of the summer, and the noise in the buildings [155].

The reaction to fire of the non-surfaced glass wool (bare, without vapor barrier) is A1 (incombustible product); With the particular surfacing of glass or aluminum veil type, it is classified A2s1d0 (non-combustible product) by the European classification Euro classes. When glass wool is coated with Kraft paper, its fire reaction class is F (unclassified or untested).

By its nature and constituents, Glass wool responds to the characteristics of dimensional stability at temperature and in the presence of moisture.
Concerning the mechanical behavior, it should be verified that the glass wool chosen corresponds to the intended application (roof, wall, floor). Thus, for an application between rafters or a wall application that requires mechanical strength of the insulation, it must be ensured that the glass wool chosen is at least semi-rigid. The semi-rigidity characteristic of insulation is evaluated and certified by the Acermi certification.

The polystyrene

The polystyrene shells, covered with a lacquered sheet coat, are removable (but sometimes limited to certain temperatures).

expanded polystyrene: it has good mechanical strength, is easy to install. The insulation, which is realized with rigid plates of white or gray expanded polystyrene, can concern roofs, floors, walls (insulation from inside or outside), or terraces. Fragile in contact with fire, expanded polystyrene is always associated with an incombustible material: plaster, for example, combined in the form of a plate, especially for insulation from the inside. The gray PSE contains components that improve the thermal performance by approximately 10 to 20%, making it possible to reduce the thickness required [156].

The melamine resins

New material very resistant to high temperature and easily separable from the outer mantle

5.1.3. External cover

The external cover is manufactured by several materials such as PVC.PVC foamed rigid PVC foam boards with remarkable properties. This high strength foamed plates are manufactured using the Celuka process. A unique cooling process gives the material the desired internal cell structure, i.e., a uniform structure and a smooth homogeneous surface. Due to the type of PVC used, tested for years and endowed with high resistance to shocks, and the manufacturing process specific to the material, the foamed PVC plates possess a remarkable set of properties. They are very stable and resistant to shocks, light, weather, humidity, swelling, chemicals; they do not corrode and are excellent thermal and acoustic insulation [157].

Characteristics

- Resistance to chemicals
- Physiologically without disadvantage
- Aging resistance
- Stiffness and solidity
- Resistance to deformation under calorific effect
- Not flammable
- Electrical insulation
- Low density
- Smooth and pore-free surface.
- Ease of processing.

Aluminum sheet

Metallic aluminum is highly oxidizable but is immediately attacked by a thin layer of waterproof Al_2O_3 alumina, which protects the metal mass from corrosion. This resistance to corrosion and its remarkable lightness made it a material widely used industrially. Aluminum is an essential industrial product, in pure or alloyed form, particularly in aeronautics, transport, and construction[158].

The main properties of aluminum are:
- Good conductor of heat and electricity
- Low density: 2.7 kg / dm^3
- Melting point: 658 ° C
- Low Young's modulus: 70000 N / mm2 70000 Mpa 7000DaN / mm2
- Low elastic limit
- Long elongation at break (thin sheets, sheets, paper)
- Good conductivity (67% of that of copper).

Polished stainless-steel sheet Low-carbon steel Are the extra-soft steels have a content of less than 0.022% of carbon; They are outside the "zone of influence" of the eutectoid (perlite) and therefore have no perlite hardened by precipitates of cementite in small quantity. Compared to the empirical name: Mild steel: S185 (A33), S235 (E24), C10 (XC10,1010), C22 (XC18,1020).

Polypropylene

A distinction is made between isotactic, syndiotactic, and atactic polypropylene. For technical applications, isotactic PP has been used mainly because of the isotacticity increases, the more the crystallinity, the melting point, the tensile strength, the stiffness, and the hardness increase.

The two most common types of PP: PPDWU and PP DWST:

PP-DWU is a homopolymer PP stabilized by heat. Due to its excellent properties (particularly chemical resistance and high resistance to corrosion), PP-DWU is the most widely used material in composite construction and coatings [159].

PP-DWU is the most widely used material in constructing chemical appliances and tanks, with remarkable cost/benefit potential. The cover plates complete the range of products for the field of composite construction and coatings.

PP-DWU: Standard polypropylene gray, homopolymer, heat stabilized, and made from isotactic PP.

PP-DWST: Natural polypropylene, homopolymer, heat stabilized, and made from isotactic PP.

Characteristics.

The properties of polypropylene are different from those of polyethylene despite a similar molecular structure: it presents a lower density, higher glass transition temperature and higher melting Dimensional temperature stability superior to heat.

5.1.4. heat exchanger (inside tanks)

Specifications for core and frame materials can significantly increase the cost of a heat exchanger. The core, which may consist of tubes, fins, and/or metal sheets, can be made using various metals. The most common metals used in the manufacturing process are aluminum and copper, or frequently stainless steel for heat exchangers. These metals' cost has increased significantly in recent years, further increasing their share in the total cost of a heat exchanger. Since stainless steel is more expensive than aluminum or copper, it is reasonable to opt for copper or aluminum, unless it requires stainless steel. Heat exchangers can also be manufactured using nickel, cupronickel, Hastelloy, Inconel, titanium, or other metals. However, these metals are not used very frequently because of their high cost. Generally, core materials are specified to ensure that the liquid passage metals are compatible with the heat transfer fluid selected for the application. For example, stainless steel can be specified for use with deionized water so that cupronickel can be indicated for saltwater. The core material of the heat exchanger can also be selected according to the weight. The coating of the heat exchanger, to protect it against corrosion or for aesthetic reasons. Coating for corrosion protection is most common on aluminum heat exchangers since aluminum corrodes more readily than other metals. Several types of heat exchanger coatings minimize corrosion: chemical conversion coating, anodizing, electrolytic plating, and painting [160] [161].

5.1.5 auxiliary heater

The auxiliary heaters are manufactured of:

- Alloys: Nickel-based austenitic alloys, and FeCrAl ferritic alloys.
- Ceramic materials such as Molybdenum disilicide, Silicon carbide, Chromite of lanthanum, and zirconia.
- Graphite and carbon-carbon composites.

5.2. Collectors

The subject of solar thermal collectors is a fundamental axis in scientific research in renewable energies and their technologies. Many reviews that have attacked this subject by showing off the latest technologies and applications of this solar promoter component. (L. Evangelisti et al) presented a complete analysis of the latest scientific outputs in terms of relevant journals and articles on solar thermal collectors, with an exhibition of the different technologies that exist and a detailed description of the operation. His work also focused on the latest developments in hybrid systems based on in-depth theoretical analyzes. The collectors' performances were also presented with all the relevant evaluation tests to comply with standards [162].(R.Agathokleous et al) works' presented a new prototype of a flat solar thermal collector integrated into a tertiary building model; the prototype was presented under a dynamic simulation model in MATLAB. The simulations results present the economic performance of the entire system (prototype integrated into the building). An investigation of the design and the energy performance was made. The proposed device's main novelties are the adoption of simple design solutions and cost-effective materials compared to commercial collectors in the market [163]. the integration analysis of solar thermal technologies collectors in the building is also the subject of the (M.S.Buker et al)review which gives an overview of this technology advancement and the future work needed based on the current trend. The technology was presented under the model integrated into the building; its different applications were unveiled and the standards and requirements for a better thermal performance of solar thermal systems, evaluating the different factors that affect it. The subject was dealt with comprehensively, presenting the various problems linked to the design of the systems and the architectural barriers of the installation by evaluating the difficulty currently experienced by thermal solar collectors [164].

all solar thermal collectors' technological types have been studied separately in various works, according to technological progress, innovation, and integration of innovative materials and fluids to improve the thermal and energy performance of systems. (A.A.Hawwach et al) studied the flat plat collectors' performances. Using experimental and numerical investigation and focused on FPC with different working fluids, Alumina nanofluids, and double-distilled water under variables volume fractions. The study showed that optimal thermal efficiency is improved by increasing the alumina nanofluid fraction until 0.5% provoking the pressure drop increases. However, any further increase affects thermal efficiency negatively [165]. The flat plat collector's performance is improved through the search also using the reflectors, (H. Bhowmik et al) introduced this new technology to collectors increasing reflectivity to take advantage of both direct and diffuse irradiation, playing on the angle of the day to maximize the intensity of the light. Incident radiation, the study was finalized by a prototype, which showed an improvement in the efficiency of 10% [166]. The technology of thermal solar collectors was also improved by (A. Allouhi et al)

who integrated the heat pipes into the conventional system; the system was modeled by Matlab to assess its thermal, energetic, exergetic, and financial performance. The model was optimized, fixing the number of 13-wire heat pipes. The results showed that the system must be optimized with care, making a projection and optimization based on the climatic context [167]. Regarding the vacuum tubes, technology (K. Chopra et al) worked experimentally on the collector with heat pipes by integrating the phase change materials in the system to always improve the performances. The study presents a comparative analysis that concluded that the system with the PCMs has a better energy efficiency, which is evident because of this type of material's unique thermodynamic characteristics, giving a high latent heat. The models also have been optimized based on the flow rate presenting a value of 20L per hour to achieve better daily thermal efficiency [168]. the absorbent type used is a critical parameter used by researchers to improve evacuated tube collectors' performance. (A. Gholipour et al) worked on three types of absorbents; a spiral tube, a U tube, and a helical coil. The experimental studies were carried out with a flow rate at four different volumes. The results of this work favored the use of the helical coil, which allows the best performance by increasing the volumetric flow [169].
other reviews focused on a specific technology to present it in terms of scientific and technological innovations such as (E Bellos et all) Who has chosen to shed light on the concentrating solar thermal collectors technology[170].

5.2.1. Flat plat collectors

A flat plate collector is generally composed of a boot, glazing, insulation, an absorber, and tubes allowing the heat transfer fluid passage.

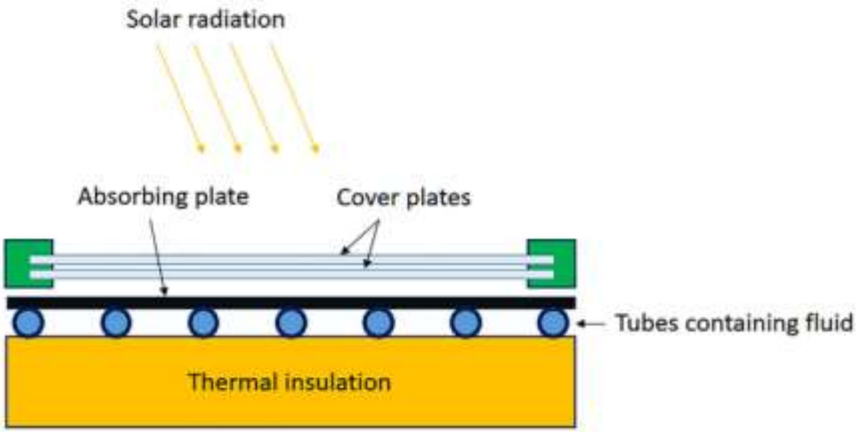


Figure 77: flat plate collectors' components [171]

5.2.1.1. The glazing

The glazing makes it possible to protect the collector's interior against the effects of the environment and improve the system's efficiency by the greenhouse effect. If efficient glazing is desired, it must have the following properties : Reflecting the light radiation to the minimum regardless of its inclination; Absorb the light radiation to a minimum; Have excellent thermal insulation while keeping the infrared radiation at maximum; Resist in time the effects of the environment (rain, hail, solar radiation...) and to large variations of temperatures. The foremost glazing used for thermal collectors are based on non-ferruginous glass or acrylic glass and often have an anti-reflective coating [172].

5.2.1.2. The absorbers/ The exchanger

The absorber is one of the most critical thermal collectors' components; It converts solar radiation into heat.Two parameters characterize the absorber[173]:
*The solar absorption factor α * (or absorptivity): the ratio of the light radiation
absorbed by the incident light radiation.
*The infrared emission factor ε (or emissivity): the ratio between the energy radiated in the infrared when the absorber is hot and that a black body would radiate at the same temperature [.
It is desired in solar heating applications to obtain the best ratio of solar absorption factor / infrared emission factor. This ratio is called the selectivity.
The material constituting the absorber is generally made of copper or aluminum but also sometimes of plastic.
In order to obtain a better yield, specific systems are thus constituted of a particular coating.

Here are the properties of some materials used as absorbers [174]:

Materials	absorptivity A *	emissivity E	selectivity A*/ε	Max T
Black nickel	0.88 - 0.98	0.03 - 0.2	3.7 – 32	300 ° C
Graphitic films	0.876 - 0.92	0.025 - 0.061	14.4 - 36.8	250 ° C
Black copper	0.97 - 0.98	0.02	48.5 - 49	250 ° C
Black chromium	0.95 - 0.97	0.09 - 0.30	3.2 - 10.8	350 - 425 ° C

The are several materials of thermal collectors first exchanger such as[175]:
Steel
easy to find material, this was also the first used. It was found that the steel absorbers were very sensitive to corrosion. They were not very successful. There were two types:
Steel coil absorbers are enclosed between two welded steel sheets.
The "water blade" absorbers form two sheets of spot-welded steel and are subjected to high pressure to "inflate" the non-welded parts.
Stainless steel
these absorbers consist of a coil of stainless-steel tubes glued between two pre-stamped aluminum sheets, are resistant to corrosion, but a loss of contact between Tubes and aluminum foil.
Aluminum
these absorbers have the disadvantage of being sensitive to corrosion with certain poorly proportioned heat transfer fluids (corrosive antifreeze). There were two types: The roll-bond absorbers made of two aluminum sheets first covered with a coating reproducing the canals' network. Firmly pressed together, then welded, both sheets are subjected to high-pressure inflation.
Materials of today's exchanger
Copper
The absorbers currently in use are made of copper or stainless-steel tubes welded to aluminum foil.
They rarely show a trace of corrosion, even after 20 years. There are two types: The absorbers made of aluminum sheets copper plated, Copper tube absorbers, welded on copper or aluminum sheets [176].

5.2.1.4. Insulation:

The thermal insulation makes it possible to limit thermal losses; its characteristic is the coefficient of conductivity; The lower, the better the insulator is. The primary materials used for thermal collectors are rock and glass wool, polyurethane foams, or melamine resin. Sometimes insulators are more natural [177].

Some insulators used for thermal collector:

Materials	Thermal Conductivity
Rockwool	0.032 - 0.040 W / mK
Glass wool	0.030 - 0.040 W / mK
Polyurethane foams (waterproofing)	0.022 - 0.030 W / m.K

In the case of glazed thermal collectors, it is also advantageous to replace the glass's insulation and the absorber by air! Indeed, the air has excellent insulation; it is thus used in the double glazing. Still, intending to obtain better yields, some manufacturers use other gases such as argon or xenon, and where possible, even use a vacuum.

Here are the gas insulation coefficients used as insulation:

Gas	Thermal conductivity at 283 K, 1 bar.
Air	0.0253 W / mK
Argon	0.01684 W / mK
Xenon	0.00540 W / Mk

5.2.2. Evacuated tube

There are different types of vacuum tube collectors [178]:

Direct flux: in this type of collector, the heat transfer fluid circulates inside the absorber, thus allowing a high efficiency.

In the heat pipe vacuum tubes, the absorber contains a liquid vaporized under a partial vacuum. This heated vapor condenses in a condenser and returns in liquid form to the absorber. The condenser takes care of transferring the heat to the heat transfer fluid. This system requires a minimal inclination of the absorber tube.

Type "Sydney" / CPC: the "Sydney" tube is characterized by a tube of glass with a double wall to avoid a loss of the vacuum. The absorbent surface is located on the inner glass tube. The rounding of the tube requires a reflector to use the entire surface of the absorber, hence its name of CPC tube (Compound Parabolic Concentrator).

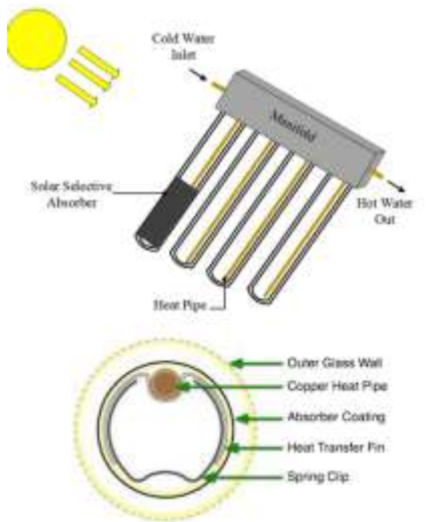


Figure 78: Evacuated tube collector components [179].

5.2.2.1. Tubes

In general, the most material used for the ETC tubes is the Borosilicate glass[180]; Which is a type of glass mainly composed of boron trioxide and silica. The following three points can summarize its qualities:

its neutrality and high hydrolytic strength and the advantage of being quenched at a high softening point with low thermal shock-resistant expansion.

Composition:

70% to 80% silica (SiO_2)

7% to 13% boron trioxide (B_2O_3).

4% to 8% alkaline oxides (Na_2O; K_2O) 2% to 7% alumina (Al_2O_3)

0% to 5% other alkaline oxides (CaO, MgO ...)

"Borosilicate" glass takes its name from the two most abundant compounds, silica, and borates.

Thermal Properties:

This glass is resistant to thermal shocks, even in high thickness. It can be used up to temperatures of around 1500 degrees. However, when these temperatures are reached, it is recommended to carefully monitor the cooling, which must be done slowly and gradually, especially if the object is thick.

5.2.2.2. Pipe

Reinforced copper for protected is the essential material used for the pipe due to its high thermal characteristics notes above. In a few using, we can find the aluminum as material that gives a product chipper but with lox efficiencies because of these material's thermal criteria [105].

Conclusion

This chapter reviewed the different technologies of solar water heaters, showing the different typologies that exist based on the mode of operation and the method of heat transfer. This technology, which tends to the operational maturity, can be divided into two systems; the active (open loop and closed loop) and the passive system (thermosiphon and ICS).

More This part also examined the components of the solar water heater, making a decortication of the whole system by presenting its technical compositions passing from the primary and most essential parts to the accessories. All the components presented in the first part are described in a way based on their importance and operation within the solar thermal system. All the exposed parameters are solar collector, storage tank, heat transfer fluid, heat exchanger, pump, and accessories. All components have been described and detailed.

The second bet of this review was dedicated to the standardization related to solar water heaters. The normalization has been specified diverting the solar thermal products generally in two parts; the solar thermal collectors and the solar water heating systems (a forced circulation or thermosiphon). It has passed all the existing international standards, focusing on European standardization applicable for international certification. The European standards met by this technology have been presented with different types of certifications and standards.

Besides, the paper throws the light mainly on the EN 12976 norm, which targets the thermosiphon systems by a presentation of the totality of the tests and the methodologies and procedures of the realization of the tests to respect the limited and the limits fixed by the standard. The paper then presents all certification bodies and testing laboratories working according to European requirements.

The quality of the materials is an integral part of the standards application and predominantly European. This review part details all the components materials previously described in the first part by presenting the most used materials existed on each component's market, and which presents a remarkable quality respecting the normative requirements. The presenter material makes it possible to identify products representing a certain resistance to the test conditions and specific requirements; this provided an overview of the materials used to manufacture solar water heater components, which are the key to a right, certified, and efficient product.

This chapter represents a technological choice guide for solar water heaters; This makes it possible to identify the existing national market in technological terms and materials to evaluate or measure the chosen solar water heaters' optimal choice. the part of the standardization completes the guide passing from the technological technique to the international requirements, which allow making a better combination of materials which respects the normative limits in order to be able to describe the SWH products as efficient, secure, and normative.

Chapter V: *SHEMSY domestic solar water heater; the best solution for Moroccan social and economic context*

Introduction

Sol'R-Shemsy project aims primarily to produce, industrialize, and market a solar water heater «Made in Morocco» meeting European standards and the market's best quality/price ratio. At a competitive price for the social, it comes to strengthen the energy pole of the University Sidi Mohamed Ben Abdellah (Ecole Supérieure de Technologie de Fès).

The project strengthens the Moroccan market for solar water heaters by introducing a product with improved and competitive performance and yields, with customers' price accessible. Price remains a significant factor in developing this market and the integration of this green technology in all social segments to be in line with the image marketed internationally for Morocco as an example of the adoption of energy renewable energy and environmental protection.

The high prices resulting from the import build a remarkable blockage to the Moroccans' familiarization with this current necessity. This project comes as a response to this problem by presenting a product compliant with European standards with much better performance resulting from the extensive research of all stakeholders in the SHEMSY project.

The problem is the level of the price debate and the lack of control and supervision of products marketed in the local market; this influences the customer's reaction to this technology and results from several products that do not meet the quality criteria required by international bodies. Furthermore, as a result, a deterioration in this clean technology's real image and a discouragement of the population to invest in a clean, efficient, and profitable solution and generate remarkable gains.

Therefore, the solution is at SHEMSY with a promoter product of a much more fulfilled future and answers to all current problems. Presenting an orientation that comes in line with Morocco's vision today gives renewable energies a priority place as alternatives to any source of energy. In order to shine internationally as a clean force and an ambitious example friend of the environment. It integrates this philosophy into each individual's policy and behavior before being a national orientation on a macro scale.

This chapter presents the solution provided responding to the problem of the project. The main objective is to innovate, design, and industrialize a "Made in Morocco" solar water heater under European standards and the best quality/price ratio on the market and a competitive price for social, reinforcing the Moroccan energy pole.

The solution comes in two separate configurations (low pressure and high pressure), representing various characteristics and conditions of use in terms of requirements and needs, and budget. Technical details and performance studies, are presented in this chapter.

1. *SHEMSY' prototyping procedure*

Objective: to relate the proposed solution's characteristics to the constraints and expectations stated, which was expressed using sketches and preliminary diagrams. For the shemsy prototype design, different steps were followed to ensure that the technical solutions envisaged are always compatible with the constraints set out in the specifications.

1st step Drawing or drawing: The search for the solution is often carried out from drawings, which has been prepared and presented in the form of preliminary sketches for the solar water heater SHEMSY.

Step 2: Plan the solutions envisaged: The plan consists of drawing different parts to scale. It is also necessary to indicate their dimensions (rating). All the detailed drawings of the prototype have been completed; present as an Appendices.
3rd step model production: To check the characteristics of a technical solution, models are made. It is manufactured using materials that are easy to use (cardboard, paper, polypropylene) and often different from those used to produce the final solution.
Several test models were made in the workshop for testing before the final product was produced.

Figure 79: SOL'R SHEMSY SWH model.

Stage 4 Production of the prototype: The final step is to build a prototype. It brings together all the solutions selected and will be made from the material defined in the specifications. Before making it on a machine tool, the drawing was done with Computer-Aided Design software.
The prototyping project was developed according to well-organized decision-making steps:
Planning (Feasibility Study); Requirements Specification; Analysis (Formal Specification); Design (Technical Specification); Implementation (Coding); Unit Testing; Integration and Testing; Delivery (to IRESEN); Maintenance.
On the other hand, the prototype made according to the organizational method of cascade projects:

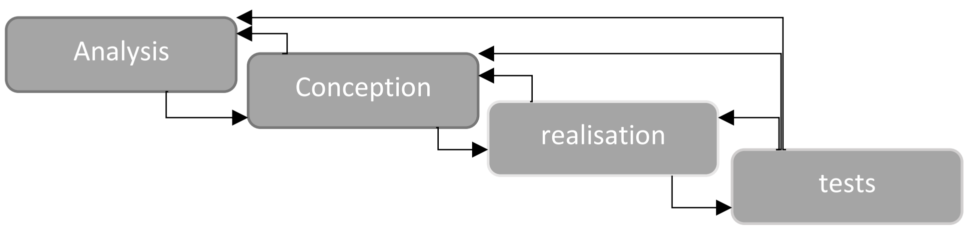


Figure 80: Cascade method for prototyping.

Figure 81: thermosiphon SWH SOL'R SHEMSY (real prototype).

2. SHEMSY' products: general description

2.1. Presentation

Individual solar water heaters (ISWH) SHEMSY forming sets of variants:

A solar vacuum tube water heater in two configurations.

- A low-pressure solar thermosiphon water heater
- A high-pressure solar thermosiphon water heater.

All variants from sets consisting of:

A solar collector with a vacuum tube (with or without) heat pipes, with fluid circulation.

- a solar storage tank with a capacity of 200 L.

(The storage tanks are optionally equipped with an electrical auxiliary heater).

The process also includes the hydraulic and fastening accessories necessary for its implementation.

The SHEMSY water heaters operate by thermosiphon with the fluid's indirect passage between the tank exchanger and the collector(s).

SHEMSY water heaters come in different versions, as described in Table 38.

2.2. Commercial designation

The SHEMSY solar water heaters are available in two models depending on the type of vacuum tube solar collectors (with or without heat pipe) with the same collection surface.

The commercial name of the solar water heaters according to their type (high or low pressure).

"**Star**" describes the solar water heater at low pressure. The "**star plus**" describes a much more advantageous variant with a high hot water temperature than the **star**. It is thanks to the heat pipes present in the vacuum tubes that promote heat transfer.

Designation	Product description
SHEMSY STAR	Solar water heater one piece with evacuated tube collector technology 200 L; low pressure
SHEMSY STAR PLUS	Solar water heater one piece with evacuated tube collector- heat pipe technology 200 L; high pressure

Table 38: SHEMSY'S products.

2.3. Area of use

a) SHEMSY solar water heaters are intended for domestic hot water production.

b) Use at an angle between 30° and 45°, corresponding to the limit of the collectors' use.

c) Implementation must be done in a "stand-alone" manner on:

- sloped roofs covered with corrugated and ribbed metal plates,
- on a roof terrace,
- on the ground.

3. Description SHEMSY STAR/SHEMSY STAR+

THESE SHEMSY STAR and SHEMSY STAR PLUS are vacuum tube water heaters whose main element is: the solar collectors and the storage tank.

3.1. Components

3.1.1. Solar collector

Solar collector with vacuum tubes with fluid circulation consisting of:

- 20 vacuum tubes equipped with heat pipes for SHEMSY STAR+, and without heat pipe for SHEMSY STAR (low pressure).
- a hydraulic manifold

Each tube consists of a borosilicate glass tube welded high on a metal plate. The vacuum inside the tube provides insulation.

The absorber consists of a selectively coated copper sheet and is welded to a copper heat pipe. This heat pipe passes through the tube's metal plate and carries out the heat transfer between the absorber and the collector.

The process also includes support elements and fasteners intended for the supporting structure.

The collector is available in two variants:

Designation	***Tubes number***	***Absorber area(m^2)***
SHEMSY STAR	*20*	*3.03*
SHEMSY STAR+	*20*	

Table 39: SHEMSYs collectors types.

- ***Vacuum tube***

The vacuum tubes' body consists of a borosilicate 3.3 glass tube.

The tubes are filled with air at low pressure: 10-5 Pa.

The tubes are held on the frame by covers and comb in PC-10GF and EPDM, on the frame lower rail.

The comb has graduations for the tube orientation adjustment.

The tubes are inserted into the holes in the storage tank; they are maintained through EPDM seals. The EPDM seals have graduations to adjust the orientation of the tubes.

Glass transmission coefficient: 92%

The thickness of the outer and inner tube glass is: 1.6 mm

Overall dimensions of the glass tube:

External diameter ø 58 mm, Internal diameter ø 47 mm.

Tube length with glass wedge: 1800 mm

The quality of the vacuum rate is displayed over time by a barium-based getter placed in the tube's middle part.

The disassembly of the tube is possible without special tools. It is possible without precise technical intervention.

collector	
Collector type	Evacuated tube collector
Vaccum tubes number	20
Heat Transfer technology	Integrated Heat pipe to vacuum tube (star+) Direct transfer to water without heat pipe (star)
Liquid type	Direct heating of water entering vacuum tubes (star) Direct contact of heat pipes with water inside tank (star+)
Vacuum tube diameter	External 58 mm/ Internal 47 mm
hydraulic connections diameter	cooper 22 mm
Maximum operating pressure	7 bars (star+) /Patm (star)
Resistance to hail	Resistant to hailstones up to 25 mm
Fixing solar thermal panels	Mounting on sloped roof and mounting on frame at 30-45° on the floor or optional flat roof terrace.

Table 40: characteristics of SHEMSYs' collector.

Heat pipe condenser	*Lenght*	*70 mm*
	thicknes	*0,8 mm*
	diameter	*24 mm*
Heat pipe	*Lenght*	*1700 mm*
	thicknes	*0,6 mm*
	diameter	*8 mm*
	Max temperature	*300 °C*
aluminum fin	*Lenght*	*1600mm*
	thicknes	*> 0,2 mm*
Borosilicate Glass Vacuum Tube 3.3	Lenght	*1800 mm*
	thicknes	*External 1,6 mm / internal 1,6 mm*
	diameter	*external 58 mm/ internal 47 mm*
	weight	*2 Kg*
	Absorption coating	*AI-N/AI (nitrite de cuivre)*
	Absorption	*> 92% (AM 1.5)*
	Emittance	*<8 % (80 C°)*
	perfect vacuum	*P < 0.0005 Pa*
	temperatures of stagnation	*> 200 °C*
	Heat loss	*< 0.8W/m2/ C°)*
	catchment area	*0,08 m2/ tube*

Table 41: : collectors' components characteristics (STAR +).

- ***Heat pipes and absorbers (for star)***

In each tube, the absorber consists of a selectively coated copper sheet.
The absorber thus formed is ultrasonically welded to the copper tube of the heat pipe.
This assembly is a heat pipe that allows heat to be transferred to the collector via its condenser.

Operation of the heat pipe

The heat pipe is sealed and sealed; it contains a liquid in equilibrium with its vapor phase. The liquid evaporates in the tube; the steam is driven to the condenser to give up its energy. The condensates then return to the tube.

Maintaining the heat pipe in the glass tube.

The heat pipe is welded through the iron-nickel disc.
It is held in the glass tube by two stainless steel supports.
The heat pipe operates up to a 2° slope.
By turning the tube, it is possible to change the orientation of the absorber. This orientation must not be greater than 25° from the collector plane.

Absorber characteristics	**Description**
Material and thickness	cooper - 0,12 mm
Absorber dimensions	1980 x 63,7
Selective coating	Classic Tinox
Absorption	0,95 ± 0,02
Emissivity	0,04 ± 0,01
External diameter and thickness of tube	Ø 10 mm x 1 mm
The bulb dimensions	Ø 22 mm x 65 mm (useful part)

Table 42: Absorber characteristics.

3.1.2. Storage tank

The SHEMSY solar water heater (prototype) is available in one volume.

- **Internal tank**

The tank consists of a cylindrical body and two curved bottoms. The two domestic hot water fittings are welded to one of the convex bottoms. The inside of the tank is made of stainless steel, while the outside is insulated with polyurethane.

The tank's cylindrical body is made of sheet steel INOX 304, of thickness1.5 mm the domed bottoms and the cylindrical body of the tank are made of sheet steel INOX, of thickness 1.3 mm.

• the two tanks (star and star+) are similar with an inside diameter of 370mm, while their lengths are 1300 mm for the 200L capacity.

• A steel flange is pre-assembled at the factory. The flange is fixed to the tank using 5.8 galvanized steel screws. The flange joint is made of EPDM 268. The flange can be removed to install an electrical auxiliary heater.

• The tank is always installed horizontally and above the collectors.

- **Auxiliary heater**

If an electrical auxiliary heater is required, it is possible to substitute the tank's standard flange by a power resistance adapted to the storage tank volume and its management mode.

If the power delivered by the auxiliary is more generous than 1000 W, this power shall not exceed:

- 12 W/liter (relative to the total volume of the storage tank).

If the top-up is managed by a manual rearmament system to limit the time, with a maximum of 3 hours, the operation of the top-up,

- 12 W/liter if the auxiliary heater is controlled by a clock or a controller which allows its use in hours of the night only (from 22 hours to 6 hours),

- 6 W/liter in the absence of the top-up management devices mentioned above.
•the resistance for this SHEMSY solar water heater (star and star+) has a power of 1.5 kW, insert with a diameter suitable for the flange (44mm)
• The electrical auxiliary heater is supplied at 230 V and has a thermostat.
It is inserted into the flange. The setpoint is preset at 60°C, and the cut-off safety is 105°C.
• The electrical auxiliary heater is placed inside the tank, and the entire block is mounted in the intended position on the tank located at the bottom of the storage tank.
• The auxiliary device complies with EN 60355 parts 1 and 2 and LVD (Low Voltage Directive) 2006/96/EC).

- **Insulation**

• The thermal insulation of the tank is made of polyurethane.
The injection takes place at high pressure in a mold. The dosing and mixing of the two components that make up the polyurethane foam (polyol + iso-cyanate) are checked systematically.
• The insulation thickness adopted for tank of 200L (star and star+) is 40 mm.
• This minimum insulation thickness of the flask can be estimated for other volumes, which will be the subject of another future SHEMSY variant. For example, for a tank of 300L with the same characteristics previously mentioned is 55 mm.
• Insulation density is 46 kg/m3.
• The thermal conductivity of the insulation is 0.0235 $W.m^{-1}.K^{-1}$.
• Fire classification according to EN 13501: F.

- **Outer envelope(jacket)**

The tank's outer coating is made of a 0.2 mm thick painted steel sheet, coated with a prior application of 35 µm thick RAL 7035 paint.
The same outer shell material covers the ends of the tanks. It is made of painted steel with a thickness of 0.2 mm.
If necessary, this cover can be removed to mount the electrical resistance.
PA6 seals are mounted around the two solar connections. Finally, blue and red polyethylene collars are placed around the two cold and hot water fittings on the tank's side.

- **Protection against internal corrosion**

The inside of the flask is made of stainless steel due to its high resistance to corrosion. Its ability to not regulate chemically by presenting a sanitary safety for limestone water and a magnesium anode prevents corrosion due to currents galvanic.

3.1.3. Support and attachment elements to the supporting structure

The supports are made of DX51D steel components that are Covered with a metal coating ZM195 (Magnélis) composed of an alloy of zinc, aluminum, and magnesium with a minimum thickness of 14 µm/face.

- **Sloping roof**

The collectors and the tank's load-bearing structure consists of 2 mm thick rails (Z-shaped cross-section view), 1.5 mm thick tank support, and 2 mm thick collector(s) mounting brackets.
DX51D steel and are covered with a metal coating ZM195. And blue paint.
These elements are fixed by means of M8 screws in 8.8 steel with zinc and nickel coating with a minimum thickness of 7 microns.
The size and number of components may vary depending on the system's capacity and area to be installed, but the installation procedure remains the same.
Installation kits include the following:
- "Z" cross-section support rails,

- support for tank,
- collector mounting bracket,
- M8 screws made of zinc-plated nickel-plated steel,
- M8 zinc plated steel nuts,
- M8 washers made of zinc-plated nickel-plated steel,
- M8 cage nuts in stainless steel A2,
- M8 x 20 stainless steel bolts A2,
- double threaded screw EJOT JA3-SB8.0x80/50FZD diameter M10 in stainless steel A2.

- **Flat roof**

The supporting structure for installations on flat surfaces inclines 30-45°. It is made up of columns of an average thickness of 2 mm, supporting the tank and rails of average thickness 2 mm, supporting the solar collectors. These components are made of DX51D steel and are covered with ZM195 metal coating. The uprights and profiles are fixed together using M8 8.8 steel screws with zinc and nickel coating with a minimum thickness of 7 microns. The screws for securing the supports to the concrete strip are not provided. The system must be fixed to the load-bearing structure using 12 A2 stainless steel M8 screws, each with a minimum pull-out resistance of 5 kN. The dimensions and number of components may vary depending on the system to be installed, but the installation procedure is always the same.
Installation kits on flat surfaces include the following:
- transducers supporting the collectors,
- support posts for tanks,
- collector mounting bracket,
- shear bar,
- M8 screws made of zinc-plated nickel-plated steel,
- M8 zinc-plated steel nuts,
- M8 washers made of zinc-plated nickel-plated steel,
- M8 x 20 bolts in stainless steel A2.

3.1.4. Safety devices and accessories

The system circuit must include a safety valve set to the maximum operating pressure of the tank, and in all cases less than or equal to 7 bar.
Hoses, pipes, hydraulic system accessories, pontets.

3.1.5. SHEMSY's products summary

Storage tank		
	SHEMSY	**SHEMSY+**
volume	200 L	
reservoir (INOX 304 L)	Longueur : 1624 mm Diameter : 450mm Thickness: 0.7 mm	Longueur : 1624 mm Diameter : 450mm Thickness: 1.5 mm
Isolation (Polyuréthane / 40 kg /m3/0.0024W/m.K)	Thickness: 40 mm	
jacket (acier peinté)	Thickness: 0,2 mm	
Revêtement extérieure (jacket) (époxy)	0.4 mm hot-bonded	
Piquage eau froide/chaude	Located at the right-left ends of the horizontal tank	
Intégration de l'anode en magnésium	diameter: 30mm	
Résistance électrique	1,5 KW/ 230 v ;Diameter: 44 mm	
pression de service	Max 2 bars	Max 7 bars

Table 43: SHEMSY's products sumary.

4. SHEMSY' SWH performances.

The performance assessment and the prototype's functioning prediction were made first concerning the climatic conditions of Fez's city (climate zone 3). Once the performances are validated, the simulations were made on all the Moroccan climatic zones to estimate the solar fraction, the system efficiencies (thermosiphon solar water heater with vacuum tubes), and the hot water produced temperatures. To define how well the Solar shemsy water heater can meet the needs estimate at 200L per day for residential consumption. The simulations were conducted over a typical one-year period to visualize the system's behavior under the favorable conditions and adverse stresses representing the summer and winter periods.

The simulations were based on the weather files generated by the Meteonorme software. The Fig.82 and 83 give an overview of the conditions displayed for Fez's city in terms of temperature and overall incident irradiation on the horizontal plane. It is noted that the maximum of the temperature displayed does not exceed 3O°C. In contrast, in this zone, the temperatures in summer can reach 45-46°C, and the same for irradiations, representing a value much less than the real value; this deviation can be noticeable due to the software's prediction programs representing a margin of error. From there, we can conclude that the simulations are carried out under very unfavorable conditions to be impacted by this error of the meteorological data. It will not reflect the reality of the operation. The results presented in this section are much lower than the actual results and values of the SHEMSY system's operation.

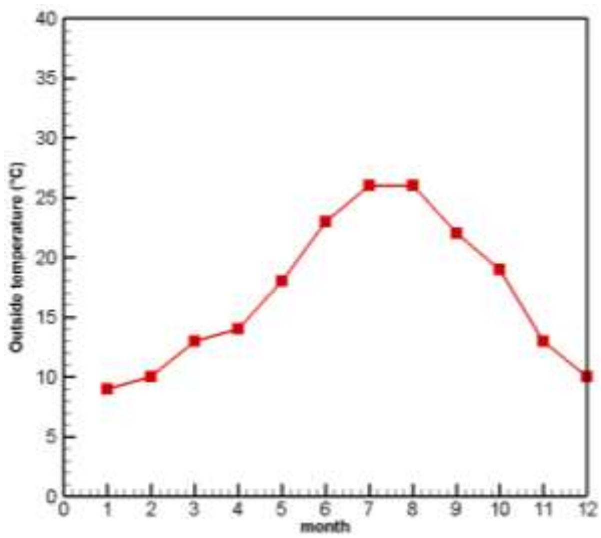


Figure 83: the outside temperature (Fes/zone 3).

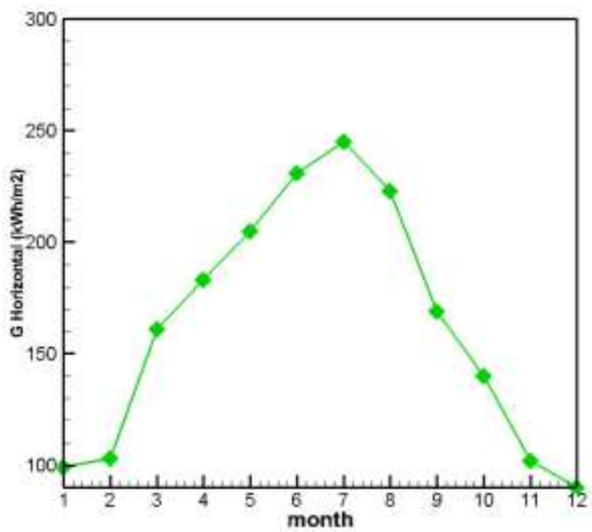


Figure 82: the horizontal incident radiation kWh/m^{2}.

Fig. 84 represents the resulting solar fraction for the city of Fez, representing an annual average of 80% over the typical simulation period. It falls between a minimum of 62% in winter in February. And a maximum of 99% in summer in July and August. These results are very satisfactory under unfavorable climatic conditions, as mentioned in the screen.

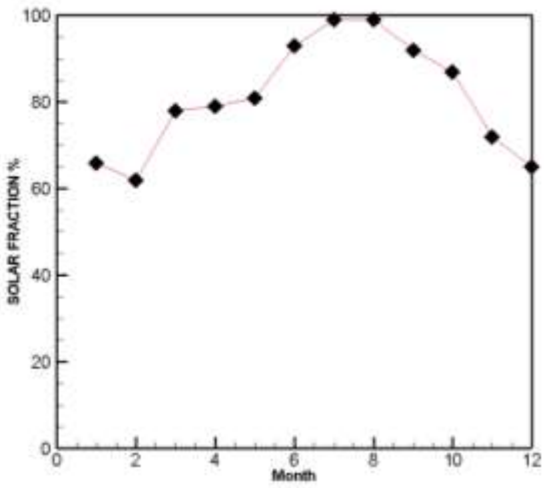


Figure 84: the solar fraction Fes case study (zone 3).

Fig. 85 describes the SHEMSY system production profile (Green line) and the demand under 200L per day requirement (red line). According to the graph, the total annual production of the SWH is estimated at 2116 kWh. The demand is 2211 kWh/year, representing an acceptable deviation of 95 kWh, which will be compensated by the auxiliary heating system. The maximum demand is identified in January with 219 kWh value against only 163 kWh as production. This result is reversed in summer, where production is estimated to be much higher than demand, whereas, in August, production is 205 kWh against a demand of 160 kWh. These two indicators (demand and production) intersect in two periods of the year: in May with a demand of 170 kWh and a production of 171kWh, and October with 190 kWh produced and a requirement of 184kWh. These two periods represent the most optimal operation without auxiliary heater consumption and loss of energy encountered in the summer due to the low demand.

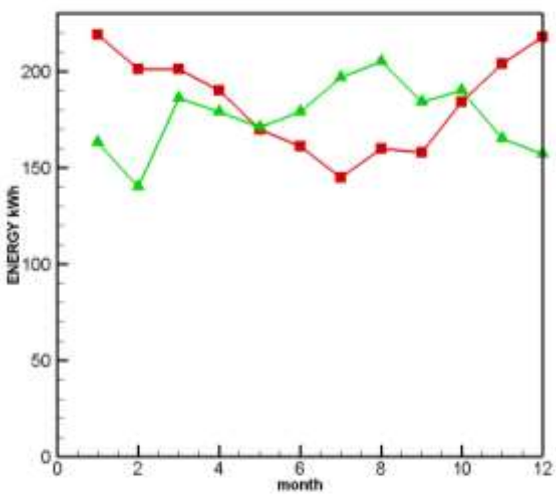


Figure 85: energy production VS requirements (fes/Zone 3).

Fig. 86 shows the set of heat losses produced at the collector level, which is a critical indicator that affects the system's overall redaction. The total loss is estimated at 885 kWh over a representative year. This value is spread over all months. The loss profile follows the production of the system in line with the production of the system; the maximum production is recorded as losses concerning the other periods of the year and vice versa. The figure shows that the minimum losses are recorded in February with a 60 kWh value equivalent to the production minimum over the year. Maximum losses are estimated in July and August, with a monthly total of 80kWh.

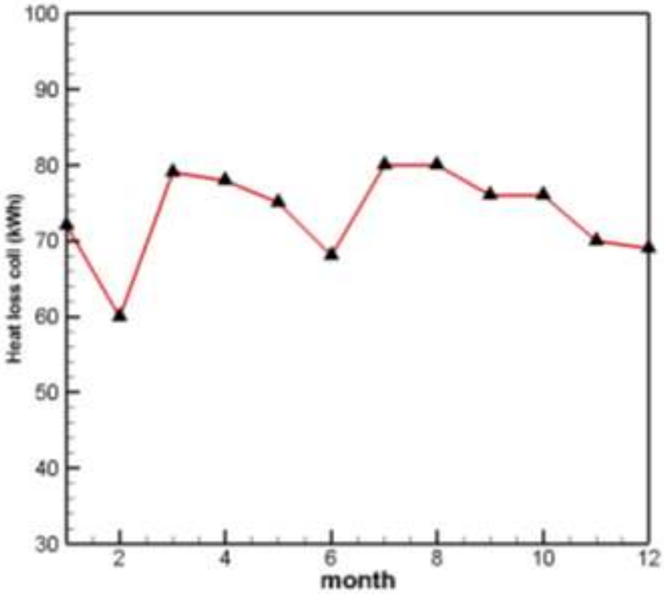


Figure 86: Heat loss on collector (fez).

The collector's optical losses are shown in Fig.87 this indicator directly reflects the optical efficiency of the solar thermal collector. They follow the profile of heat losses previously treated with the same speed and the same monthly developments. A minimum of 57 kWh is also recorded in February, and a maximum in August of 87 kWh. The annual total loss is estimated at 877 kWh.

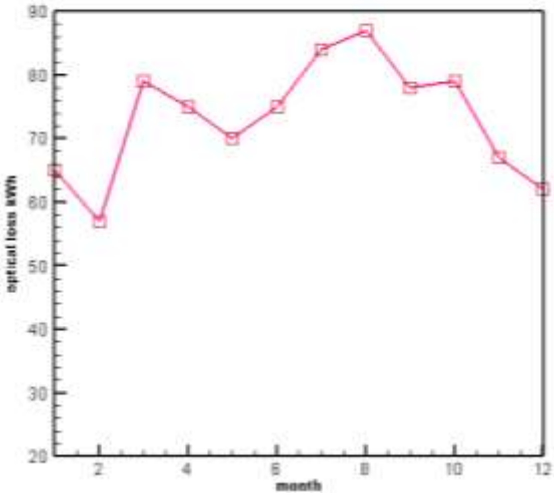


Figure 87: optical collector loss (Fez).

The hot water temperature is also represented according to the overall irradiation received. Fig. 88 Shows that with the increase of the irradiation, the hot water temperature also increases. The increase in hot water production explains once the radiation is intense. There are some fluctuations in the graph explained by other causes of system operation, which can cause losses, namely the system's components, the profile of hot water consumption. Nevertheless, also, the outside ambient temperature can affect this indicator.

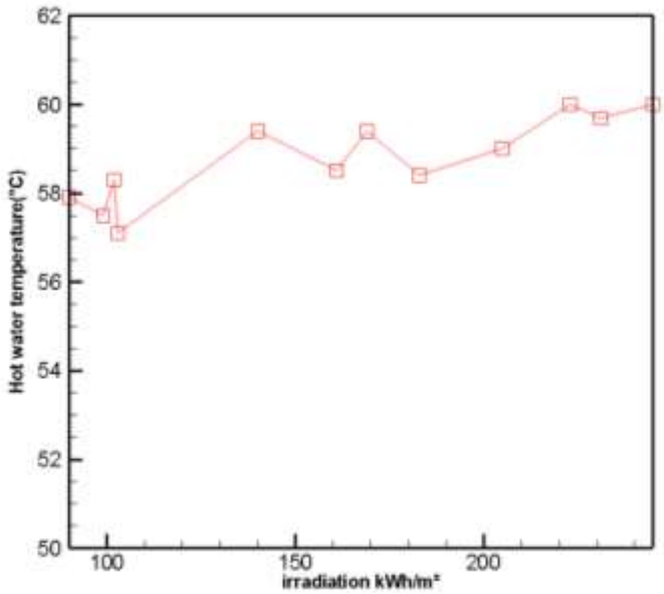


Figure 88: hot water temperature variation / irradiation.

The system's operation results in CO_2 remissions reductions; the figure shows the CO_2 avoided monthly over a representative year. The annual total of emissions avoided is estimated at 1940 kg. The maximum CO_2 emissions avoided are recorded in August by a quantity of 182 kg. The monthly average avoided by the installation of the solar water heater SHEMSY is 161 kg.

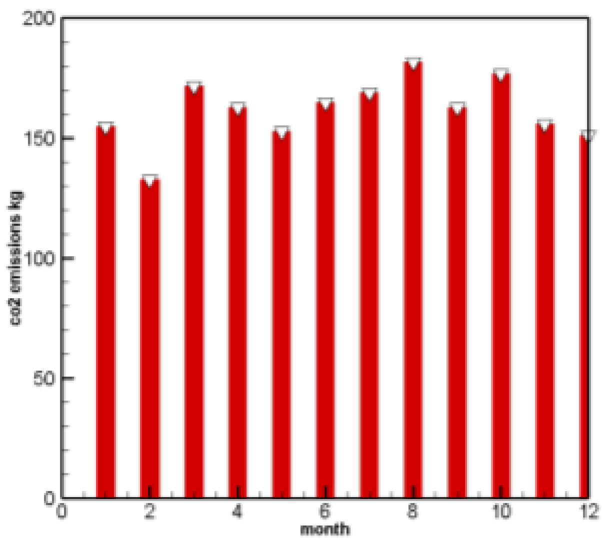


Figure 89: CO_2 emissions avoided in fes.

The system's performance assessment is also carried out on the six Moroccan climate zones to study the adaptability of the product to the local climate context. Fig.90 shows the variation of the solar fraction of the system over the six zones. We note the same trend of monthly variation on all the locations studied; the difference is identified only at the level of values is c is due to the diversity of the climate in Morocco from the warmest zone Z6 to the coldest Z4. Overall, the system's solar fraction varies 76% as the national average minimum in zone 4(Ifrane), and 92% as the maximum in zone 6(Er-Rachidia). The other zones guarantee operation with FS of 86%, 83%, 80%, and 89% for Agadir, Tangier, Fez, and Marrakech. At the national level and during the summer period, the system can operate under a minimum solar fraction of 57% in February for Ifrane. A maximum of 100% in Tangier Marrakech and Er-Rachidia during the summer (June, July, and August). The total national average for the SHEMSY water heater is estimated at 84.6%. These results are very satisfactory, which validates the feasibility of integrating this product into the Moroccan market from a technical point of view, recalling that the simulations were made under the most unfavorable conditions when in reality, we can have better.

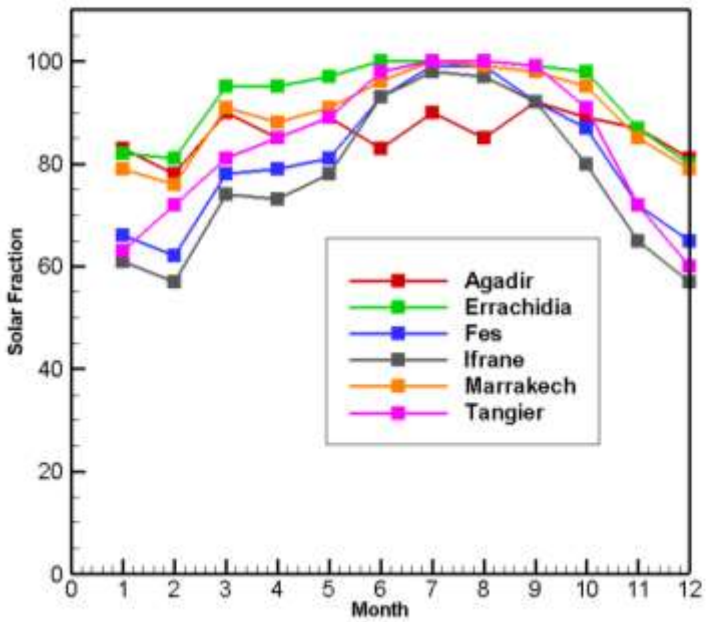


Figure 90: SHEMSY's solar fraction for the six climatic zones in Morocco.

Hot water temperature

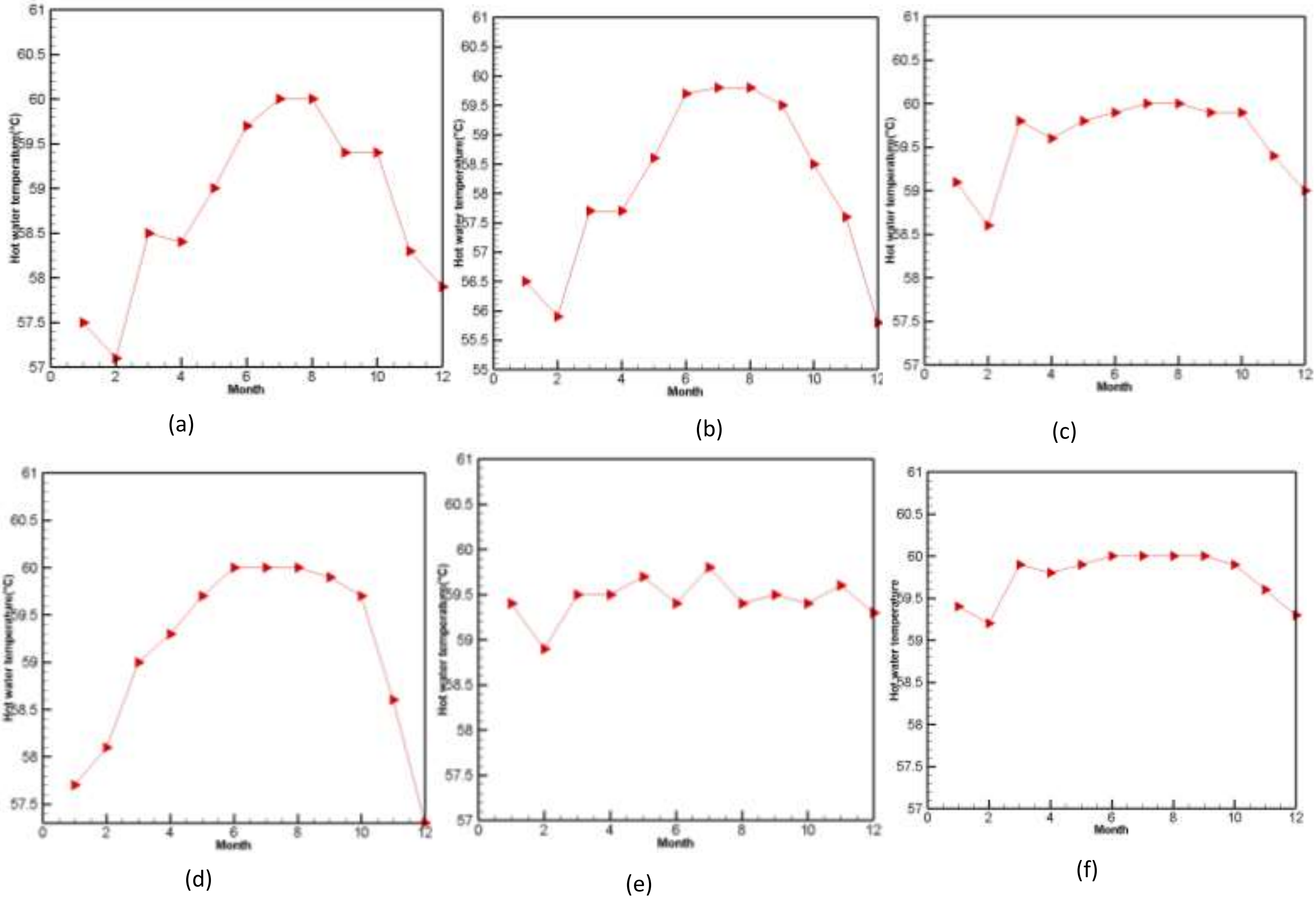


Figure 91: hot water temperature (a)FEZ(b)IFRANE (c)MARRAKECH (d)TANGIER (e)AGADIR (f)ER-RACHIDIA.

Fig. 91 shows that the hot water is at a temperature satisfactory to domestic needs in all zones. At the national level, the hot water is at an average temperature of 59°C, adequate to the 60°C requirement set at the simulations' start. The minimum temperature that water can reach is 55°C in the coldest Moroccan zone (zone 4: ifrane) in December and February.

The maximum temperature reached corresponds to the set temperature of 60°C; the water reaches this temperature in 4 different zones (errachidia-fes-tanger-marrakech) in July and August. In contrast to errachidia the system ensures this temperature from July to September. In the rest of the zones, the summer period's temperature shows excellent values presupposes equal to the set (59.8, 59.7...).

The graphs' appearance is preset identical in all the zones, except that there are some minimal fluctuations of difference explained by the difference of the climate. The minimum temperature record period is common between all zones (February) except tangier (Z2); the minimum temperature is recorded in December.

Solar contribution to DHW

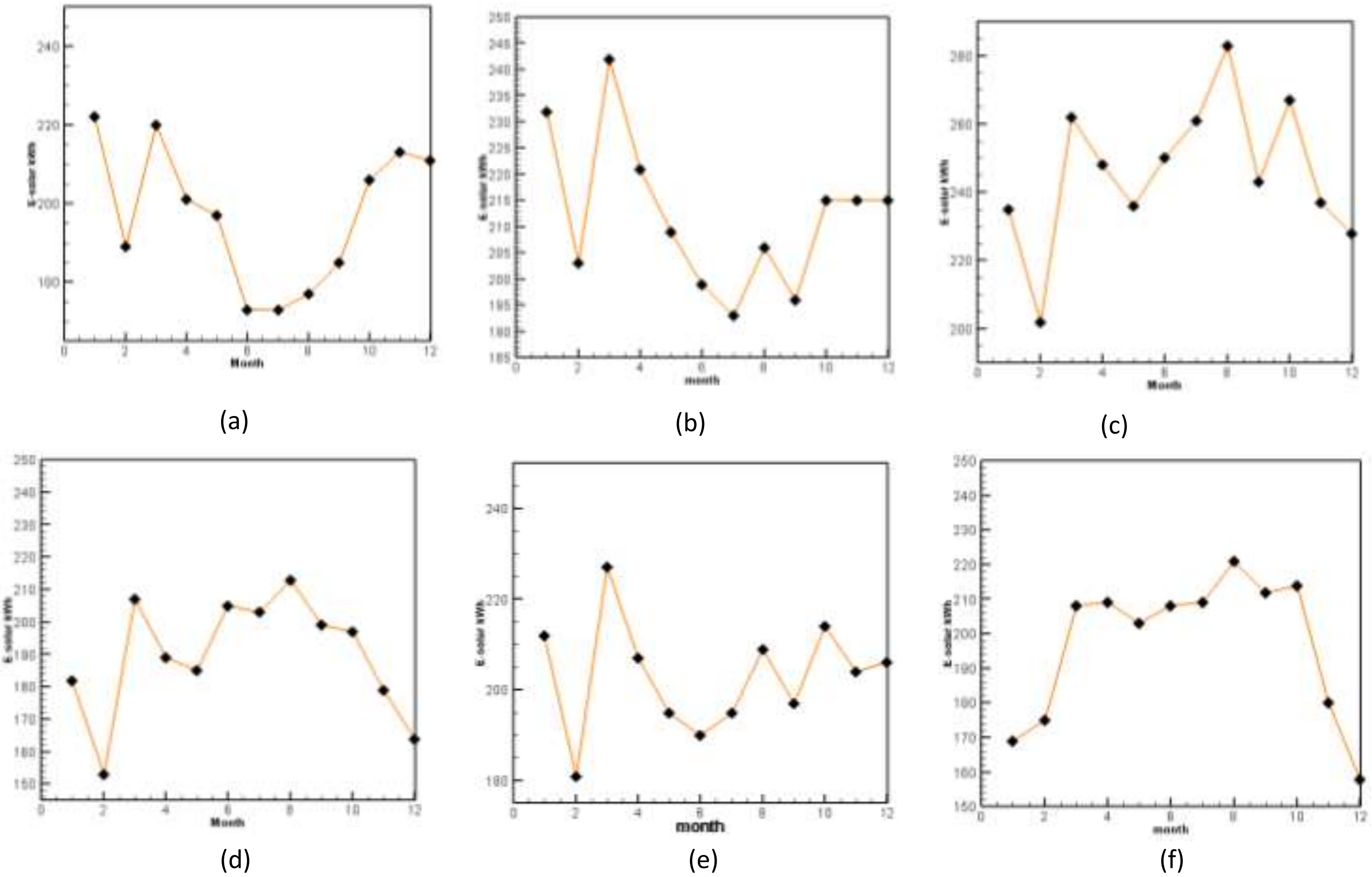


Figure 92: the solar contribution.(a)agadir(b)errachidia(c)fes(d)ifrane(e)Marrakech(f)tangier.

Solar contribution is the direct indicator of the solar fraction, which is the first performance indicator for any solar system.

The overall average annual contribution is estimated at 2382 kwh, with a minimum average contribution of 2276 kwh/year to Ifrane and a maximum of 2545 kwh/year to errachidia.

The minimum monthly average is 189 KWH at Ifrane, and the maximum is 212 kwh at errachidia.

The minimum required value is 153 kwh in zone 4 always, and the mawimum is 215 kwh.

The solar contributions explain the results of the solar fraction and the demand previously presented, which will be supplemented by the presentation of the auxiliary heating system's consumption.

The shape of the curve of solar energy and its proximity from one zone to another shows the same points of fall and increase. It is explicated by the Moroccan climate's harmony and very different values passing from zones with a freezing climate to very hot Saharan zones (zone 6). Tangier has a somewhat particular climate with a small difference, which explains the differentiation of its appearance. Tangier's climate is of Mediterranean type, tempered by the oceanic influence: Autumn, winter, and spring are mild, see cold and very humid. In inter-season, moderately rainy. Summer quite hot (30 degrees during the day) and dry.

Auxiliary heating consumption

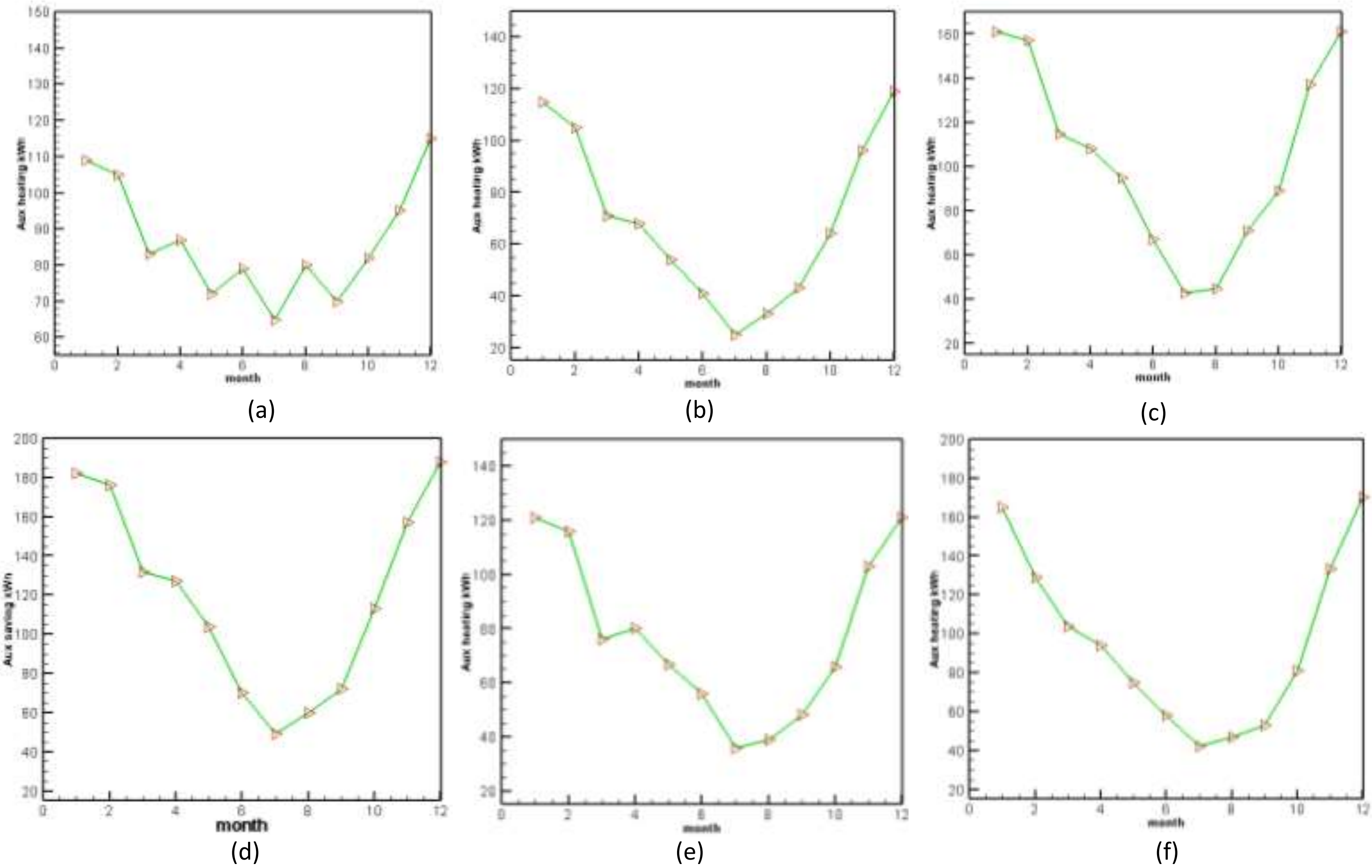


Figure 93 : auxiliary heater consumption (a)agadir(b)errachidia(c)fes(d)ifrane(e)Marrakech(f)tangier.

When the solar contribution does not meet the energy demand necessary to satisfy the needs of hot water at a temperature of 60°C, the auxiliary heating system starts to allow to incubate 100% of the needs. Fig. 93 shows the change in consumption of the auxiliary system during the typical year of the simulation. Note that the curve pattern for the six climatic zones is similar, a maximum consumption recorded in winter and a minimum in the summer, which represents the inverse of the solar contribution curve pattern to create a harmony of the system as a whole that meets the satisfaction of the consumer’s demands, which increases in winter. The figure shows that the overall annual average consumption is 1106 kWh. The maximum of this average is 1430 kWh recorded in zone 4 (Ifrane). A minimum where one has a maximum of needs satisfaction by the solar; at errachidia with a value of 834 kWh.

The maximum monthly average consumption of the auxiliary system is 188 kWh in December, and the minimum average is always errachidia during the summer period: 25 kWh.

The consumption of the auxiliary system is present throughout the simulation, we winter because of the unfavorable climatic conditions (cloudy days), and in summer during the nights. The differences in the fluctuations of the curve between increases are falls and are explained by unique weather differences for each zone.

Energy savings (electricity)

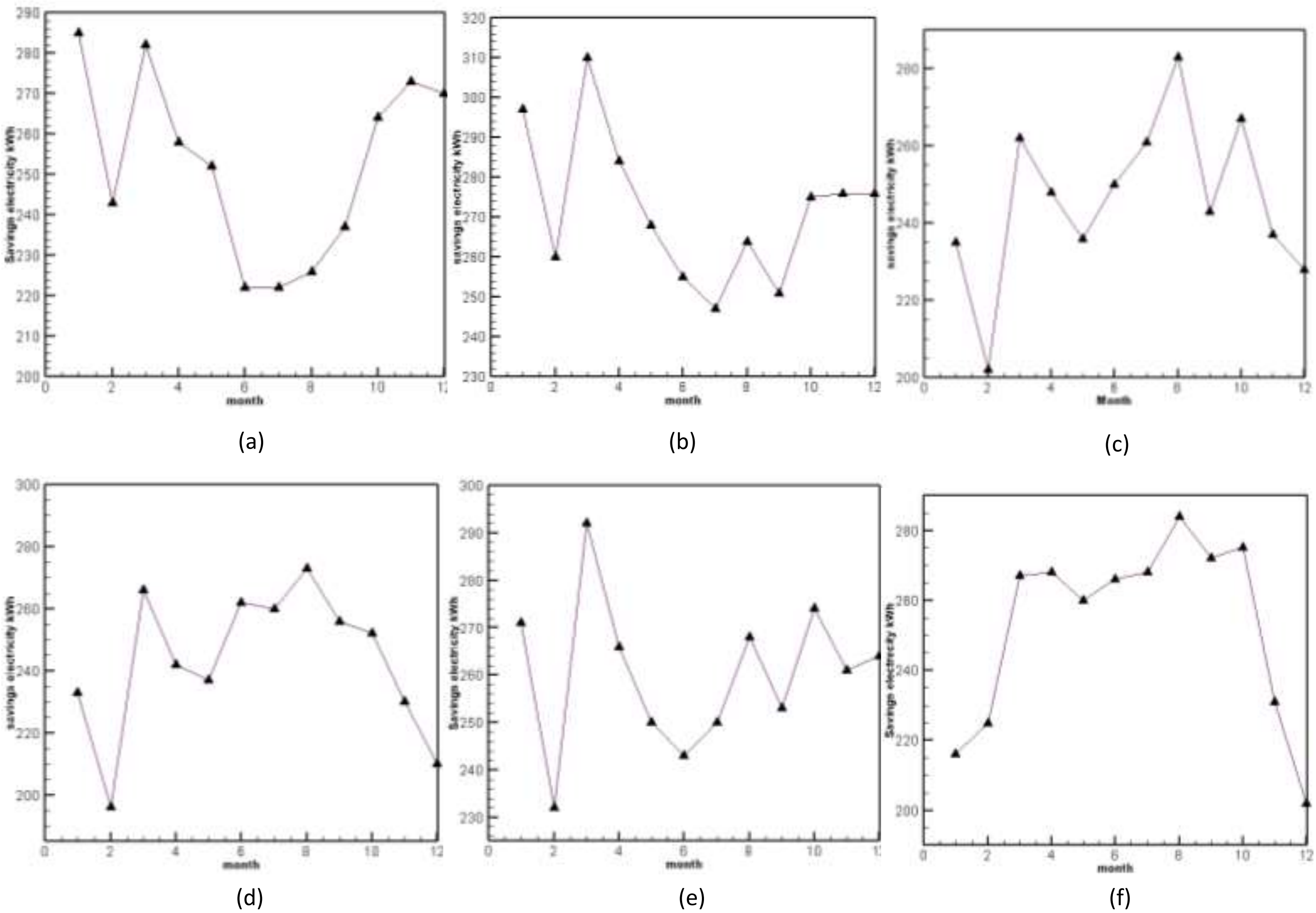


Figure 94: Energy savings (kWh) .(a)agadir(b)errachidia(c)fes(d)ifrane(e)Marrakech(f)tangier.

The integration of a solar system leads to significant economic and energy gains. Fig. 94 shows the variation in energy gains, considering the reference system an electric water heater. The annual average of estimated energy gains is 3054 kWh. The maximum average recorded is 3263 kWh (zone 6), and the minimum is 2917 kWh (zone 4). Zone 1 represents an annual average of 3,035 kWh, with a maximum monthly average of 285 kWh in winter, and a minimum of 222 kWh for the entire slope. Zone 2 has a total annual average of 3034 kWh. With monthly gains varies in an interval of 202-284 kWh. 2951 kWh generated as energy gains in Zone 3; This represents the sum of the monthly averages, which varies over the whole representative year from 202 to 283 kWh. Zone 4 and 5 represent an annual total of 2918 and 3124 kWh, respectively. These two zones define two contradictory weather conditions between the coldest zone of the Moroccan climate zoning and a hot zone Z5. The monthly minimum in these areas is 243 ET 196 kWh. Moreover, the maximum is 268 kWh Z5 and 266 kWh Z4.

The results obtained represent very encouraging values that describe a properly functioning system, adapted to the entire Moroccan climate zoning, and generate significant gains.

5. *Development of an experimental plat form for research studies*

The system is the subject of a didactic bench and research platform in the field of solar thermal. This installation aims to study in experience solar thermal systems with different configurations and technologies to validate the theoretical and numerical studies and properly study and dissect the functioning and the different physical phenomena acting in this system.

By characterizing the systems and operation by experimental studies, which are essentially based on the systems:
- Forced circulation solar thermal.
- Thermosiphon effect thermal solar.

The present systems include the two types of thermal solar collector technologies, namely:
- Flat plate glass collectors.
- Vacuum tube collectors

5.1. System description

This solar water heater presented is, in principle, a system with forced circulation and electrical backup, which makes it possible to study an instrumented solar thermal production system.

The hydraulic system reproduces a simple installation with a hot water tank and connects to a circulation pump.

The installation is equipped with a transfer unit that ensures the circulation of the heat transfer fluid from the collectors to the storage tank safely thanks to the included accessories; safety valve, expansion tank, regulation, etc. etc.

The temperature collector data is recoverable on a PC and stored, from where the installation is connected with a laboratory controller that allows to control and manage the operation and collect and record the different parameters of control and follow-up of the installation.

The installation represents a set of variable configurations and parameters by presenting a flexible model with multiple studies and research guidelines.

4.1.1. Educational Objectives

The facility aims to tackle scientific issues according to different guidelines:
• Study the physical principles of solar thermal.
• Study installation performance in different configurations.
• Study solar thermal collector technologies (plane and vacuum tube).
• Study the hydraulic system.
• Perform commissioning and maintenance operations.
• Study the thermal regulation system.
• Interpret the measurements:
o Thermal Balance,
o Economic Review.
o … etc

4.1.2. Technical description

The installation consists of:
- two solar thermal collector technologies (plans/vacuum tube).
- An electrically assisted solar tank.
- Hydraulic components of the primary system (expansion vessel, circulation pump, pressure gauge, thermometers, safety valve, release valve, non-return valve, etc.).
- Hydraulic components for connection to the service water inlet (ball valve, safety valve, non-return valve, pressure gauge).

- Hydraulic components for connection to an external integration circuit (not provided).
- temperature collectors.
- an energy meters.
- a flow meter (water demand).
- a commercial controller.
- SHEMSY controller for laboratory
- SHEMSY energy meter.

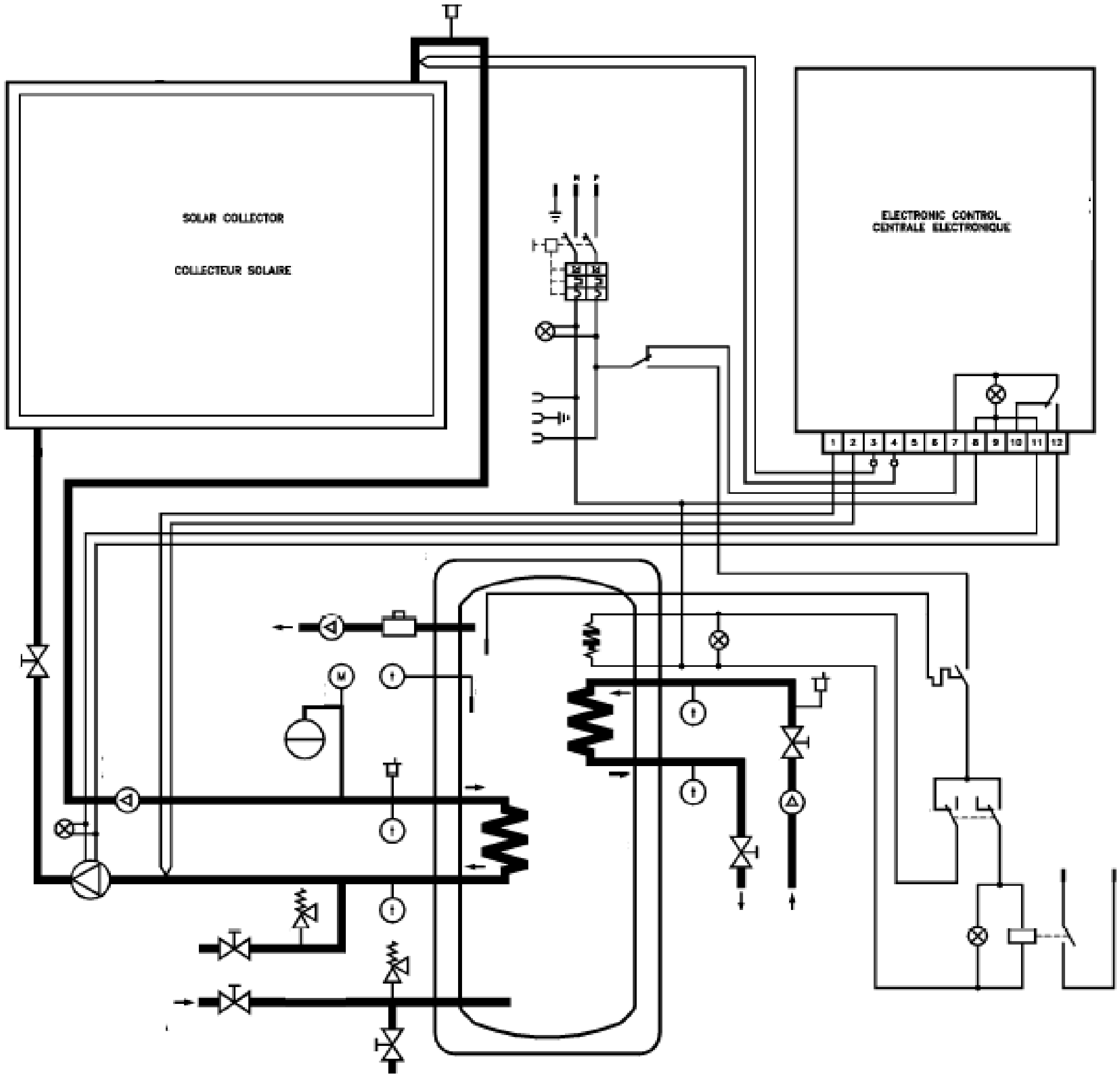


Figure 95: the experimental installation developed.

4.1.3. Functioning

The installation presents a didactic bench of a solar water heater with forced circulation. In this installation, the water that flows between the collector and the accumulator cannot do it by natural convection since the hot water (collectors) is at its highest point. There is no natural force that moves the cold water already at the lowest point and is the heaviest; This requires a conventional electromechanical circulator, used in heating circuits, to ensure the fluid's circulation. A forced-circulation solar water heater comes from an installation in which a pump or fan is used to circulate the heat transfer fluid in the collectors.

A heat exchanger allows heat transfer from one fluid to another. In a solar water heater, the heat exchanger allows heat transfer from the heat carrier in the primary circuit to the domestic hot water in the storage tank.

The Circulator (pump) drives the liquid (usually from the bottom of the accumulator, from a cold zone) to the solar collectors' bottom.

The forced-circulation solar thermal system presented has the following elements:

Solar collectors

As in these assemblies, the fluid flow through the collector is forced, pressure losses are not a significant extreme condition in terms of value. The crucial element is to know the pressure drop needed to select the circulator. In this installation, two solar thermal collectors are chosen (the flat plane and the vacuum tubes). The choice of the two types allows the study of these two technologies by presenting several configurations to focus on each one and combining them to vary the cases studied.

Accumulator

This mounting makes use of the force to variations in the accumulator. Since the circulator will pass the integrating water exchanger for the installation with the fixed volume of accumulation, the storage tank allows keeping the water at the desired temperature due to its insulation. Ensure the water's heating by an internal exchanger that promotes the heat transfer between the heat carrier fluid and the water to heated.

Control System

On forced circulation computers, we must control the pump so that only the water readers when there may be energy gain (sometimes do Sol and, therefore, the fluid temperature collectors exceed the accumulator). The unit responsible for this is the differential thermostat, which continually compares the collector temperatures and the tank to connect or disconnect the pump depending on the higher temperature.

security

To protect the overpressure collectors, installing a safety valve (VS) in each group or a row of collectors was mandatory.

On the other hand, the primary circuit will be equipped with a safety group consisting of at least: an extension (VE), a safety valve, and a pressure gauge.

4.1.4. Components technical characteristics

Solar collectors

The installation comprises two types of solar thermal collectors.

- **Un capteur plan « FCS 2 nouvelles générations »**

collector with test ratio: UNI EN12975

Solar collector marked Solar Keymark and certified CSTBat

One-piece sealed case (perfectly sealed).

The glazing is secured with an EPDM seal.

Laser-welded full-surface absorber. It has tempered glass and anti-reflection.

Area	2,09 m²
Inlet area	1,78 m²
Absorption area	1,87 m²
Dimensions (L x l x h)	2032 mm x 1031 mm x 94 mm
Weight	32 kg
Absorber volum	1,4 L
chest	Expanded aluminium sheet with protection sheet
Material	Aluminium AIMg3
color	Aluminium
Absorbrs	

Aluminium sheet with highly selective coating 0.4 MM. Copper tube Ø 8 mm x 0.54mm thickness Flat fitting DM 3/4'. Full surface profiled absorber, collector and tubes are welded together and then welded to the absorber plate using a laser process.	
Coating Highly selective	Absorption 95 % ± 2 %, emissivity 5 % ± 2 %
Glass type	Tempered solar glass (ESG) thickness 3.2 mm without iron, anti-reflective
Transmission Coefficient	90,6 % ± 2 %
Glass dimension (L x l)	2000 mm x 1000 mm
Overall solar panel footprint	2032x1031x94
Extruded, UV-resistant, glue-free EPDM glass gasket (shore 70)	
Isulation	Rock wool 40 mm, even 9 mm on the sides (without spraying)
Heat transfer	0,035 W/mK
Insulation density	50 bars/kg/m²
Recommended flow rate	15 à 40 l/h/m²
Maximum operating pressure	10 bars
Stagrantion temperature	199°C
Liquid type	glycol and water 40/60%
flanges	Black ABS - Hold the manifold and create thermal separation with the trunk
Labelling	UV and weather resistant silver polyester sticker
Raccords 2	Diameter 3/4'
Assembling	Pressure with EPDM seal, frame.

Table 44: technical characteristics of FPC.

- **Evacuated tube collector with heat pipe**

characteristics	
Operating pressure	10 bars
Stagnation and operating temperatures	1000w/ m²°c < 220°C
Collector dimensions	250 x 200 cm
Tube dimensions	58 – L 180 cm
Tubes numbe	20
Catchment area	2,52 m2
Verre 3,3 borosilicate résistance aux chocs de grêlons	25 mm
Absorption coating	Nitrite de cuivre
Absorption	> 92 %
Emittance	7%
Heat loss	< 0,35 w /m².C°
Tube insulation	P< 0,0005
exc hanger insulation	Polyuréthane
Optical performance	ηo = 0.7
Thermal loss coefficient	K = 3.9 w /m²K
Dimension des caloducs	L 100mm ⃠27mm
Supports	Alliage Aluminium 250-200
Inclinaison	10° à 90 °

Table 45: ETC technical characterestics.

<u>Hydraulic chassis</u>

- **Solar storage tank: double exchanger with 2 kW auxiliary heater.**

A tank with heavy-duty industrial construction, with a shape that optimizes the phenomenon of water stratification.
Heavy steel construction
Double Thick Hot Enamel
Internal ECS flask coated with vitrified ceramic.
Total insulation 10 cm polyurethane

Two high capacity exchangers
Electrical resistance with double-cut thermal circuit breaker
Zinc anode at the top of the flask (easy change)
External anode tester.
Thermostat adjustable from 30 to 90°C.
One glove finger for temperature probes.
Bolted access hatch.
External temperature gauge.
Domestic hot water storage is connected to a solar system. Heating and hot water tank (2 in 1) including a domestic hot water tank «bain-marie» inside). more compact, more straightforward, and more economical.

BCS 800	
Capacity	800 l
Tampon capacity	600 l
Hot water capacity	300 l
diameter nu/ avec insulation	790/990 mm
height	1910 mm
Mounting height	2020 mm
Internal serpentin S1 (solar loop)	
area	2,9 m2
capacity	17,9 l
Second serpentin S2	
area	1,8 m2
pacity	11,1 l
Iseful power/max, serpentin temperature	16/110 bar/°C
Useful pressure/ tampon temperature	3/95 bar/°C
Useful pressure /hot water time	10/95 bar/°C
Auxiliary heater connected to tampon	15-27 kW
Finger glave for collector 1/2"	570 A
Electric Auxiliary heater	920 B
Finger glave for collector 1/2"	1290 C
Purg 1/2"	1910 D
connexion 1'1/2	1573 E
Inlet serpentin 1"	1390 F
Finger glave for collector 1/2"	1290 G
connexion 1'1/2	
Outlet second serpentin 1"	1072 I
connexion 1'1/2	980 J
connexion 1/2'	
Inlet serpentin 2	820 L
coupling	170 P
recirculation	Top flang
Outlet hot water 1''	Top flang
connexion 1''1/2	Top flang
Inlet cold water	Top flang
protector anodique 1''1/4	Top flang
weight	237 kg

Table 46:storage tank technical characteristics.

- **Hydraulic system with circulation unit and expansion vessel**

Transfer group for solar installations, start and return connection is composed of:
- Grundfos Solar 15-80 circulator;
- 253 series solar safety valve;
- 2 fill/drain valves;

- accessory pole with pressure gauge;
- flow meter;
- air separator with manual drain screw;
- start thermometer;
- return thermometer;
- 2 shut-off valves with a check valve;
- 2 teat connections;
- preformed insulation shell

characteristics	
Alimentation	230 V (~).
Maximum operating pressure Pmax	10 bar.
Temperature range safety valve	-30÷160°C
Safety valve tapping	6 bar (for other threads, see series 253 using adapter code F21224).
Temperature range balancing valve with flow meter	-10÷110°C.
Maximum percentage of glycol	50%.

Table 47: transfer group characteristics.

- **Circulation pump**

General characteristics	
Brand	wilo
model	RS30/7-3PL 180 6
type	Electrical circulator
kit	circulator,
pump	simpl
Hydraulic part	threaded body
Technical characteristics	
tension	1*230 V 50Hz
Max operating presure	10 Bars
Maximum flow rate	5,5 m3/h
Insulation class	F
Pretection index	IP44
Water temperature rang	(-10) °C à 110°C
Maximal ambient temperature	40°C
speed	2300/2650/2800 rpm
power speed 1	62 W
power speed 2	92 W
power speed 3	132 W
Centre distance	180 mm
filtering	2''
Motor protection	Not required (self-protected)
threaded piping connection	Rp 1 1/4
Pump body	Grey iron
wheel	Plastic
Pump shaft	Stainless steel
bearing	carbon, impregnated metal
weight	2,8 kg
European standards	EN 61800-3/ EN 61000-6-2 / N 61000-6-3

Table 48: circulation pum technical characteristics.

Electronic control system.

The control system includes the SHEMSY controller developed in the laboratory version adapted to the didactic installation, connected to the temperature collectors and the flow collector, has the resistance, according to an organized architecture of the different parameters to be measured.

The control is linked to an acquisition system and communication via the Internet, Operating Software that allows for data to be received and unlimited.

The energy meter

The system is equipped with an energy meter used to measure hot water flows through the pipeline and the water temperature differential between the inlet and outlet. Consumption is expressed in kWh.

Model 75525 CONTECA

Central data acquisition with a local reading by LCD or centralized on the controller code 755010, for solar installations.

Exercise max pressure of 10 bar

Temperature range 5-120°C

The maximum percentage of glycolysis 50%.

The CONTECA module includes:

- Two temperature probes for divers.
- Y-connections for plunger probes.
- Volumetric counter with pulse output (Tmax 120°C).
- Electronic integrator counter with LCD display. 24V /50Hz/1W power supply.

It Predisposed for Bus transmission RS485. Complies with EN 1434-1.

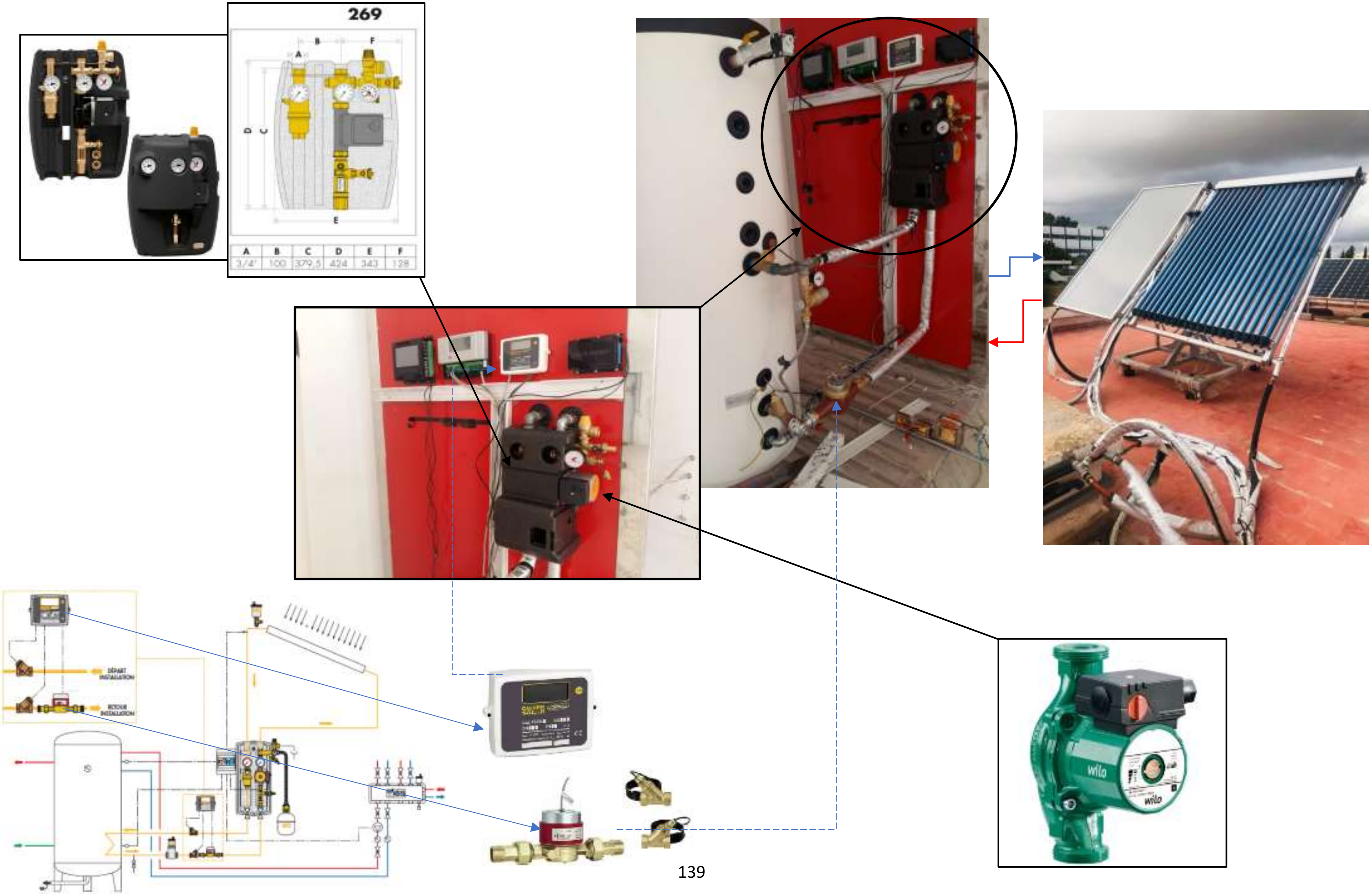


Figure 96: experimental installation(connexions and components).

5.2. Weather station

To complete the experimental installation, a weather station has been installed. The installation comes for the collection of real meteorological data justifying the operation of the experimental installation from a technical point of view and in connection with climatic conditions.

Figure 97: weather station- EST FES.

4.2.1. Components

- **Thermometer DS18B20**

The DS18B20 digital thermometer provides 9-bit to 12-bit Celsius temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. In addition, the DS18B20 can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply. Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1-Wire bus. Thus, it is simple to use one microprocessor to control many DS18B20s distributed over a large area. Applications that can benefit from this feature include HVAC environmental controls, temperature monitoring systems inside buildings, equipment, or machinery, and process monitoring and control systems.

Figure 98: DS18B20 .

Temperature and humidity collector and barometer: BME280

BME280 is an environmental sensor that integrates onboard temperature sensor, humidity sensor and barometer. The sensor is of high precision, multiple functions, and small size etc. It provides both SPI and I2C interfaces, which make it easy to make fast prototypes. It can be widely used in environmental monitoring, story height measurement and Internet of Things (IoT) control and so on. Gravity I2C BME280 Environmental Collector has based on

Figure 99:BME280 .

BoSCH newest MEMS collector (MicroElectro-Mechanical System). It is very stable to compare with other kind of collectors, especially the air pressure measurement, the offset temperature coefficient is ±1.5 Pa/K, equiv. to ±12.6 cm at 1 °C temperature change. Therefore, the stable and multi-function make BME280 become a good choice in many scenes.
Specification

- **Optical Rain Collector RG-11 Review**

Dreaming about a little device capable of measuring rainfall or closing a skylight when it starts raining? Recently I found an amazing Optical Rain Gauge introduced by Hydreon Corporation. The RG11 Optical Rain Gauge is a novel, futuristic and relatively inexpensive optical rain collector good for hobbyists and experimentalists, including those who need a sensor to trigger some electromechanical action when it starts to rain, as well as for more traditional weather monitoring applications. The RG11 senses water hitting its outside surface using beams of infrared light. It uses the same sensing principle used in millions of automotive rain sensing windshield wiper controls, and is suitable for almost any application that requires a reliable and sensitive rain sensor, including condensation sensing, irrigation control, drop detection, and wiper control.

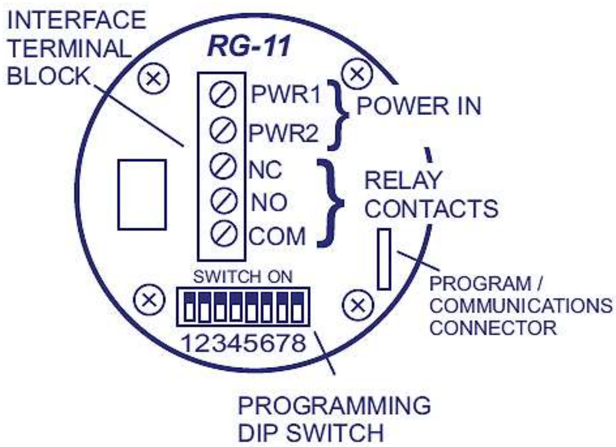


Figure 100 :Rain sensor RG-11.

Wind collector :Davis Anemometer

The Davis 6410 Replacement Anemometer includes both wind speed and wind direction sensors. Rugged components stand up to hurricane-force winds, yet are sensitive to a light breeze. These Davis Vantage Pro2 anemometers for sale include sealed bearings for long life. The range and accuracy specifications of this Davis Instruments anemometer have been verified in wind-tunnel tests (information available upon request). A Davis Anemometer reported wind speeds of 175 miles per hour before its tower collapsed during hurricane Andrew, 1992. Digital filtering, with time constant as specified below, is applied to wind direction measurements. In areas where icing of the anemometer is a problem, the included Anemometer Drip Rings deflect water from the joint between moving parts. The Davis 6410 is compatible with Vantage Pro and Vantage Pro2.Replacement anemometer with mounting base for wireless and cabled Vantage Pro2. Rugged components stand up to hurricane-force winds, yet are sensitive to the lightest breeze. Includes both wind speed and wind direction collectors, mounting hardware, and 40 ft. (12 m) cable.

Figure 101: Davis enemometer.

- **Light and irradiation collector**

TSL2561 Ambient Light Collector

The TSL2561 is a light-to-digital converter that transforms light intensity to a digital signal output capable of an I2C interface. Each device combines one broadband photodiode (visible plus infrared) and one infrared-responding photodiode on a single CMOS integrated circuit capable of providing a near photopic response over an effective 20-bit dynamic range (16-bit resolution). Two integrating ADCs convert the photodiode currents to a digital output that represents the irradiance measured on each channel. This digital output can be input to a microprocessor where illuminance (ambient light level) in lux is derived using an empirical formula to approximate the human eye response.

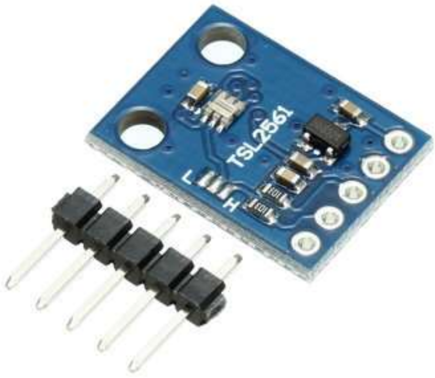


Figure 102: Light sensor.

ML8511 UV Collector Breakout

Figure 103: utra-violet light sensor

The ML8511 breakout is an easy to use ultraviolet light sensor. The MP8511 UV (ultraviolet) sensor works by outputing an analog signal in relation to the amount of UV light that's detected. This breakout can be very handy in creating devices that warn the user of sunburn or detect the UV index as it relates to weather conditions. This sensor detects 280-390nm light most effectively. This is categorized as part of the UVB (burning rays) spectrum and most of the UVA (tanning rays) spectrum. It outputs an analog voltage that is linearly related to the measured UV intensity (mW/cm^2).

5.3. Testing the experimental installation

The platform was started up connected to SHEMSY LAB controller. The system is evaluated for a month and a half in 2019, from January until March 15th. The evaluation resulted in some recordings of the solar water heater's monitoring parameters and the weather station.

The results presented represent a first test of the operation of the installation, which is described by some flaw, especially at the control system level, which was an achievement specific to the project as a whole.

The first attempts were to detect the strong points and weak points of the system to attack another phase of improvement, arriving at a complete final installation and with the correct functioning of all the platform components.

The evaluation tests concerned the whole of the proposed system, namely:

- the weather stations
- the forced circulation solar water heater
- the shemsy lab controller.

4.3.1. Weather data

The evaluated parameter is temperature (Internal and external). Fig.104 shows that the collector started to give an approximatively logical value from 13 January to 20 January.

The maximum temperature measured is about 11°C. Moreover, the minimum was 8°c.

The values were approximatively near to reality but steal incorrectly, and the error is remarkable. The connection and the functioning of the collector must be verified.

The logic comparing the internal and external temperatures is too real; there is a small difference; wich is realistic because of the building's thermal conditions (no insulation or efficiency improvement).

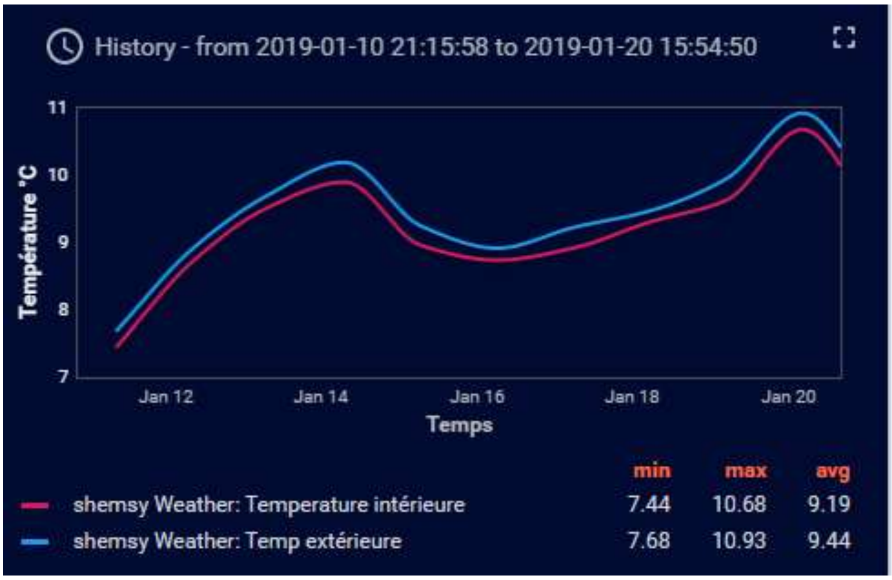


Figure 104: measurements of the temperature from 11 to 20 january 2019.

4.3.2. solar water heater- forced circulation

The system installed for this first test is a forced circulation installation with two solar thermal collectors coupled in series.

Figure 105 shows the measured data display interface which represents a measurement storage and display unit linked to the lab controller.

Figure 105: Display interface of the controller.

The interface displays the different pressure and temperature levels linked to the collectors installed on the platform. The data represents the different temperatures of the solar collectors and the storage tank. the consumption of hot water as well as other parameters that will not be processed (consumption of the pump, the status of the pump, etc.)

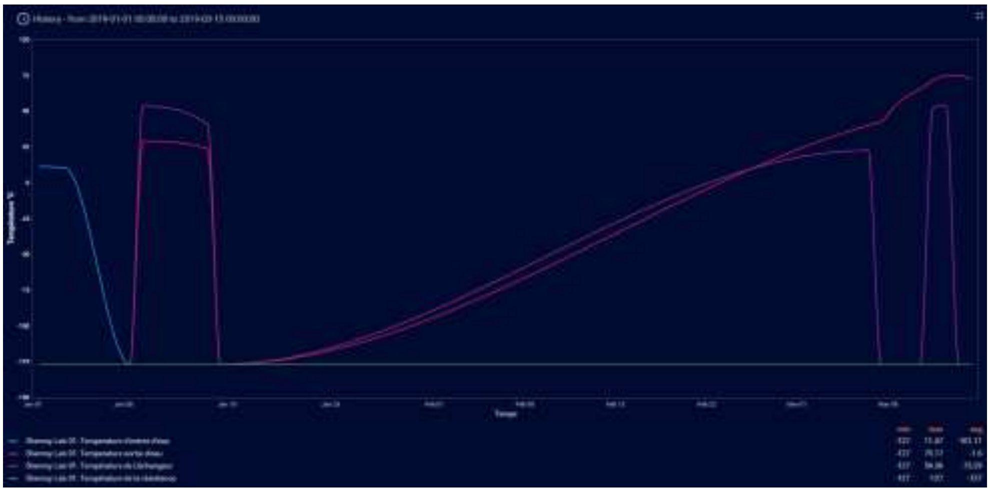


Figure 106: temperatures variation- experimental installation.

Fig.106 gives an overview of the entire test period, making it possible to identify the periods when the functioning was normal and well and the periods when there were anomalies.
The problems detected at the displayed results can be caused by the solar water heater, the controller, or the measurement collectors.
The system's operation is evaluated from the ready to the lab by checking the hot water production and visually checking the collectors where there was no problem.
The source of inaccurate data is necessary due to the control and measurement system.

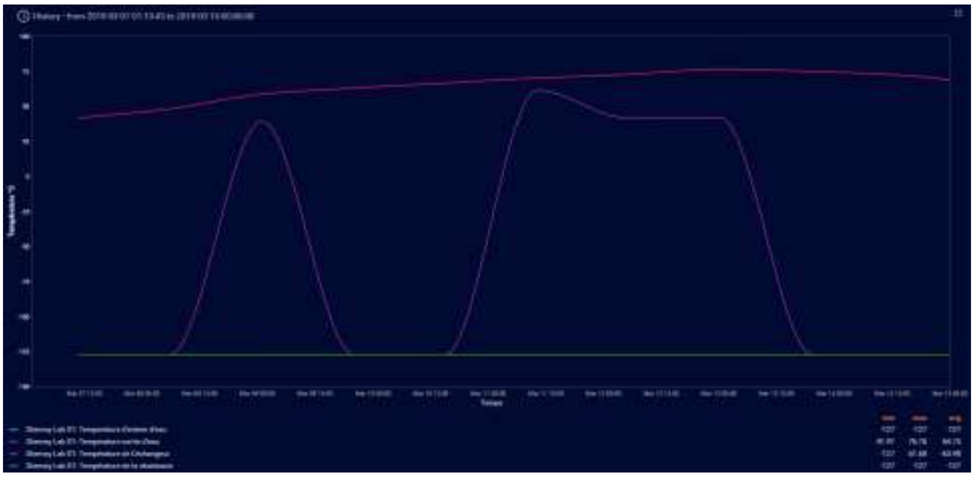


Figure 107: temperature of an operating period.

We have zoomed in on the part where operation appears normal with logical temperature values. This period was in March after a month of operation full of anomalies and interventions in the lab trying to improve results.
Fig.107 shows the produced water outlet temperature at an average of 50 ° C, which is logical and correct.
It is detected that the exchanger's temperature inside the tank experiences a sinusoidal behavior between logical values and negative values. This data reveals the source of the problem: the temperature collectors connected, the problem can be functional or related to a connection that is not well made.

The auxiliary heater's temperature remains negative since this component was not in operation, and there was no collector for this temperature.

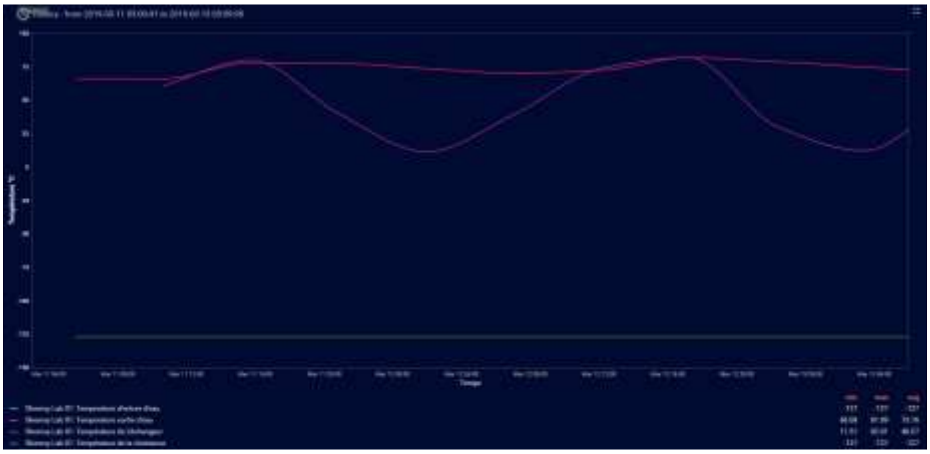


Figure 108: temperatures of a good functioning period in March.

March 11th AND 12th, when the collectors' operation appeared correct, a temperature difference was detected between the water produced and the temperature inside the storage tank.
This difference is considered logical given the hot water outlet point position, which is at the top of the tank. On the other hand, the collector measuring the temperature inside the storage tank is at the bottom. This difference is explained by the difference in water density, which imposes hot water at the top.

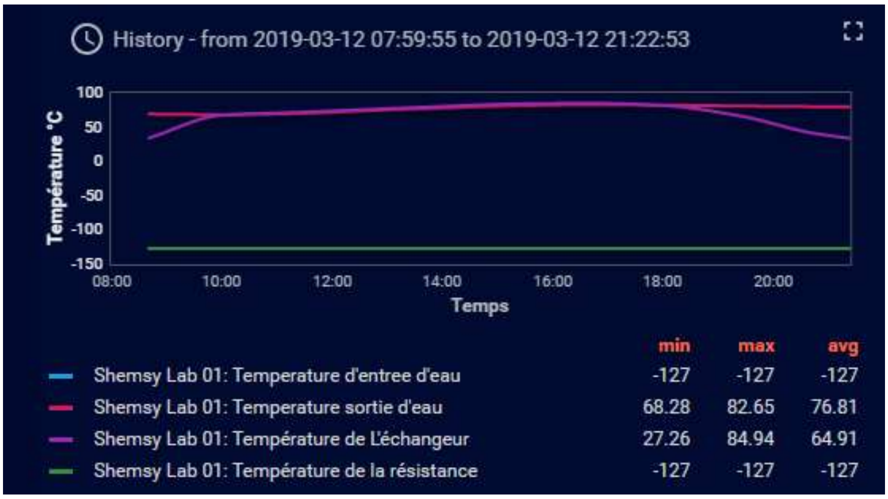


Figure 109: temperatures evolution in a day (12 march 2019).

For more analysis, a zoom was made on a day of correct operation to evaluate the results by referring to the exact times. We notice that the temperature difference between the temperature between the produced water (top of the storage tank) and the bottom of the tank is zero during the day since there is an energy source that ensures hot water throughout the reservoir with useful stratification.
The difference between the temperature begins to appear in the evening and in the morning. The backup system is not working during these test tests, which justifies a cooling of the tank's water. By density effect, we notice much colder water at the bottom of the tank.

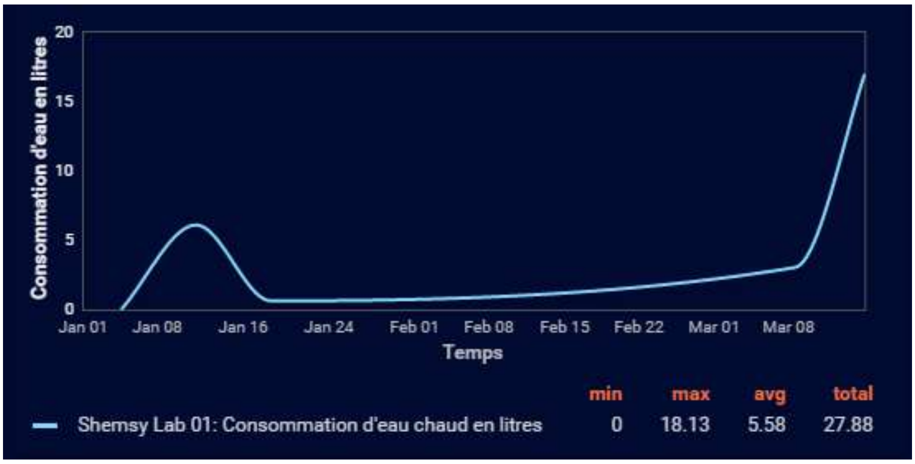


Figure 110: monthly hot water consumption.

Fig.110 shows a positive of 5L as a maximum consumption in the first period of the test, and also in March with a maximum of 18 L.

Figure 111: Water consumption from 06 to 15 March 2019.

The displayed consumption is visualized in Fig.111. The first period in January is explained by taking the water from the tank to check the availability of hot water. The second period of consumption, which recorded maximum values, is explained by using this water by the staff of the innovation and research center where the system is installed.

Conclusion

This chapter presented all achievements made within the framework of the SOL'R SHEMSY project; the prototype was presented in terms of these technical characteristics and an evaluation of its performance; this proved a preliminary validation of the Solar's technical feasibility water heater. On the other hand, the experimental installation carried out was detailed with an initial simulation of its operation and an analysis of the results, which proved the need to improve the control and monitoring system attached and prove stable and efficient operation water temperatures it produced.

Chapter VI: *Development of a Control system*

Introduction

The automatic control, currently renamed «automatic, » is embedded in modern techniques of control- robotics, production, Etc., mainly because of the appearance of electronics, then around the 60s of microprocessors and therefore of computer science.
Nevertheless, it is useful to point out that the old classical control techniques are still widely used in the industry. They still have good days ahead of them because the theory automatically advances much faster than the application. Because the computer means are more «efficient» than the knowledge of the system to be processed, i.e., the model.
It is also interesting to note that today, regulation has become an indispensable option in all areas (industry, service, Etc.), and it is the result of the changes that have occurred in recent years. And the requirements of different applications in terms of the quality of products, services, and operations.
Solar installations are also part of the applications whose control is the subject of an essential operation. Given the importance of its role in controlling the system's operation, control the energy flows consumed. As a result, system energy consumption is optimized, production, performance, and efficiency are improved.
This chapter first part gives an overview of the techniques and technologies of controllers on the market, according to the different types present, as well as their applications in solar thermal installations for the domestic hot water production, in order to control the various systems and actuators of the installation, namely the auxiliary heater system and the water circulation pump.
Then the objective of solar water heaters control is defined. It s as an opening line for the system model under TRNsys studio software, to study its behavior according to different parameters.
Finally, the optimized management of the auxiliary resistance inside the storage tank is studied by minimizing electricity consumption.

1. *Controllers: generality*

Comfort, temperature control, and energy savings lead to control systems development. In solar hot water production systems, two elements require a control system: the pumps and the electrical auxiliary heater. The control is essential to:

- Increased reliability.
- Increase in repeatability.
- Increased speed, performance in general.
- A decrease in costs.
- Guarantee of operator safety.
- Often the system is too fast to be managed manually.

1.1. Controller types

For brevity and to maintain relevance, the control methods currently deployed in buildings are discussed, including conventional controls of the previous generation, the current techniques, and the more critical calculation methods that attracted the most research activity.

1.1.1. Classic controllers

- **<u>binary controllers (0 or 1)</u>**

When no output modulation is sought, the gold on/off binary control has been widely used for small systems in buildings, especially for temperature control via thermostats. Characterized by two switching points and a deadband between the two; this mechanism is prone to hysteresis and

exceedances[181]. In its basic form, binary temperature control also produces a deviation from the setpoint, which requires more sophisticated controls to be corrected. The solution could be to use a switching algorithm such as pulse width modulation to generate a pulse train. This approach can complement pulse width and pulse frequency modulation that is easier for practitioners to configure [182].
that the most commonly used controllers are based on differential theory for a solar water heating system[183].
An ON/OFF differential controller automates the heat recovery system by generating a control function with a value of 1 or 0 (the pump is either on or off).
The control signal's value is chosen according to the difference between the high and low temperatures Th (Temperature at the output of the solar collector) and Tl (Temperature of the bottom of the storage tank). compared to two differences of the deadband temperature and, knowing that the new value of the control function depends on the value of the control function at the previous time step, and the output related to the input to create a hysteresis effect.
The algorithm is as follows: [50]
If the controller was previously enabled

If $\gamma_i = 1$ and $\Delta T_L \leq (T_H - T_L)$, $\gamma_O = 1$

If $\gamma_i = 1$ and $\Delta T_L > (T_H - T_L)$, $\gamma_O = 0$

If the controller was previously disabled

If $\gamma_i = 0$ and $\Delta T_H \leq (T_H - T_L)$, $\gamma_O = 1$

If $\gamma_i = 0$ and $\Delta T_H > (T_H - T_L)$, $\gamma_O = 0$

The controller function is shown graphically in Figure 111:

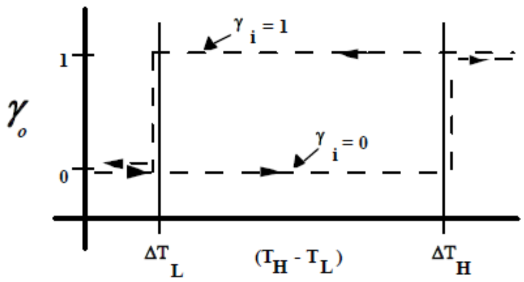


Figure 112: Graphic function of the differential controller[50].

- **Proportional – Integral – Derivative (PID).**

P, PI and PID are used to modulate continuous controls; therefore, only clearly applicable to systems whose production is capable of modulating. Even though PID was developed in 1910 for ship and aeroplane automation, remarkably, 90% of industrial controls continue to use them [184]. The proportional controller (P) corrects the error by multiplying the deviation from the setpoint by a constant proportional to the error's magnitude. The P controllers undergo sustained offsets (persistent error between the setpoint and the predominant value) which can only be corrected by the introduction of an integral action (I). Integral also adjusts the control signal by including the time error integral, so that as long as an error exists, the integrated controller will continue to adjust the signal. Adding an integral action clears the offset, but it can slow down the system and reduce stability. The differential action (D) is therefore added to complement the IPs further as it corrects the low-frequency errors accumulated by the integrator's action. The differentials act on the rapid changes in the error values and ignore the slow-moving values (i.e., they act on the «error change rate», the fast errors activate them). However, derived controls are widely used for the control of construction plants. It should be noted that P controllers are also used in isolation with I or D components (PI or PD controls). Of course, to get the most out of a PID control system, various parameters and constants (i.e., gains) must be chosen wisely. However, the problem is the non-linearity of all HVAC systems, so the system can be put to work correctly in one part of the operational range (i.e., full load) but responds poorly to the others (i.e., partial load). The research community has proposed several auto-tuning techniques; for self-regulation of the Relay instance [185], open-loop pitch tests [186] or a combination thereof [187]. Several building automation companies offer products that incorporate these ideas [188]. Adaptive algorithms are alternatives to those discussed below. The extensive (and continuous) application of PID has enabled many PID tuning techniques and associated hardware and hardware packages [189]. However, academic research on PID has reached a declining level of performance, and trends are evolving towards the integration of PID with computational control methods to improve stability and response time.

A corrector is a calculation algorithm that delivers a control signal from the difference between the setpoint and the measurement.

The PID corrector acts in three ways and actions[190]:

• the proportional multiplies the error by a G gain;

• the Integral integrates and divides the error by a Ti gain;

•the Derived derived and multiplied the error by a Td gain.

There are several possible architectures to combine the three effects (series, parallel or mixed). We present here the most classic: a parallel PID structure that acts on the error.

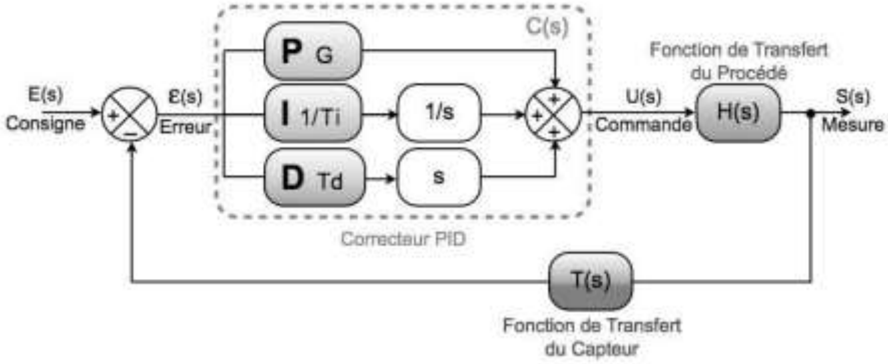


Figure 113: The PID controller Operation[191].

In the diagram above, the transfer function expressed in the Laplace domain (where designates the Laplace variable, of dimension [T1], in the following article, this Anglo-Saxon notation is replaced by p) of the parallel PID regulator is the sum of the three actions:

$$C(p) = G + \frac{1}{T_i} \times \frac{1}{p} + T_d \times p \quad (105)$$

In process control, we prefer to implement the PID transfer function in the mixed form:

$$C(p) = G(1 + \frac{1}{\tau_i \times p} + \tau_d \times p) \quad (106)$$

Where $\tau_i$and τ_dd are time constants (different from$T_i$and $T_d$in the previous formulation), and G is the gain of the proportional part.

The various parameters to be found are G, T_d and $\tau_i$to regulate the process's physical size with the transfer function H(s). There are many methods to find these parameters. This parameter search is commonly called synthesis.

The transfer function of the presented PID controller is ideal. It is impracticable because the degree of the numerator is greater than the degree of the denominator. In reality, we always filter the derived action as follows:

$$\tau_d p \rightarrow \frac{\tau_d p}{1+\frac{\tau_d}{N}p} \qquad (107)$$

With N>1 We obtain a new transfer function for our regulator. The choice of N results from a compromise: for significant N, the derived action is practically no longer filtered, which results in a high sensitivity of the control signal concerning the measurement noise. If N is taken too small, the effect of the derived action becomes practically non-existent. A theoretical study makes it possible to specify that 3>N>10.

The following equation generally describes the version of the PID algorithm:

$$u(t) = T_P\left(e(t) + \frac{1}{T_I}\int_0^t e(\tau)d\tau + T_d\frac{de(t)}{dt}\right) \qquad (108)$$

1.1.2. intelligent controllers (computational)

Advanced solutions replaced conventional control methods by including hybrid solutions in the elements of conventional controls. This subsection describes some of the most notable methods.

- **Monitoring methods**

The monitoring was developed for industrial automation in the late 1990s and, thanks to its possibilities, encouraged scientific research to expand its scope [192]. Over the past two decades, the collection of large volumes of operational data online and the increasing integration of BAS software have enabled the development of super visual (and optimal) control strategies. In its most comprehensive form, this approach can find the optimal solution (operational mode/setpoint) for a system equipped with energy storage (thermal and electrical) while taking into account the carbon and monetary costs of electricity and gas [193]. It is important to note that the supervision method encompasses various techniques, often involving training methods (such as artificial neural networks, fuzzy logic, or genetic algorithms). Supervision controls are classified under the following categories:

A) Method without model

Monitoring control systems could use a model of the targeted system (i.e., Based on a model) or be without a model. Expert systems and e-learning techniques are applied to guide the system to its optimal point or allow the process to function optimally. Although each version can take many forms, supervisory control is practically suitable for complex control problems. The operating points must be continuously updated to find the most optimal under changing conditions. Model-free visibility control (also known as an expert system) uses information from online data streams to determine optimal system operation parameters. It essentially attempts to simulate a human operator's behavior and, therefore, can even operate with 'incomplete' data sets (although precision is required). Reinforcement learning (LR) is a particular example of supervision control without a model, although the control system tries to improve its behavior due to previous actions. Although reinforcement learning does not require any prior knowledge of the system, the learning process can sometimes be unacceptable, making it impossible to apply it [194].

B) Method with model

Model-based supervision control optimizes optimization by selecting the setpoint and "predicting" the optimal time for a setpoint change. An illustration of this could be a dynamic model of the two refrigerated ceiling and ceiling installations that have been successfully developed at the Hong Kong Polytechnic University. A monitoring algorithm was used to automatically set setpoints every 10 minutes to achieve comfort and energy efficiency conditions [195]. This method is suitable for more complex systems where updating operating points can generate higher returns. Cooling plants are particularly suitable for this application. A similar study used simplified models of the main components of the central chiller with a genetic algorithm. The virtual system achieved a reduction in cooling energy from 0.73% to 2.55% [196]. System models with simplified structures, high predictive accuracy, easy calibration, and reduced calculation costs [193] are essential to the model-based monitoring method's success. A demonstration of this was made where an optimal model defined by several operational constraints was developed to control the building's heating. The model is then solved by a real-time optimization technique, using dynamic programming and online simulation. The system included a weather predictor that provided a forecast of solar illumination and temperature from 12 hours to 1 day. This approach was tested in a 'solar room' where high-capacity concrete floors were deployed to absorb and store solar energy. A floor heating system completed the solar heat. The results showed energy savings of 10 to 27% [197]. Supervision control could also be a hybrid of techniques based on independent models and models—a network of artificial neurons (ANN) or empirical relationships. S. Wang & Z. Ma [193] concludes that the hybrid supervision control method is the best for the following practical applications because detailed model-based methods are not computationally effective.

C) Reinforcement learning (RL)

Initial control policies generated to oversee a complex building's operation may be optimal as the building goes through different phases of its life. RL tools can provide a solution by allowing auto-calibration of control parameters. In more advanced forms have been applied in conjunction with ANN or Fuzzy [198].L. logic, however, continues to suffer from a long formation process. The learning parameters and dimensionality of the state and action space can also -troller to find the right policies [194]. RL appears in several domains, such as construction controls and its applications [199]. The most recent efforts are limited to the use of LAN to regulate a monitoring control that neglects the energy system and to develop optimal controls for thermal storage inventories of active and passive buildings[194], [200].

LAN, known as the semi-supervised learning model in machine learning, is a technique that allows an agent to take action and interact with an environment to maximize total rewards. RL is generally modeled as a Markov decision process (MDP).

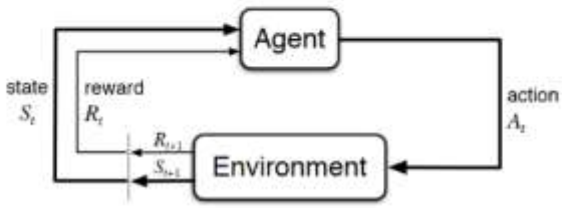


Figure 114: RL controller.

it is not necessary to use RL, and in some cases, it should not be used. It is essential to check if the problem has some of the following characteristics before deciding to use RL:(a) testing and error (it is best to learn to do better by receiving feedback from the environment); (b) deferred rewards; (c) can be modeled as an MDP; d) the problem is a control problem.

A simulated environment: Many iterations are needed before an RL algorithm works. Therefore, a simulated environment capable of correctly reflecting the real world is necessary[201].

CDM: the problem must be formulated in a CDM. Moreover, design the state space, the action space, the reward function, etc. the agent will do what it is rewarded to do under constraints. It is risky not to achieve the desired results if the problem is not conceived differently.

Algorithms: There are different RL algorithms to choose from and questions to ask (Do you want to discover the policy directly, or do you want to learn the value function? Do you want to go without a model or based on a model? Do you need to combine other types of deep neural networks or methods to solve your problems?).

RL applications:

- Information Cluster Resource Management.
- Control of signal lights.
- Robotics.
- Web system configuration.
- Chemistry.
- Games.
- Etc

D) FUZZY LOGIC control

FL resembles the process of human thought; it is capable of dealing with a partial truth (sets of classical binary variables are true or false). Therefore, FL can work more efficiently with the uncertainties of multi-variety control systems. Except for initial attempts [202], FLC controls are rarely used alone for construction control applications. The most effective applications involve integrating FL with PID, ANN, or other adaptive techniques [203]. FL has the same scope as the PID, where its application would have helped improve visual and thermal comfort and improve natural ventilation [204], [205]. Where comfort expectations are related to changing occupant occupancy over time, Control systems could be linked to a pervasive detection strategy so that a building learns to adapt to new preferences or new occupants.

FL, combined with other methods, shown great promise as a Hybrid technic. Figure 114 is a simulation comparing performance improvement of the first FL used to program the gain coefficient of the PID controller (F-PID), and later the genetic algorithm (GA) used to optimize the efficiency of the adynamic energy system (ie, GA-F-PID) [203]. The latter provides the best stability control with virtually no oscillation or overtaking [206].

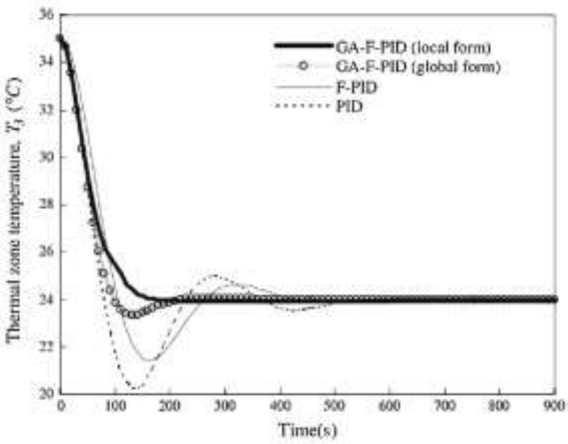


Figure 115: Comparison of transient thermal response of the thermal zone for global and local PID, F-PID and GA-F-PID regulators [203].

An FL system has three parts: fuzzification, inference engine, and defuzzification.

Step 1: Fuzzification;

the affiliation function created by the FL system designer allows transforming input data into fuzzy amounts.

Step 2: Inference engine;

It is a matter of assigning to each variable degrees of belonging to different states that must be defined, then giving rules that link data to actions.

If (condition) Then (action)

Step 3: Defuzzification;
Finally, the last step is to merge the different commands generated by the inference engine to turn fuzzy decisions into determined numerical output values.

E) Robust controls

HVAC installations are selected for the maximum load they must serve, even if they will operate in partial loads for most of their lifetime, sometimes with severe efficiency penalties and control problems. Robust control is designed to solve this problem using algorithms that provide disturbance mitigation and stable operation over the entire operational range [207]. Optimization synthesis (H –inf) has proven effective in building robust controllers [208]. However, this technique requires a definition of installation uncertainty and space to form fixed (or variable) parameters. It contains high-level mathematics, making it challenging to implement from a numerical point of view.

F) Artificial neural networks (ANN).

The research community used ANN's learning ability to initially map the relationship between input and output data to predict (behavior) and ultimately optimize system control. Examples of recent simulation-based attempts include the adaptation of CAN to control a double-skin face [209], the operation of the terrestrial hybrid heat pump [210], and the optimization of building energy and comfort [211]–[213]. In all these attempts, ANN makes predictions that are used to decide the next control action. Another work reported improvements of more than 50% in HVAC systems' efficiency when NAS are used to develop 'predictive controls' for medical management and comfort [214].

G) Agent-based controls

Agents (in the form of electronic devices) have been deployed and strategically placed primarily in process automation and electronic engineering, allowing for control flexibility and robustness. These are interactive, automated, and flexible components that have found widespread applications in extremely complex systems [215], [216]. The vast, dynamic, and multifaceted nature of buildings mean vast amounts of information exist inside and outside the envelope. Building scientists have deployed agent-oriented methods to perform different tasks to enable comfort and energy management. Building-specific applications include developing agent-based management systems with particle swarm optimization (PSO), a method inspired by the collective movements observed in birds and fish [217], [218] to optimize complex non-linear control problems. A study of this type (based on simulations) reports improvements in energy and comfort compared to different operating scenarios [219]. Similar work has managed energy savings while achieving optimal comfort levels [220]. A further feature of these systems is their open architecture, allowing subsequent adaptation to the existing BAS to facilitate better functionality [221]. However, controls based on autonomous agents steer the system towards a more decentralized decision-making model, which makes it more difficult to predict the system's overall behavior. One area of active research is the fusion and interaction of integration agents to produce desirable system-wide behavior. However, except for a few demonstrations of prototypes of industrial processes (and manufacturing lines), agent-based systems' actual performance, whether under real conditions or even controlled, is not yet available.

2. Solar hot water control system

2.1. Pump controller

The circulation pump allows a faster transfer of the energy captured by the collectors to the storage tank. This pump interrupts the heat transfer when the water in the collectors is not warmer than that contained in the tank.

The control system compares the two temperatures (at the solar collector's output and in the storage tank). It controls the circulation pump only when the first temperature is higher than the second. In practice, the temperature difference is set independently at the start (between 5 and 10°C) and at the start of the circulator (between 2 and 5°C). A differential controller is sufficient for these operations.

2.1.1. Differential control system

The control device's role is to control the transfer of the captured energy, only if the fluid temperature in the collectors is higher than that of the water contained in the storage tank[222]. The circulator control depends on two adjustable differential values

-ΔT1 = adjustable value of the circulator interlocking differential.

- ΔT2 = adjustable circulator stops differential value.

ΔT2 < ΔT1

The pump is engaged when Tc > Tb + ΔT1. And the fluid circulation is established in the collectors. On the other hand when Tc < Tb + ΔT2. The pump stops, and the fluid circulation is interrupted. In general, the following values are used to ensure the right operating conditions:

- ΔT1 rang of 5° K to 8° K.
- ΔT2 rang of 1° K to 3° K.

The differentials may be smaller because the primary circuit will be short and well isolated. See the following flowchart:

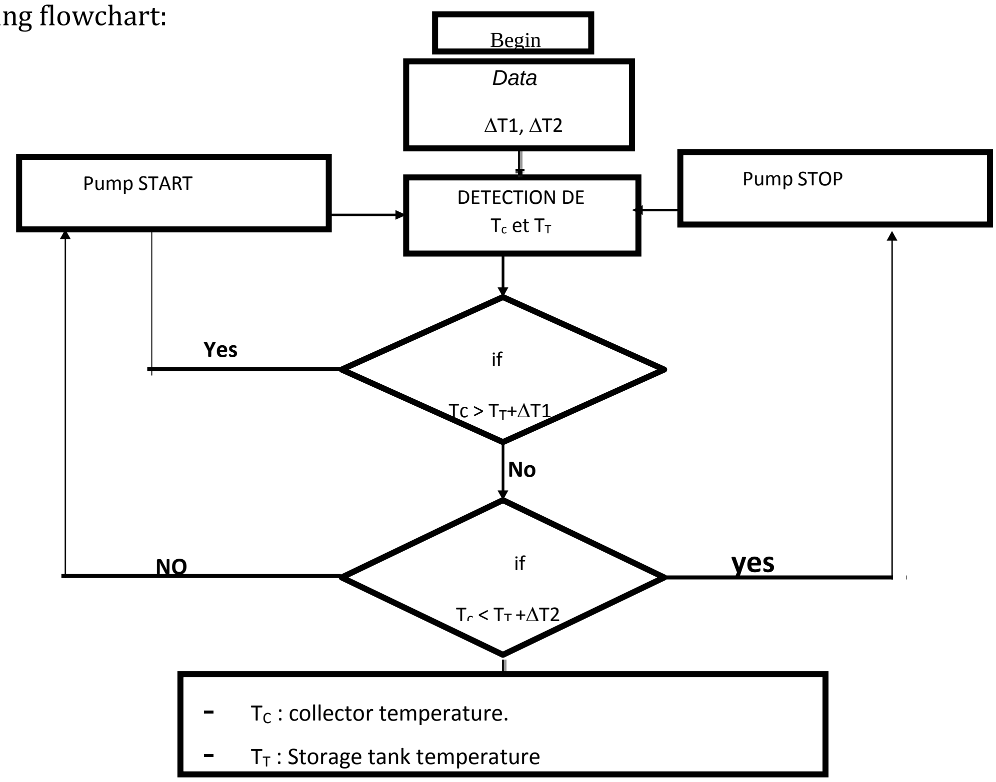


Figure 116: differential control system flowchart

2.1.2. Differential control with a switching valve

When the catchment area and the inertia of the primary loop are significant (length of piping greater than 50m), the regulation of the primary circuit is completed by the regulator's action on a switching valve[223].

When the Tc temperature at the output of the collectors becomes more significant than the T_T+ΔT1 value of the water in the storage tank, the controller forces the starting of the circulator P1.
Valve V1 is opened in the fluid recycling position on the collectors (primary circuit temperature stabilization).
If the temperature T1 exceeds T_T of the water in the storage tank $T1 > T_T + \Delta T1$, the controller forces the opening of the switching valve V1 to the storage, and there is heat exchange in the tank.
If $T1 < T_T + \Delta T2$, the switching valve V1 closes the storage circuit. The fluid is recycled into the collector loop.
Finally, if $T_c < T_T$, the controller stops the circulator P1.
The regulation is based on the 'ON/OFF' principle of the switching valve V1, which reduces the risk of pumping the circulator (inadvertent commissioning and shutdown of the circulator). Besides, the system's thermal performance is improved due to the faster heating of the primary loop in the morning.

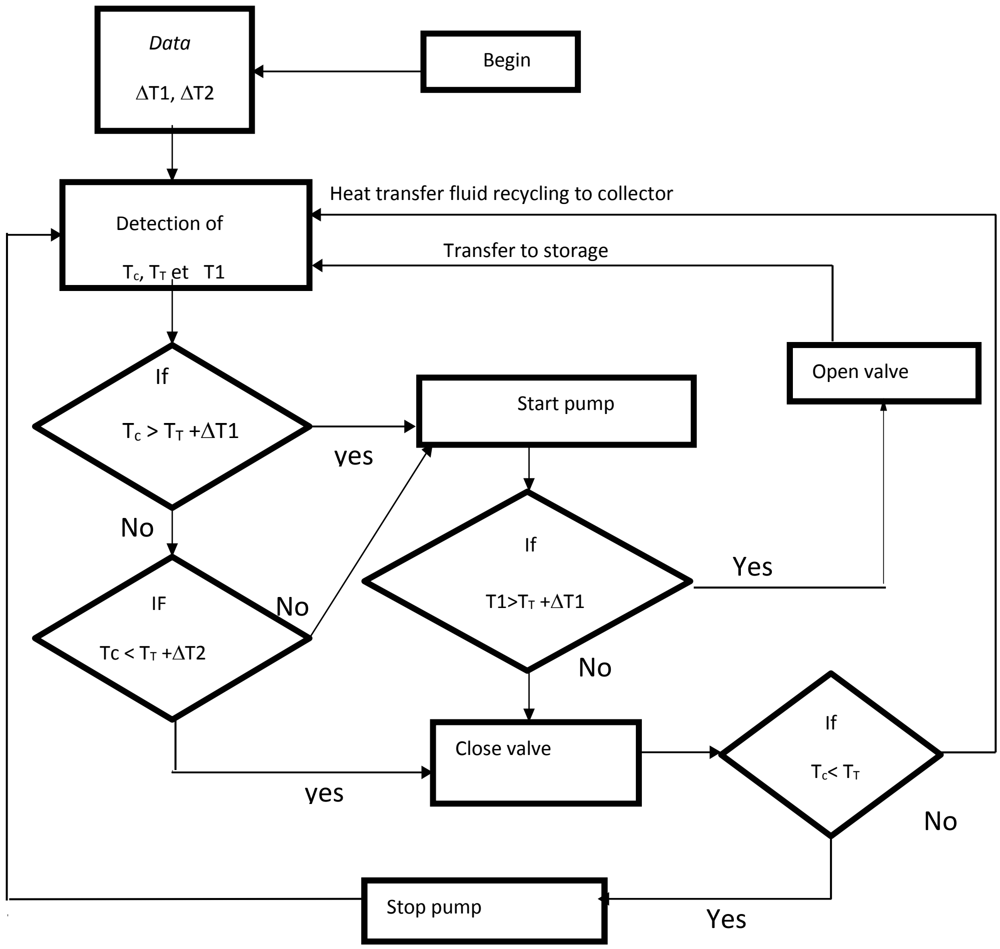


Figure 117: differential control with switching valve flowchart.

2.1.3. Differential control with external exchanger

When the system contains an external exchanger, the circulation of sanitary water in the secondary circuit of the exchanger requires a second circulator's implementation[224].
In general, the regulation of the installation is ensured by two differential controllers R1 and R2.

the operation of the circulator R1 must be delayed, avoiding untimely stops and recirculation when starting the installation each day. to promote inertia ((the energy quantity of fluid is significant).

If $T_c > T_T + \Delta T1$ the circulator of the primary circuit P1 is in operating.

If $T1 > T_T + \Delta T1$ the controller R2 forces the circulator p2 activation (the secondary circuit).

If $T_c < T_T + \Delta T2$ stop circulator p1,

if $T1 < T_T + \Delta T1$ stops circulator p2, recycle the coolant to the collector.

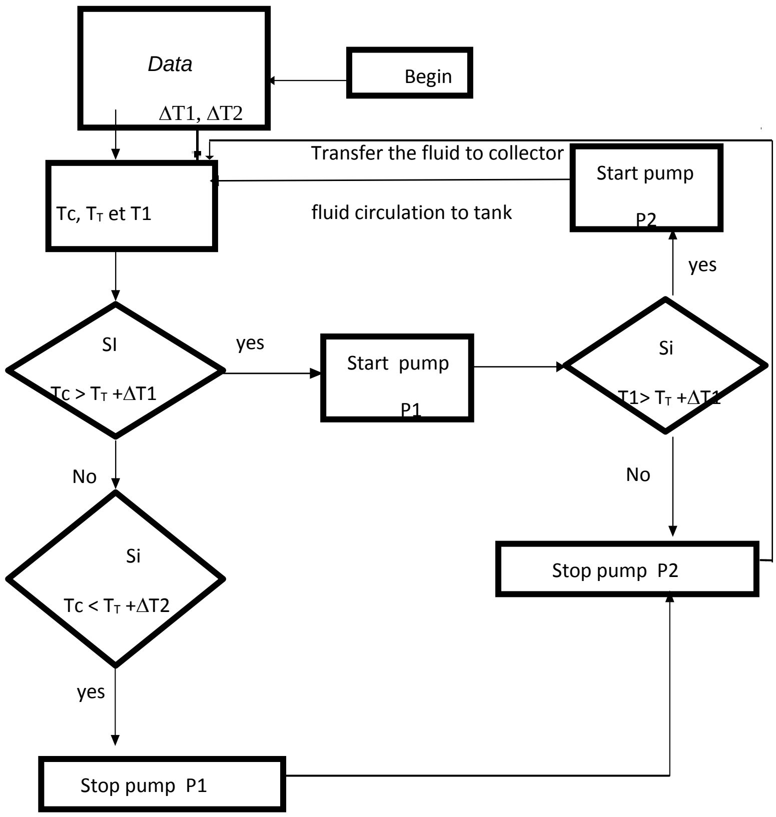


Figure 118: differential control system with external exchanger flowchart.

2.2. Auxiliary heater control

On cloudy days or at night, It is necessary to use supplementary energy to a sufficient temperature; among the most used auxiliary energies is cited electrical energy.

A temperature control system is necessary to take advantage of solar energy, which is free to the maximum; for this purpose, there are two types of regulation:

• A control system that adapts to all heating systems. This device works with (ON/OFF) mode, that is to say by activating or deactivating the electrical auxiliary heater.

• A control system with fuzzy logic.

2.2.1. Controller ON/OFF

this control system requires

A temperature collector

A device that translates probe variations into an electrical signal to obtain directly exploitable analog information.

A voltage comparator compares the device's output voltage to a predetermined reference voltage that represents the set temperature (50°c in our case).

Two-threshold comparator, to introduce the concept of hysteresis or tipping delay.

This control system is a comparator controls' output via a power interface, an electromechanical relay that allows the activation or the deactivation of the electrical auxiliary heater.

Power supply: The energy required to operate the circuit is taken from the network.
The operation of this system is plotted in a graph on which three phases are distinguished:
- The first phase concerns the beginning of the day when solar supplies are insufficient to heat the water to a temperature that satisfies the real need for hot water, so the resistance is activated.
The second phase begins when the water temperature in the storage tank increases with the solar inputs. The controller intervenes to trigger the electrical auxiliary heater, respecting the set temperature, which is 50°c in general.
- In the last part of the day, the water temperature decreases with the end of the sun, and the regulator intervenes to activate the electrical resistance (immersion heater).

2.2.2. Fuzzy Logic control

This control system uses the fuzzy logic technique, consisting of replacing the conventional settings' algorithms by linguistic rules of the type. If the temperature is low, then it is necessary to heat. Thus, one obtains a linguistic algorithm that lends itself better than the traditional methods to the control of the systems.

3. Optimized management of the backup and regulating system of a solar water heater TRNsys modeling.

The back-up systems are obligatory for the SWH system. This solution is not at all suitable for uncontrolled use. The efficiency is not always optimized even in favorable conditions, the system must be associated with a control system, which makes it possible to control the consumption of the energy flows, ensures communication between the critical elements of the system, and control dysfunctions.
These problematic appeals for an optimized management of the back-up system, in order to propose an optimal solution of the appropriate control system.
This study aims to control the solar heater water system adjusting the energy flow between all the installation components. It's composed of a solar collector system, the elements that convert the solar energy into the thermal energy, and a storage tank equipped with a spiral heat exchanger. However, the circulation of water is ensured by a circulator and a differential controller which activates or deactivates the pump according to the difference between two measured parameters: the output temperature of the solar collector, by considering it as a higher inlet temperature, and the hot source temperature of the tank, which is considered a lower inlet temperature. Among the various existing regulation, the most used is based on the differential temperature control. Thus, the optimized management was used to predict the ideal location of the auxiliary heater inside the storage tank to overcome the lack of sunshine while minimizing the power consumption of the auxiliary heater.

3.1. Methodology and simulation

3.1.1. Simulation model

The system is a forced circulation solar water heater. It was simulated using TRNSYS studio under the climatic conditions of FES city on Morocco. Figure119 Presents the flowchart of the simulation interface.

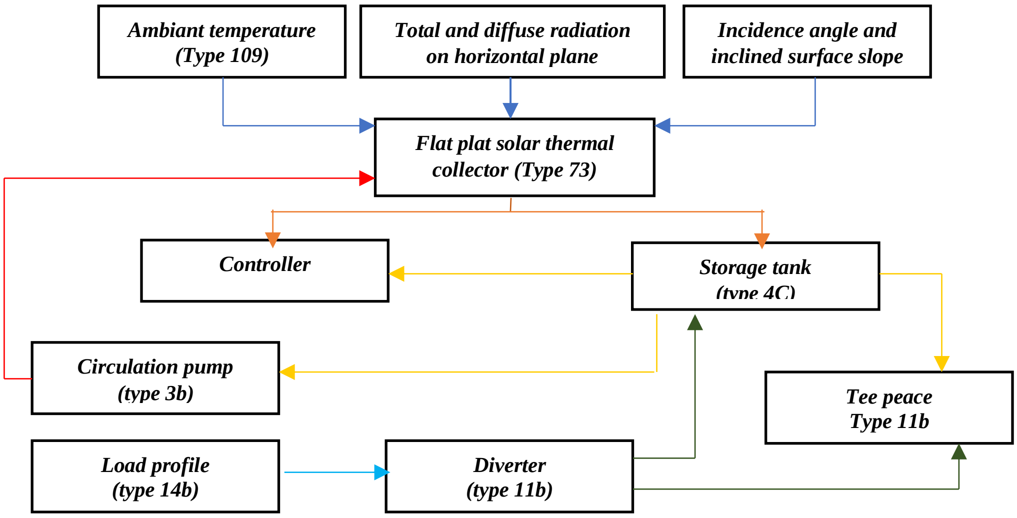


Figure 119: : the simulation flowchart.

The simulation was realized taking into account elements with fixed characteristics (tank storage, collectors) and other changes according to the studied element such as the controllers.

The studied system consists essentially of a solar energy collector which is either a flat collector (Type 73) with 5m^2 of total area, where the liquid is heated to be transferred to the storage tank, the specific heat of heat transfer fluid is 4.16 kJ / kg.k. The Type 4c water storage tank is a thermally stratified energy storage tank assuming that the tank consists of N segments of the same fully mixed volume. The storage tank is of volume 0.3, consisting of 11 segments whose distance between two successive segments is 0.3 m, and contains an electrical backup resistance.

The water consumption is represented by a time-dependent water-drawing forcing function, which is established by a set of discrete data points indicating the function's value at various times during a cycle. Fig. 120 shows the load profile used in this study.

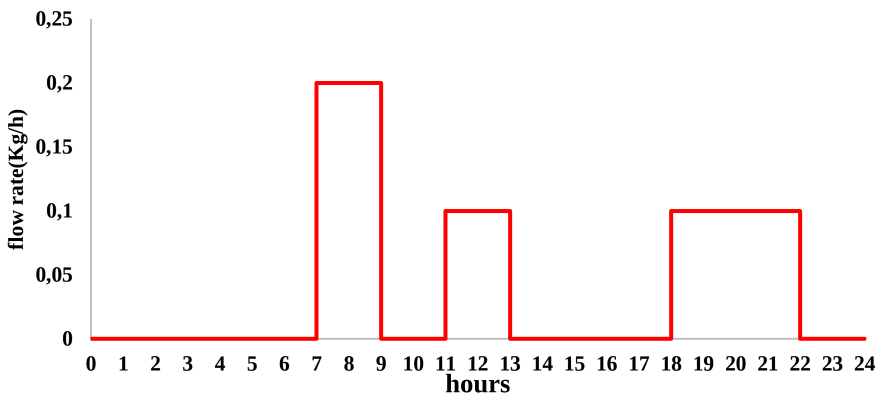


Figure 120: Load profile.

- **Optimal positioning of the electrical resistance**

It is possible to design a solar water heater to provide all the domestic hot water required in warm or warm climates, without an auxiliary system, given the sufficient area of the collector and the storage tank's capacity. However, it is not profitable to do so.

A solar water heater usually is designed to provide between 50% and 80% (or more, depending on the weather and operating conditions) of the hot water charge. The remaining energy needs can be provided by adding additional heating to the solar system. An electrical resistor is often used as an auxiliary. The auxiliary energy component must provide 100% of the heated water without any help from the solar system to provide heat when the collector's energy is not sufficient to satisfy the required energy supplied to the load. It is to know the ideal location of the backup resistance inside the storage tank to overcome the lack of sunshine while minimizing the backup system's power consumption.

The model

This part aims to calculate the various performance parameters by placing the auxiliary resistance in the different nodes of the storage tank to know the ideal location of the auxiliary heater inside the tank to compensate for the insufficiency of sunshine while giving priority to the sun and minimizing the power consumption of the backup system. The study is based on the multi-node model. In the multi-node approach, the reservoir is modeled as N thoroughly mixed volume segments. The degree of stratification is determined by choice of N. Higher values of N lead to more stratification. For N = 1, the reservoir is modeled as a thoroughly mixed reservoir, and no stratification effect is possible. In our study, the reservoir is composed of 11 nodes of thoroughly mixed volume [50]. The optimal position is chosen by calculating many performance indicators, such as electrical consumption, the solar fraction, and the stratification number.

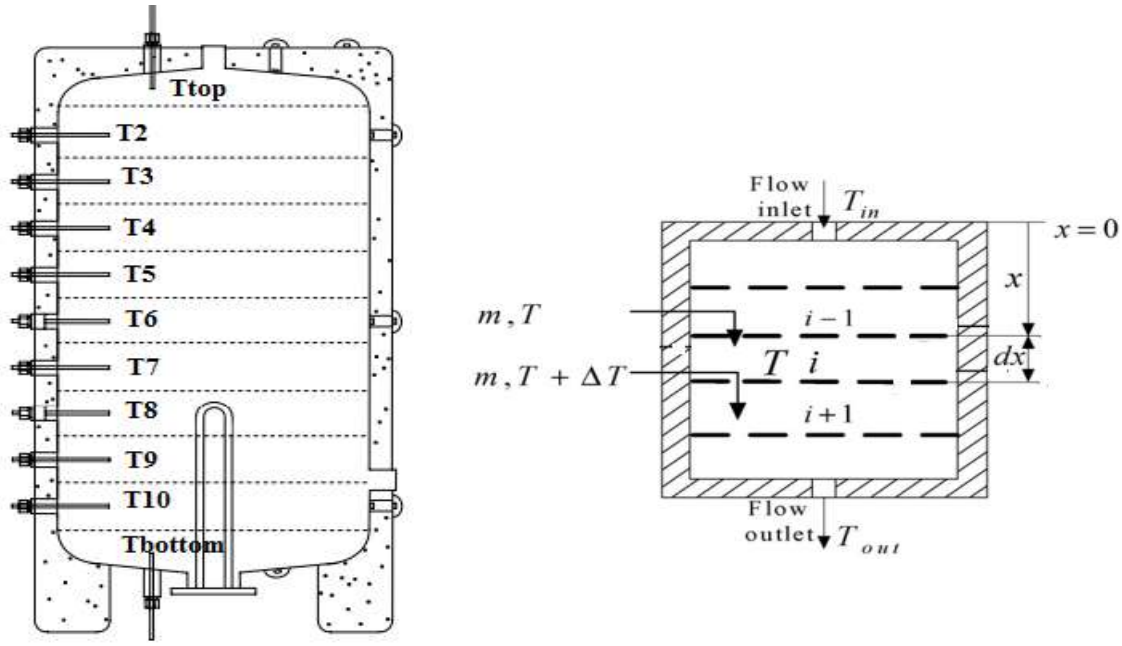


Figure 121: : Tank prototype and physical diagram of the thermal stratified tank.

<u>Electrical consumption:</u> The reduction rate of the electrical energy consumed by the backup system is showed on equation 109:

$$TauxdeRéduction = \left(\frac{C_i - C_{Bottom}}{C_{Bottom}} \right) * 100 \tag{109}$$

<u>Solar fraction:</u>

The solar fraction (eq.110) for hot water is defined as the part covered by solar energy and not by the extra energy.

$$FS = \frac{Q_S}{Q_S + Q_{aux}} \tag{110}$$

$$Q_L = Q_S + Q_{aux} \quad (111)$$

$$FS = 1 - \frac{Q_{aux}}{Q_L} \quad (112)$$

Qs is the solar energy, Qaux is the auxiliary heater energy and Q_L the energy demand.

Stratification number

Due to the effect of gravity and buoyancy force, a high-density fluid or cold water will settle in the lower part of a tank and a low-density fluid or hot water in the upper part of the tank. It can therefore be imagined that a thermal barrier is available between a hot zone and a cold zone inside the reservoir and maintains the stable vertical temperature or the density gradient. This part of the tank mimics the concept of Thermocline. Fig.122 develops stratification inside a tank with high thermal stratification value and a mixed tank. The number of stratifications is defined as the ratio of the average of the temperature gradients at any time to the maximum average temperature gradient for the discharge / loading process [50] [225].

$$Str(t) = \frac{(\partial T/\partial z)_t}{(\partial T/\partial z)_{\max}} \quad (113)$$

$$\left(\frac{\partial T}{\partial z}\right)_t = \frac{1}{j-1}\left[\sum_{j=1}^{j-1}\left(\frac{T_{J+1} - T_j}{\Delta z}\right)\right] \quad (114)$$

$$\left(\frac{\partial T}{\partial z}\right)_{\max} = \frac{T_{\max} - T_{in}}{(j-1)\Delta z} \quad (115)$$

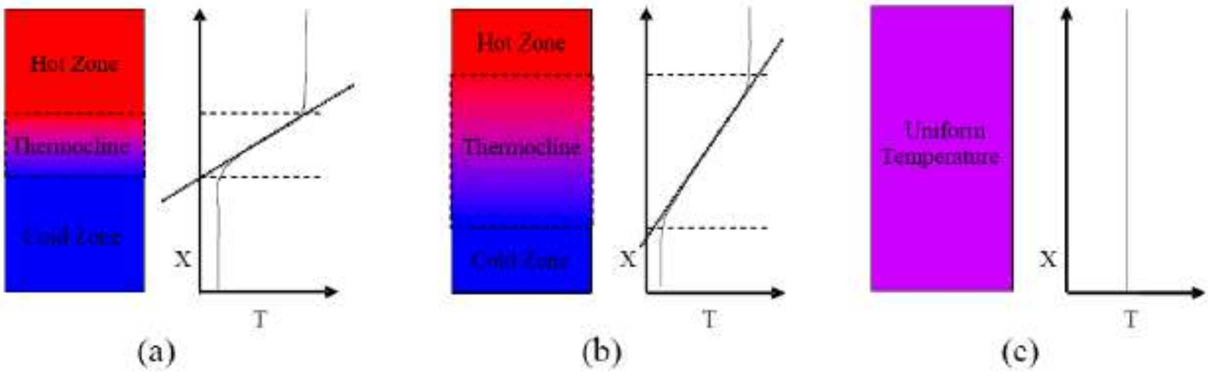


Figure 122: stratification level in storage tank (a)Highly stratified, (b) moderately stratified (c) fully mixed and non-stratified

- **Controllers comparative**

After choosing the auxiliary heater optimal position, this part consists of making an optimal choice of a suitable controller. A comparative study was to approach two types of controllers: the differential controller and the feedback technology. An ON / OFF differential controller is to automate the heat recovery system by generating a control function with a value of 1 or 0 (the pump is either on or off). The value of the control signal is chosen according to the difference between the high and low temperatures Th (the temperature at the solar collector outlet) and T1 (temperature of the bottom of the storage tank), compared with two differences in Deadband temperature and, knowing that the new value of the control function depends on the value of the control function at the previous time step, and the output linked to the input to create a Hysteresis effect. [226]

If the controller was previously disabled

If the controller was previously enabled

If $\gamma_i = 0$ and $\Delta T_H \leq (T_H - T_L)$, $\gamma_O = 1$ If $\gamma_i = 1$ and $\Delta T_L \leq (T_H - T_L)$, $\gamma_O = 1$

If $\gamma_i = 0$ and $\Delta T_H > (T_H - T_L)$, $\gamma_O = 0$ If $\gamma_i = 1$ and $\Delta T_L > (T_H - T_L)$, $\gamma_O = 0$

The iterative feedback controller calculates the control signal (u) required to maintain the controlled variable (y: collector outlet temperature) at the setpoint (y Set: Bottom +10 tank temperature)[227].
The pump's speed is controlled, thus controlling the flow rate to be provided to maintain the temperature of the outlet at a certain specified level.

3.2. Simulation results and analysis

3.2.1. Optimal position of auxiliary heater

Fig. 123 presents the backup system's monthly power consumption in the different nodes of the storage tank. The results show that the lowest energy consumption is when the backup resistance is placed at the top of the storage tank. It increases until it reaches a max consumption when it is placed at the tank bottom.

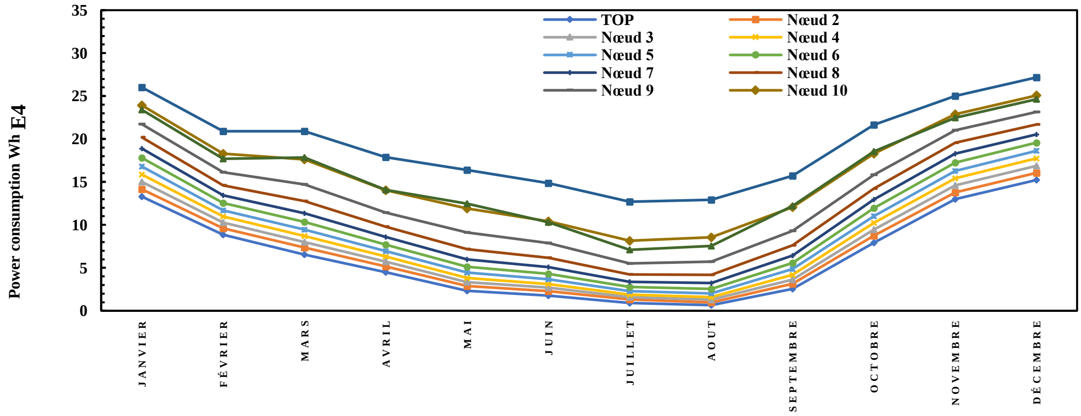


Figure 123: The electrical consumption of the auxiliary heater.

From Table 48, we find that when the resistance is placed at the top of the storage tank, the reduction rate is 64%, which is a maximum value compared to the other nodes of the tank. From this result, we can say that the resistance's ideal location is the top of the tank because of the low power consumption founded.

Position	Annual consumption Wh	Reduction rate %
Top	790680	-64
Node 2	8559800	-61
Node 3	920560	-59
Node 4	984840	-56
Node 5	1055800	-52
Node 6	1071180	-52
Node 7	1234500	-44
Node 8	1361580	-39
Node 9	1542260	-31
Node 10	1827270	-18
Bottom	2222100	0

Table 49: the reduction rate.

As mentioned before, the solar fraction is partly covered by solar energy and not by the auxiliary system. Therefore, according to Fig.124, the maximum solar fraction is for the case of the resistance placed at the top. Thus, the storage tank decreases gradually until reaching a min value when the auxiliary resistance is placed at the bottom of the tank. The backup system must be placed at the 1st node (Top) of the storage tank to improve the system efficiency.

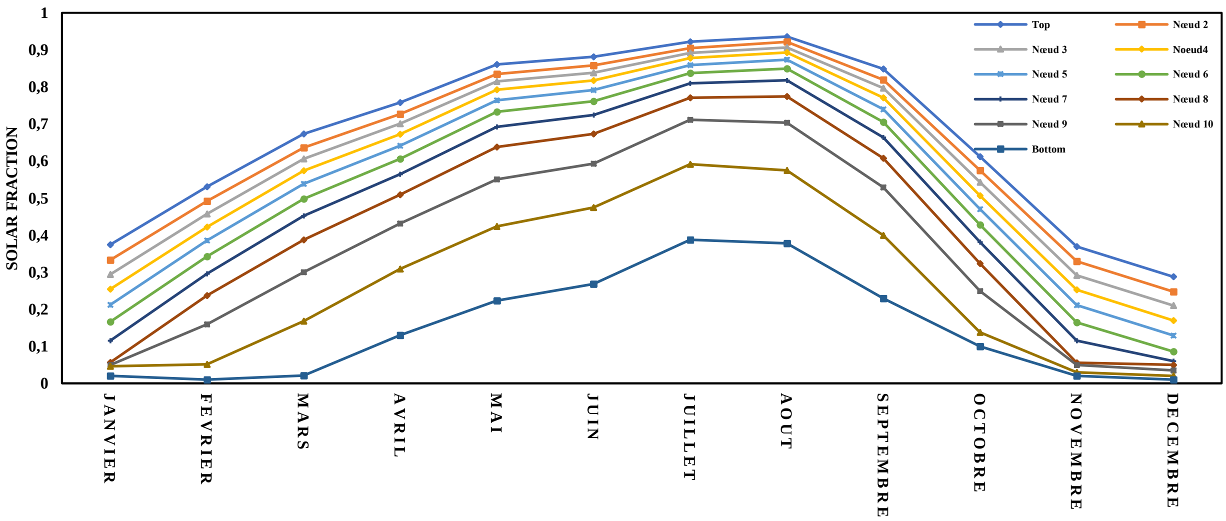


Figure 124: Solar fraction of various auxiliary heater positions.

The stratification number in the 11 nodes of the tank is illustrated in Fig.125. We note that stratification evolution is stagnant in the first 12 hours of the day, with a small variation in [13h, 19h]; This can be explained by a useful stratification of the storage tank.

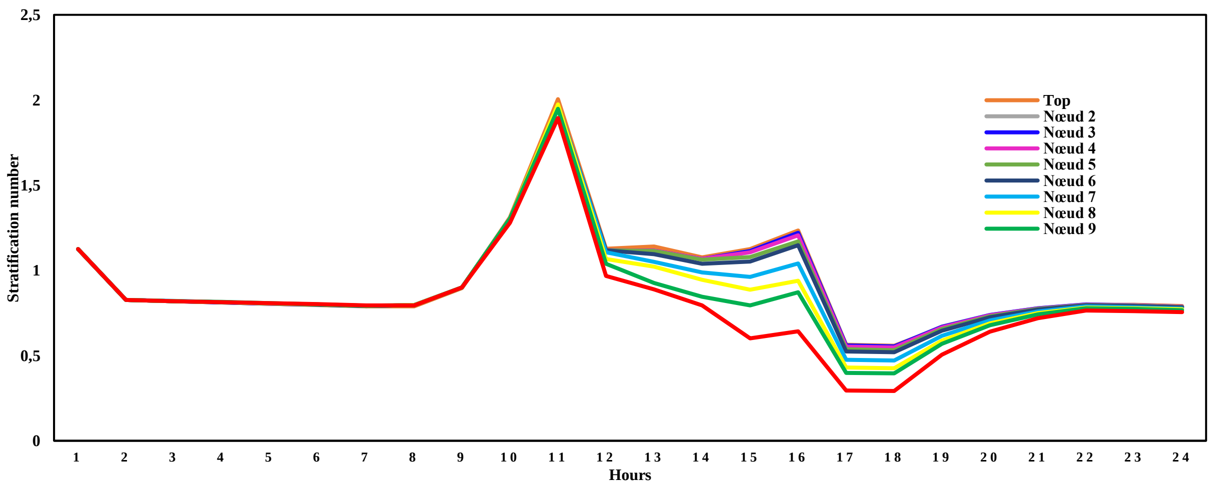


Figure 125: stratification number in various tank positions.

The backup system is an essential element in a solar water heater design, which can mitigate the lack of sunshine; This is to determine the electrical resistance's ideal location to prioritize the sun while minimizing the power consumption of this backup system. We find that the top of the storage tank is a better location for backup resistance from the calculation of the power consumption and the solar fraction by placing the electrical resistance in the different storage tank nodes.

3.2.2. Controller comparative

The controller comparison study (feedback and differential) is under the previously mentioned technical and meteorological conditions and the electric back-up's optimal position. The result shows that the differential is the optimal solution for this case study. The total system's electrical consumption is lowest using the differential and very significant with the feedback controller technology Fig.126 the result is explained by the connection of the feedback with a pump at a varied speed, which causes a much longer operating time than the controller system by the differential. We note that the pump's output in case of feedback generates a variable flow whose maximum value is 200 Kg/hour. Pumps are usually based on DC motors, thus controlling flow through a water pump means to control a DC motor's speed. The differential generates a minimum of consumption and consequently, much more improved and satisfying performance.

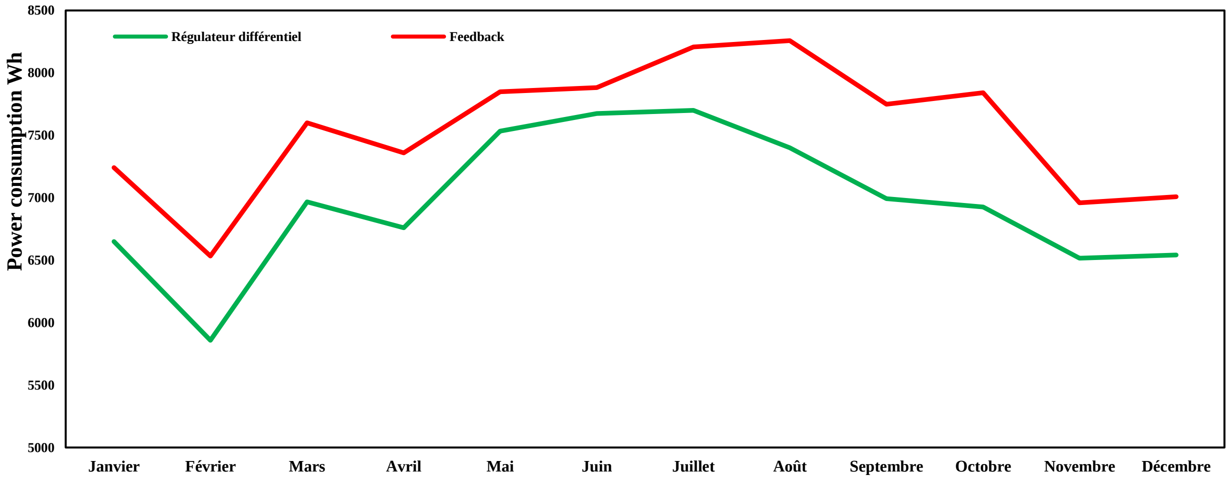


Figure 126: comparison of differential and feedback controller.

System functioning Characterization

The choice of the control system completes the proposed model with optimal and perforating solutions, this appeal for a characterization of the operation of the entire installation which is the subject of the next part of this study. Fig.127 shows the variations in the outlet temperature of the solar collector and the storage tank. The outlet temperature of the collector increases during the morning hours to reach 99 ° C as a maximum at 16 hours then begins to decline until sunset. The temperature leaving the storage tank fluctuated between 58 ° C and 70 ° C. This temperature is always higher than 58 ° C even in the case where the temperature of the collector is very low, and it is thanks to the auxiliary system.

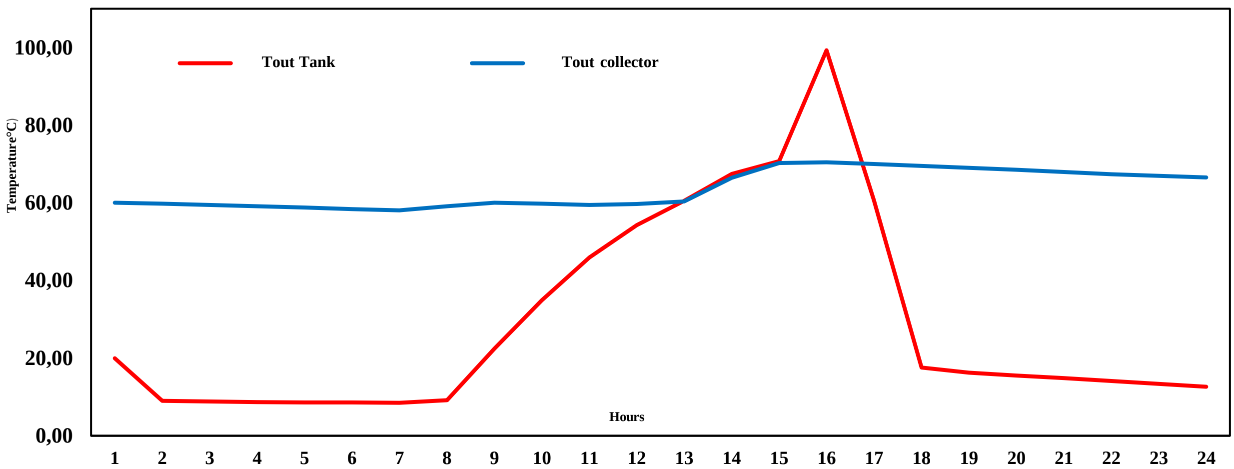


Figure 127: Outlet temperature of collector and storage tank variation

Fig.128 shows the temperature variations in the 11 nodes of the storage tank of the Top at the bottom of the tank during a typical day.

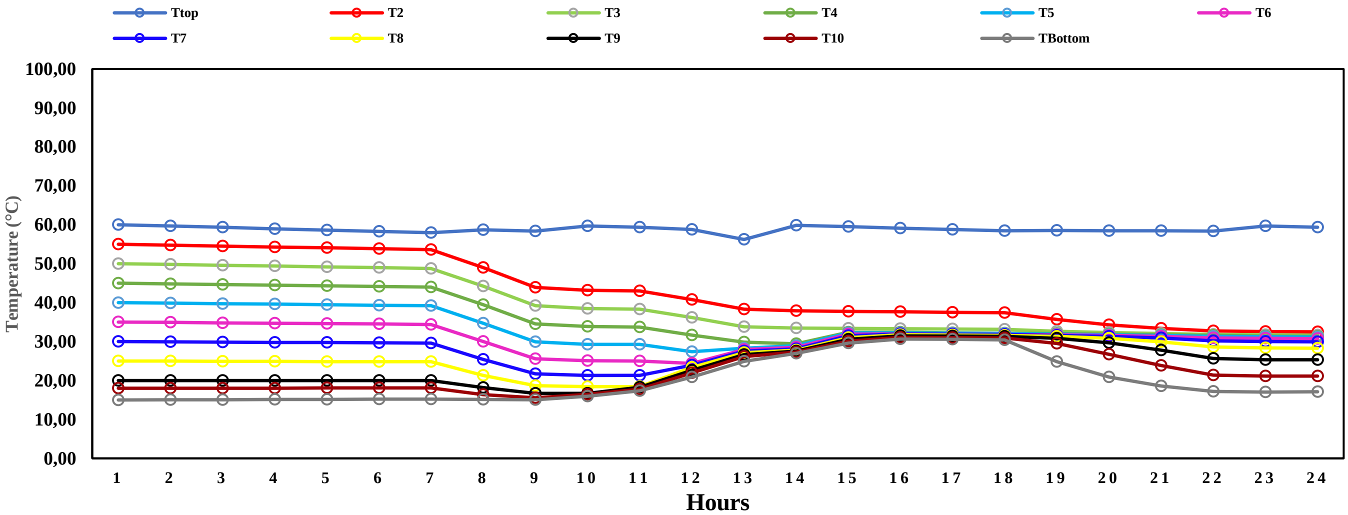


Figure 128: The temperature Variation in the storage tank.

The water flow variation and incident solar radiation are shown in the figure below. We can see that the water flow is supposed to be constant by using a circulation pump for the differential controller case. When the pump is activated, the flow rate is designed to be 200 Kg / h. The pump is activated in case the solar radiation starts to increase during the day.

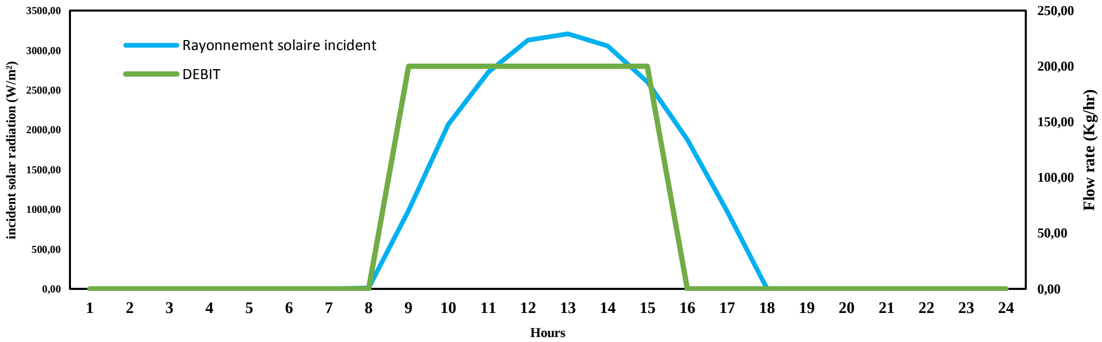


Figure 129 : Variation of incident solar radiation and water flow.

These results can be influenced by various parameters other than the technical characteristics of the subsystems used. For that, a parametric study was started to determine the parameters that influence the pump's consumption.

Location (meteorological conditions)

This part compares the pump's power consumption with two weather files: Fez and Er-Rachidia Fig.130, knowing that the meteorological data of the two regions are different (diffuse radiation, ambient temperature).

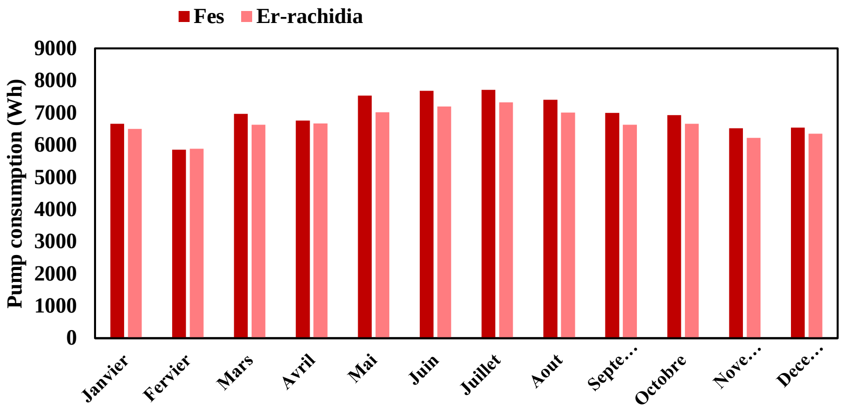


Figure 130: Power consumption of the pump in the region of Fez and Er-Rachidia.

Fig.130 shows that the pump's power consumption in Fez's region is greater than the consumption of the Er-Rachidia region because the solar radiation in Fes is more significant than er Rachidia. The collector is hot that the storage tank, and therefore the temperature difference is sufficient so that the circulation pump is put into operation.

Load profile

In this part, we are interested in studying electrical pump consumption for different water consumption profiles. Comparing the first load profile Fig. 120 with Fig.131 increasing the flow of water consumed per day compared to the first profile.

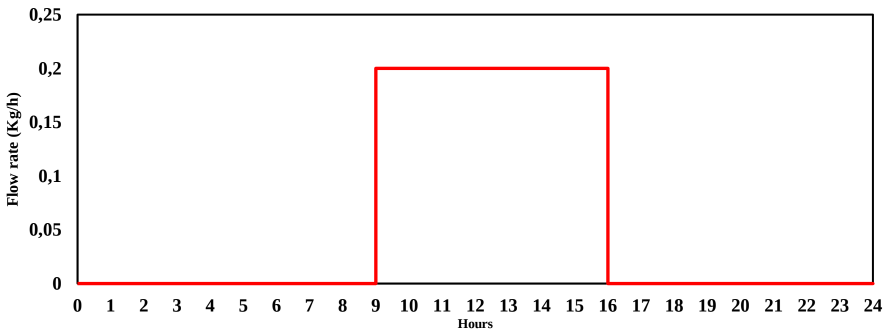


Figure 131:Load profile 2.

The variation of the power consumption of the pump for the two different profiles 1 and 2 is illustrated in Fig. 132 which shows that power consumption increases by increasing the need for water consumed during a day.

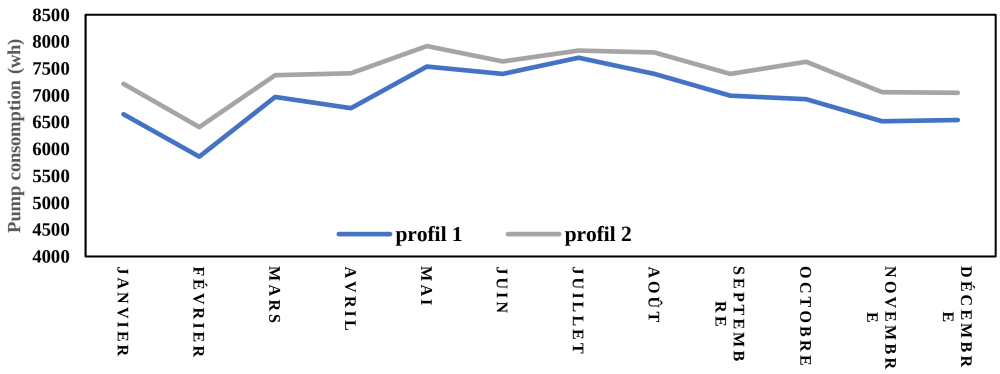


Figure 132: the variation of pump consumption using different daily water flow rate.

Profile 3, Fig. 133 The proposed is the same as 1 in terms of the daily water flow consumption, changing the distribution during the day. Fig.134 shows that for the same flow of water consumed but with a different distribution during the day, the pump's power consumption is influenced by an average of 1.5%.

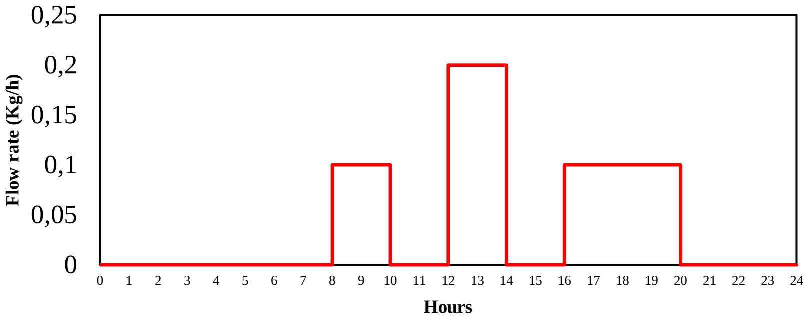


Figure 133: Load profile 3.

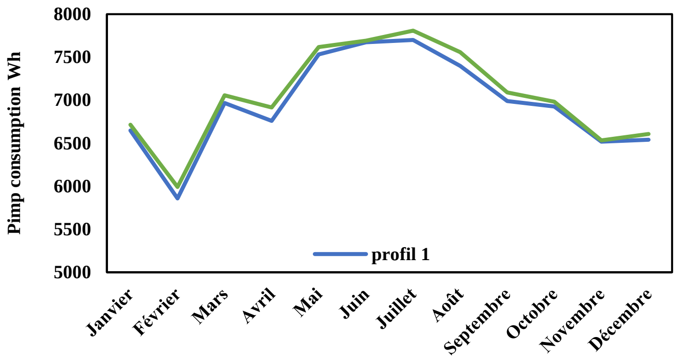


Figure 134: the variation of pump consumption using

The backup system is an essential element in a solar water heater design, which has the role of mitigating the lack of sunshine. This is to determine the ideal location of the electrical resistance to give priority to the sun while minimizing the power consumption of this backup system. From the calculation of the power consumption, and the solar fraction by placing the electrical resistance in the different storage tank nodes, we find that the top of the storage tank is a better location for backup resistance. The control of the solar water heater is an essential element that aims to regulate the flow of energy between all the solar water heater components: (the collector, the storage tank) and the user who starts and the proper shutdown of the installation. For this, a differential control is used as it is the most used, for its low initial cost, its simple algorithm, and low power consumption compared to other controllers.

4. *SHEMSY'S controllers*

As concluded from the previous parts, solar controllers have a vital role in ensuring the system's proper functioning, comfort, and energy consumption optimization. The market for solar regulators offers a wide range of highly advanced products and an excellent programmable electronic management of solar systems.

The SHemsy product offers the same monitoring and control performance with the integration of cloud computing technology connected to internet networks to ensure permanent monitoring and real-time remote monitoring of water heater operation solar by customers and the SHemsy team. The CLOUD has an impressive capacity to record data collected by all network-related points with high precision and unlimited memory.

The control of the solar installation aims to regulate the energy flow between all components of the solar water heater: the collector, the storage tank, and the user by:

• Load control for the optimal conversion of solar radiation to heat and transfer to a storage tank.

• Control of destocking (when destocking does not occur automatically by tapping) to ensure optimal heat transfer from the user's storage tank.

In small installations with dual-energy domestic water storage (one solar part, one conventional part), destocking regulation is not necessary.

The follow-up of the installation is divided into three levels below:

Visual inspection: measuring devices such as flowmeters, pressure gauges, thermometers make it possible to visually check the operation during a passage in the boiler room. They constitute the first basic level of monitoring (their accuracy is sometimes approximate). They are necessarily included initially in the system. In the case of Failure, their replacement is inexpensive (a few tens of euros per piece, excluding installation).

Control of the installation: this equipment, essential to the operation therefore necessarily present, constitutes the second level of follow-up because it allows controlling precisely the temperatures and the settings of the installation. This control can be manual during an on-site visit or automated remotely, which will generate alerts in case of malfunction. The regulation can be combined with a remote alarm box to visualize the controller. This alarm requires regular switching to the boiler room, but it can also send information to a remote server. This process will be recommended for condominiums that can appoint a "manager" within the Trade Union Council and whose maintainer has a good knowledge of the solar installation to interpret the alarms generated quickly.

Performance monitoring: at this level, it is necessary to use an energy meter (unless this type of meter is already integrated into the regulation, ask your maintainer). It helps quantify the production of useful solar energy. In the context of simplified monitoring, this data is then compared with the expected theoretical production (corrected for actual consumption of ECS or even sunlight). If the installation also has a counter that quantifies the auxiliary energy used, it is possible to know solar energy saving. All these data and their monthly evolution allow us to analyze the installation's operation and generate alerts. Again, information retrieval can be manual or automated. This non-installation equipment's cost varies from a few hundred euros for a simple energy meter to several thousand for automated general instrumentation.

4.1. Description

The SHemsy controller controls all solar water heaters (thermosiphon and forced circulation) and domestic hot water production projects, combined solar heating, and solar pool heating.

The SHemsy controller ensures a total programmable electronic management of the energy transfer from solar thermal panels to storage tanks by controlling the temperatures and water consumption (flow).

From the smallest to the complex: The controllers for adequate electronic management of all types of solar systems thanks to intelligent management of the parameters influencing system performance and the ability to connect to internet networks to ensure remote operation monitoring via mobiles and computers.

The range of SHemsy controllers presents three types of product; SHemsy Basic and SHemsy PRO for common uses of solar installations with a limited number of controlled parameters (individual domestic installation, collective installation) for the purpose is the production of domestic hot water by customers.

SHemsy LAB is a specific edition for controlling an educational installation in the laboratory that requires many more inputs.

All controllers are connected to the shemsy networks via the CLOUD space to ensure the different settings' display and registration.

4.2. Functioning

The controller continually compares the solar collector temperature (T1) and the lower part of the storage tank temperature (T2). As soon as the solar collector is heated by the sun and the temperature difference between the solar collector and the storage tank reaches 5 K, the pump activates. The pump draws the heat transfer fluid from the lower and cold part of the storage tank and routes it to the solar collector. The coolant is heated by solar radiation in the solar collector and then returned to the storage tank. Inside the tank, the heat transfer fluid heats the domestic water with a heat exchanger.

The SHemsy controller controls the temperature and the flow or consumption of hot water produced from solar installations.

4.2.1. Operating flowchart

The goal is to automate the operation of a solar water heater with a temperature differential controller.

The controller's primary function is to operate a circulating pump when temperature conditions are reached and met. There are two temperature collectors.

- T1, which indicates the outlet temperature in the solar panel.
- T2, which indicates the temperature at the bottom of the hot water tank.

When T1 exceeds T2 by more than 8°C, the circulator is started. After 10 minutes, when the temperatures balance over the whole circuit, we begin to check the conditions of stopping the circulator. It will remain in operation as long as T1 exceeds T2 by more than 5°C.

The following flowchart shows the algorithm for the operation of SHemsy controllers.

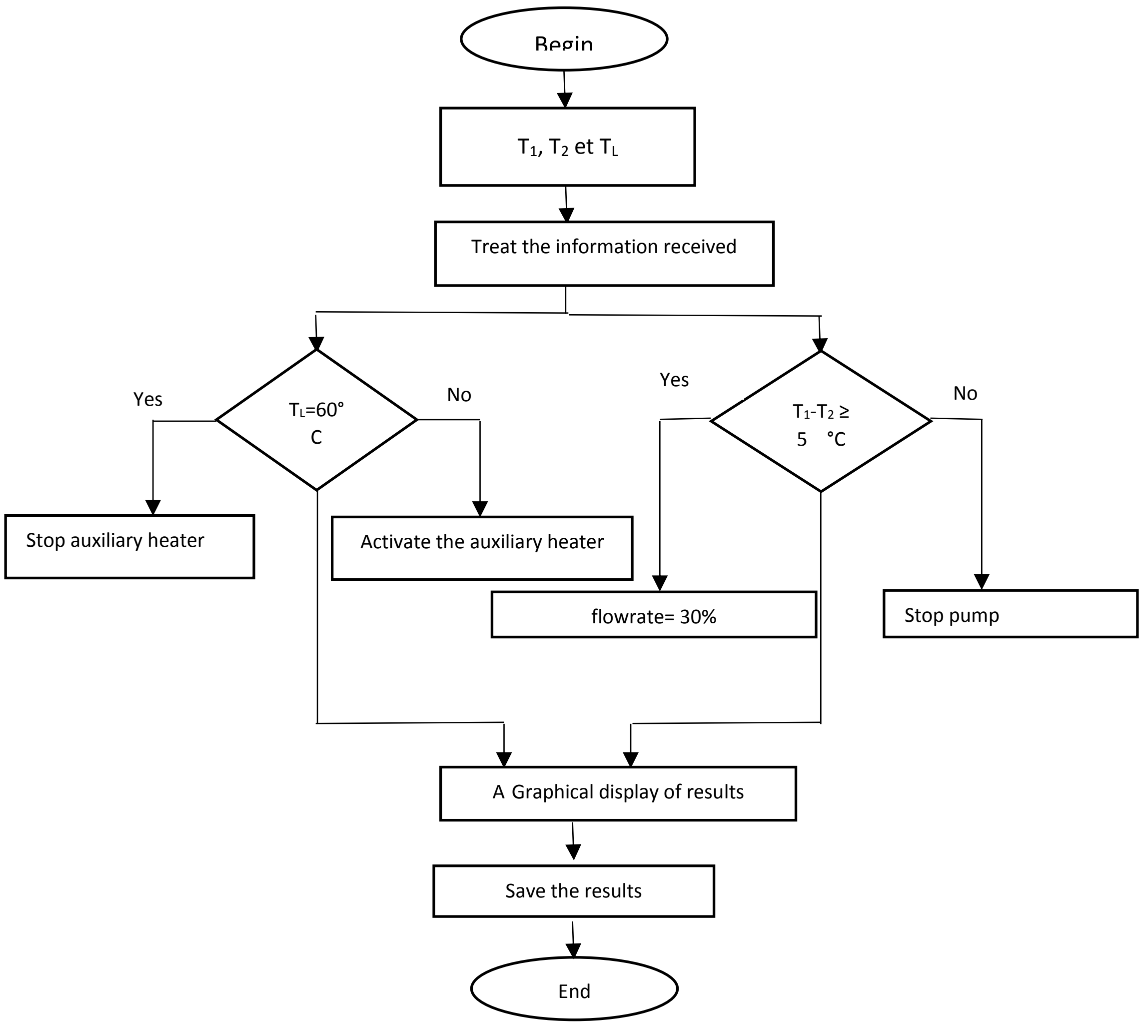


Figure 135: SHEMSY controller flowchart.

T1: the solar collector outlet temperature.
T2: the temperature at the bottom of the storage tank;
TL: Temperature to be loaded to the user;
However, the pump is activated if and only if T1-T2 5°C with a variable flow rate (between 30% and 100%) following a linear function dependent on the temperature difference T1-T2.

4.2.2. The control program

The code is divided into four parts, in this order:

- The declarations.
- Initialization.
- The loop.
- The various functions.

a) The statements(declarations)

This is where the libraries used will be declared. The advantage of the Arduino platform is that there are many ready-to-use libraries. In this case, the whole management of temperature probes already exists. It will be enough to take back the library functions, functions that we will not have to write. We will also declare the global variables, that is to say, the variables always available and the objects.

b) The initialization.

This is the setup function. This function is only run once the board is started; This is used to initialize the card before it can be used.
Here, we will initialize the board pins, power the temperature collectors, stop the circulation pump if it is on the way. The goal is to put the facility in a state that we will then be able to operate. We must not lose sight that we do not know in which state the system is.

c) The loop.

This is the core of the program; This is the loop function. Once initialization is complete, the board will run this function in an infinite loop. That is to say, as soon as it is finished, it is relaunched.
This is where the different states of the plant will be managed, and decisions will be made based on the information returned by the temperature collectors.
In summary, we start by reading the temperature collectors, and depending on the state in which the installation is located, an action and/ or a change of state can be decided.
At the end, we wait a little, here half a second, which is very short, because temperatures do not change so fast.

d) The various functions.

The purpose of these functions is often to structure the loop code. It is either a piece of code used in several applications; it is interesting to write it only once, or it is just a piece of code that is isolated, and that will now have a name. At the level of the program itself, it does not change anything. However, at the reading code level and its understanding by the author or another developer, it clarifies things greatly.

4.3. SHEMSYs' controller types

4.3.1. SHEMSY basic

The SHemsy "basic" is a controller for solar thermal installations. Integrated temperature and flow measurement (water consumption) provide information on the amount of heat produced and information on the water's load profile to properly manage its consumption and optimize the energy bill (water and electricity).

It is the temperature of the collectors and the accumulation temperature and the selected parameters that cause the pump to start. A pump outlet with cruise control is available as an option.
In the case of excessive heat production at the level of accumulation, there are three solutions:

• Pump stop: When the desired storage temperature is reached, the collector pump stops. Warning: The temperature of the collectors can then reach a very high level.
• Continuous load: The collector pump continues to operate even though the desired accumulation temperature is reached. When the collectors cool down during the night, the accumulation will be cooled through the collectors to the desired temperature. The pump stops only then.
• Alternate operation: The pump stops when the desired accumulation temperature is reached. When the collectors' temperature exceeds the value, the pump restarts, cools the collectors, and then stops again. This process is repeated so that the collector's temperature oscillates between two temperature values. When the collector cools during the night, the accumulation will be cooled to the desired temperature.
This product is subject to an energy measurement equipment .it is measures heat consumption per dwelling. The consumption is calculated in kWh from the volume of water circulating in the heating circuit of the dwelling, the temperature difference of the heating water between the entrance and the dwelling's exit.

Figure 136: SHEMSY BASIC.

4.3.2. Shemsy PRO

The SHemsy Pro controller has the same operation as SHemsy BASIC, adding a communication interface with the user (screen 3.5 touches), measuring devices such as flowmeters, manometers, thermometers allow to control. However, the screen allows monitoring the operation during a passage visually. They constitute the first basic monitoring (their accuracy is sometimes approximate) but with a response time that does not exceed 15 seconds.

The screen and the measuring instruments are necessarily originally included in the installation. Their replacement is inexpensive in case of failure (a few tens of euros per piece, excluding installation).

SHemsy PRO is a clear controller and written on the screen illuminated in full text.

Easy and fast installation with the built-in configuration wizard.

Convenient menu with clear text and graphic mode.

Understandable with English as the language of communication with the user.

Figure 137: SHEMSY PRO.

4.3.3. SHEMSY LAB

The SHemsy LAB controller is a particular purpose controller for experimental laboratory studies. It consists of multiple inputs allowing the tracking and recording of the maximum number of parameters (temperatures, pressures, flows, etc.), which will be used for scientific research laboratory studies.

SHemsy LAB is mainly intended in the project for the follow-up of an educational facility for thermal studies of solar water heaters (storage tank, solar thermal collectors, performance, efficiency, efficiency, etc.).

Figure 138: SHMESY LAB.

4.4.4. Advantages of SHEMSY controller

WIFI connexon

This mode of communication allows the exchange of a large amount of data at very short range but thanks to the Internet the range no longer has any limit. This is done via radio waves. The throughput is significant, about 1.3 Gbit/s (Gigabit per second) theoretical.
The operation is very simple and compatible with the largest number of current devices. However, it requires a router (ADSL box or 3G/4G key for example) to create the WiFi network and an internet connection to transmit the data.
It is possible to control hot water sanitary installation by smartphone or tablet online application free (compatible iOS and Android). The Internet gateway is connected to the Internet Box either by wired (Ethernet cable provided) or by WIFI (optional).

Prices
The table below presents a simple products comparative in the international market VS shemsy controller

controller	Prices
Régulateur solaire thermique et chauffage Sorel STDC V4	169,00 €
REGULATEUR-SOREL-MTDC Régulateur électronique solaire MTDC	221,00 €
REGULATEUR-SOL-XTDC Le régulateur XTDC	542,00 €
12V SR81(SR868C8) contrôleur de chauffe-eau solaire	136,72 €
average market prices	100 to 700 €
SHEMSY controller	91,87 €

Table 50: controllers prices

Thermal energy accounter	Prices
Thermal energy accounter	180 à 425 € TTC
Thermal energy accounter autonome	250 € TTC
Thermal energy accounter ultrasons	300 to 430 € TTC
Thermal energy accounter compact and ultrasons	520 to 650 € TTC
SHEMSY BASIC	73,50 € TTC

Table 51: Thermal energy accounter prices

4.4. The SHEMSY control system and connection with the CLOUD

4.4.1. Control system and CLOUD (SHEMSY NETWORK)

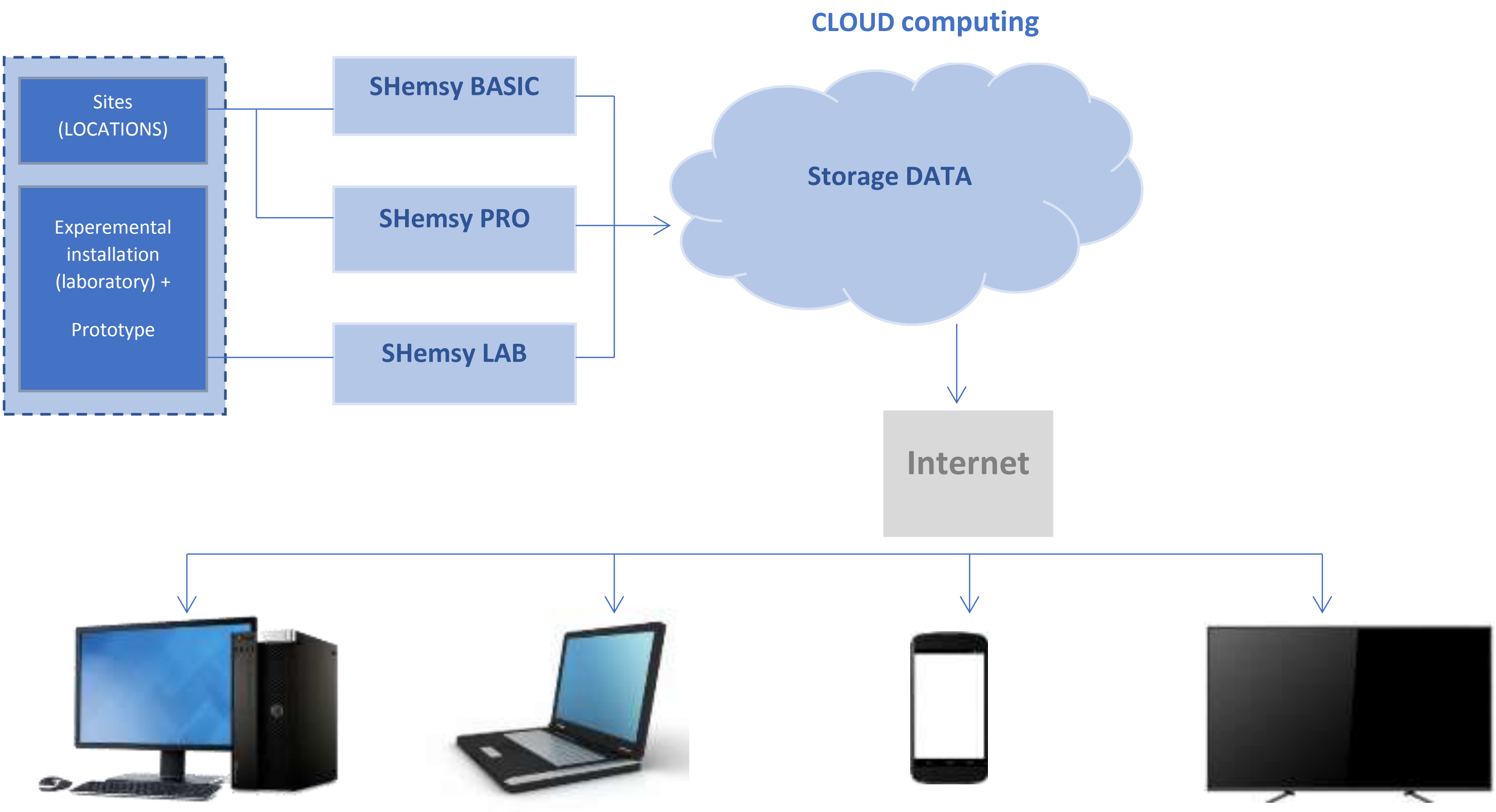


Figure 139: SHEMSY NETWORK.

Cloud computing is a set of IT services (servers, storage, databases, network components, software, analytics tools, etc.) provided via the Internet (the Cloud).
Cloud Computing is a general term used to refer to the delivery of on-demand resources and services over the Internet. It refers to storage and access to data via the Internet rather than via a computer's hard drive. It thus opposes the notion of local storage, consisting of storing data or launching programs from the hard drive. The notion of Cloud should also not be confused with that of the Network Attached Storage (NAS), used by many companies via a residential server. These local networks do not fall within the definition of the Cloud. However, some NAS allow access to data remotely from the Internet.
Generally speaking, Cloud Computing is used when it is possible to access data or programs from the Internet, or at least when this data is synchronized with other information on the Internet. It is, therefore, sufficient to access it to benefit from an internet connection.
An Internet connection allows access and display of all data stored on mobile computers and monitors.

4.4.2. CLOUD computing advantages.

Cloud computing is radically different from the traditional approach:

Cost

Cloud computing eliminates the need to invest in hardware and software and to configure and manage data centers on-site: server racks, permanent power supply for power and cooling, IT expert for infrastructure management. The bill is costly.

Rapidity

Most cloud services are provided on a self-serve and on-demand basis. Therefore, enormous computing resources can be implemented in minutes and just a few clicks, providing companies with a high level of flexibility and relieving them of capacity planning pressure.

Global Scale

Elastic scaling is one of the benefits of cloud computing services. In terms of the cloud, this means that it is possible to implement the necessary amount of IT resources, for example, more or less computing power, storage, or bandwidth, when they are needed, where they are needed.

Productivity

On-site datacenters generally require the handling of hardware, software updates, and other time-consuming computer tasks. Cloud computing removes most of these tasks, so IT teams can spend more time working towards its goals.

Performance

The most extensive cloud services run on a network of secure data centers. Whose hardware is regularly upgraded to ensure fast and efficient performance; This offers several advantages over a conventional data center, including reduced network latency for applications and more significant economies of scale.

Reliability

Cloud computing simplifies data backup, emergency recovery, and business continuity and makes these activities less costly, as data can be mirrored on multiple redundant sites on the provider's network.

4.4.3. SHEMSY CLOUD computing type

The CLOUD used in the project is a private cloud that presents all the cloud computing resources used exclusively by a company or organization (the SHEMSY project team). The private cloud can be physically located in the local project data center. The private cloud is a cloud in which services and infrastructure are located on SHEMSY's private network.

4.4.4. How cloud computing works

Cloud computing services all work slightly differently, depending on the provider. Nevertheless, most of them offer a user-friendly dashboard, accessible via a browser, that allows IT professionals and developers to control resources and manage their accounts. Some cloud computing services are also designed to work with REST APIs and a command-line interface, providing developers with multiple possibilities.

4.4.5. SHEMSY CLPOUD connector

A Cloud "Connector" allows you to establish a connection between a Cloud platform and IT systems or networks on-site and provides direct access to online storage sites. Discover the list of the most used «Connectors» Cloud, as well as their features and benefits.

The project's idea is to use the Cloud, but continue to use the on-site installations in parallel for some operations; This is called a hybrid computing environment. In this context, it is sometimes necessary to establish communication between the Cloud and on-site infrastructures; This is why the Cloud Connector offer was offered. The definition of this term, used as a proper name by a wide variety of firms, varies from one supplier to another. However, as a rule, a Cloud Connector makes it possible to establish a connection between a Cloud platform and an on-site installation.

Figure 140: SHEMSY CLOUD connector.

4.5. Use: the architecture of the Shemsy network
The SHemsy network consists of multiple data collection points, which will be sent to the Cloud network, saved and displayed on the previously mentioned communication interfaces.

4.5.1. The sites of the SHemsy network (DATABASE)
The selected sites represent users of solar water heaters in different geographical locations in Morocco and for different types of domestic installations, individual or collective use, thermosiphon or forced circulation, and a variety of technologies (with flat collectors and vacuum tube).

The choice of sites is based mainly on climatic conditions so that we will have a rich and varied database according to several locations and type of climates.
All sites will be equipped with SHemsy regulators, the total number of sites is 40, 30 sites connected with SHemsy BASIC regulators, and 10 sites with SHemsy PRO regulators.

The construction of the SHemsy network according to a well-studied architecture will serve to build a crucial database in the field of solar water heaters in Morocco, by monitoring the performance of this technology under Moroccan climatic conditions, monitoring of the various vital parameters influencing plant performance and performance, monitoring system malfunctions and monitoring for faults and shutdown frequencies and failures, quantify the consumption of hot water in the kingdom and draw up custom drawing profiles that describe the real behavior of Moroccans vis-à-vis the habits of domestic hot water consumption.

4.5.2. EST-Fes Laboratory

The SHemsy network consists of a laboratory part that serves the monitoring and control of the solar thermal system didactic to carry out studies and research. This part integrates the performance monitoring and validity testing of the solar water heater prototypes SHemsy.

Conclusion

This chapter is a lively part of the project. It gave an overview of the control systems in general. More precisely, the control of the solar thermal systems, including the operation of this primordial part, has any system. The second part s is forced on the modeling and optimization of the control system for domestic use. This part was to Carry out a comprehensive study analyzing the solar water heater's operation. This system is intended to cover the domestic hot water needs of a house. The study began according to two guidelines; the first is a study of the regulation of a solar installation which aims to regulate the flow of energy between all the components of the solar water heater: the collector, the storage tank, and the user, and to ensure proper start-up and shutdown of the installation. This management of the solar water heater is essential to make the most of the solar energy available. A state-of-the-art development of different strategic approaches to temperature control allowed an assessment of the characteristics, advantages, and disadvantages of several temperature controllers. The solar water heater's performance was evaluated according to a second director and by dynamic simulation via the TRNSYS studio software. Indeed, this step's importance remains in determining a better combination of the parameters of each of the components of the model and a parametric study that ensures optimal functioning. According to this, the regulation chosen for this system is the differential regulation that allows meeting the needs, for its simple algorithm, its low initial cost, and its low power consumption. Indeed, another parametric study was discussed to determine the ideal location of the auxiliary resistance inside the storage tank to compensate for the lack of sunlight while minimizing the auxiliary system's power consumption. This study made it possible to optimize a 64% reduction rate for the auxiliary heater to the top compared to the bottom, and a larger solar fraction.
The passage through all these previous steps has made it possible to propose the solution of control SHEMSY which is qualified intelligent, economical, technological and with a sophisticated design.

Part *III*: Manufacturing process, Business plan and quality management system design

Chapter VII: *Technical study: SHEMSY products Manufacturing process*

Introduction

This chapter is the result of all the research and development studies previously presented. This part will enable the project to be completed studying and presenting all technical elements necessary for the factory construction and operation and the project's financial evaluation and profitability.

The technical study focuses on defining all the equipment required for the manufacture of our products and their characteristics and the search for a suitable location for our equipment while calculating their cadence to ensure their ability to meet sales forecasts. Next, we will set up our production workshop. And finally, the exhaustive determination of the needs of the company.

1. Process

To define a technical study, it is necessary to establish the product's different manufacturing processes. To do this, we used the SIPOC tool (the acronym for Supplier Input Process Output Customer), which allowed us to describe the manufacturing processes in detail. the manufacturing processes adopted is to choose the right machines and in establishing the production line.

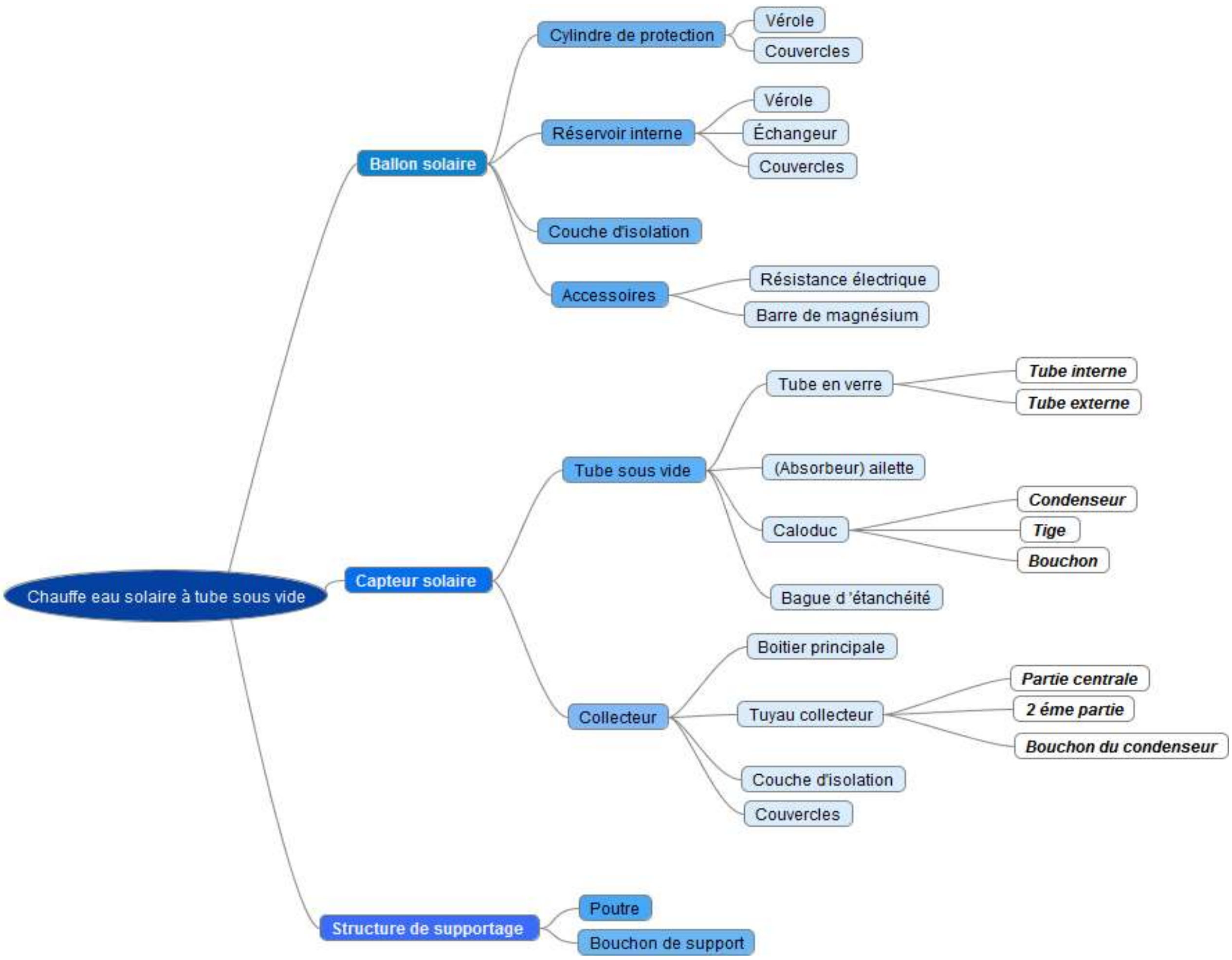


Figure 141: SHEMSY SWH components.

1.1. Storage tank

The storage tank consists of an internal tank, protection cylinder, insulation layer, and covers.

The internal tank and protection cylinder go through the same manufacturing steps

- Sheet metal cutting and rolling
- Punching of sheet metal
- Longitudinal Pox Welding

Inner cylinder cover

- Circular cutting of bottom sheet.
- Stamping of the sheet metal to have the lid's shape then drilling for the assembly of the electrical kit.

After preparing the internal tank, protection cylinder, and covers come to the assembly and assembly steps and some treatments (enameling, blasting, injection of the insulation layer,.) for more details, see SIPOC for the tank.Apendix.

1.2. Evacuated tubes

The vacuum tube consists of a simple vacuum tube attached to the thermal absorber and the heat transfer fluid line (heat pipe).

Heat pipe: it is in the form of an airtight enclosure to contain the heat transfer fluid, and consists of a longitudinal pipe and ahead called a condenser.

Fin: This is the vacuum tube absorber, consists of a single piece.

1.3. exchanger (for forced circulated SWH)

The collector is located at the top of the solar collector; it consists of a central box, a collector pipe, an insulation layer, and covers.

<u>The main box</u> goes through the following steps: Cutting, Punching, Folding, Welding.

<u>Collector pipe</u>: this is the element that brings together the heat pipes; it consists of a central part, a second part, and caps for the condensers.

The central part undergoes: Cutting, Drilling

The second part is: Cutting, Filming

Condenser cap: Cutting.

1.4. Support Structure

The support structure consists of several beams of the same shape, but with distinct dimensions:

Each Beam passes through:

- Cutting
- Punching
- Folding

2. Production means Characteristics.

The definition of the characteristics of the means of production will be based on the choice of production equipment.

2.1. Selection of machines

The choice of machines is closely linked to the manufacturing process and the volume of production. It shall be based on as precise analysis as possible of future operating conditions.

After having collected documentation through specific sales structures and catalogs of some foreign manufacturers vial' Internet,

3. Location of the means of production

Once the equipment is well chosen, a good location plays an essential role in the economic management of the company; its impact appears on many elements on which depends the cost price:

- The circuit lengths.
- the surfaces needed for the workshops.
- the number of operators required to operate the machinery and the time lost while traveling from one workstation to another.

3.1. Choice of production process type

• Online production: in an online process, machines or installations are dedicated to the product to be manufactured. There is a dominant flow of products because all units produced travel through the workstations in the same sequence.

• Job-shop, or workshop: The implantation is carried out by practical workshops which group the machines according to the task they perform (turning, milling...). The flow of products depends on the sequence of tasks to be performed. It is said that we are in the presence of a task shop which our Anglo-Saxon colleagues call a job shop.

• Production by the project: In the case of production by project, the product is unique. Examples are the organization of the Olympic Games or the construction of a dam. The production process is unique and is not renewed. Therefore, the principle of one production per project is to chain all the operations leading to the completion of the project, minimizing downtime to deliver the product with minimum time or at the agreed time[228].

An online production system is characterized by the fact that resources (machines, men) are organized according to the article to be produced: it is said that the process is organized by product. However, in a job-shop, resources are grouped based on their operations: the process is organized by function.

From this comparison between the different production systems, we can deduce that online production is the most suitable for SHEMSY case since it is characterized by:

- Only one type or very few types are produced.
- The number of units produced (production volume) is high.
- Equipment is highly specialized, automated, and not very flexible.
- Investments in equipment and system design studies are significant.
- The workforce is limited.
- The rate of use of equipment is very high (often more than 90%) [228].
-

3.2. Organization of the means of production

After having decided the production process type «in-line production» and the equipment to be acquired, the firm is still faced with more specific problems of setting up production installations (machines, workstations, departments, ...), that is to say, the relative location of the means of production[229].

The establishment of production means must be established according to a logic that makes it possible to separate the factories.

- Identify among all the means of production of the most independent production islands possible.

-Upload each identified block[228].

3.2.1. Identification of Production Islets

The machines are grouped into autonomous production units specialized by type of product that use the same machines: these units are called islands,

We present below the islands of our factory; they are chosen according to the circulation of coins:

- the solar storage tank Islet.
- Heat Pipe islet + Manifold Pipe.
- Support Islet + Aluminum Fin.

3.2.2. Placing of the islets

After identifying the most independent production blocks, each block must be set up. We applied the medium ranking method for the islets implementation as it is a suitable method for SHEMSY type of production process (online production)[230].

<u>*The middle ranks method*</u>

From the ranges of manufacturing each product, the total of the ranks for each workstation (the sum on all the row of passage on the relevant workstation in the range), and the number of products passing on each workstation are calculated.

We will apply this method to each islet.

3.3. Production rate (cadence)

After having had a general idea of how to implement each islet's machines, we opted to study the production rate by first calculating the operating cycle of each island and its corresponding rate. Indeed, the chain can never reach the maximum cadence as long as it is unbalanced, thus comes the idea of balancing the line to reach the maximum cadence and satisfy our needs for sale for the next three years.

- **The operating cycle**: (C, also called production cycle) is the time interval between two consecutive units' output. With Ti, it is time for an operation.

$$\text{Operating cycle} = T1+T2+\ldots\ldots + Tn \ [43] \qquad (116)$$

- **Cadence**: The number of units produced per unit of time, usually in hours.

$$\text{Cadence} = (60 \text{ min}) / (\text{operating cycle} \qquad (117)$$

3.3.1. The operating cycle calculation

<u>Storage tank.</u>

Operation	Operations nbr	time (s)	Commute time (s)
Unwinding + punching + bending + cutting	1	180	70
Circular division of funds + stamping (2)	2	120	
Longitudinal welding	1	90	
Arc welding	1	71	
Metal shot blasting	1	120	
Polyurethane injection	1	160	
Leak test	1	67	
Mounting accesories	1	720	
Tank assembly	1	90	
packaging	1	58	
Total		1866	

Table 52: Storage tank operating cycle.

Heat pipe

Operation	Operations nbr	time (s)	Commute time (s)
cutting (2)	2	4	9
turning	1	30	
Braze-welding (2)	2	40	
sintering	1	14	
Exhaust air from the pipe	1	13	
Filling fluid	1	8	
Total		162	

Table 53: Heat pipe operating cycle.

Manifold pipe

Operation	Operations nbr	time (s)	Commute time (s)
cutting (13)	13	4	10
Turning (2)	2	60	
Piercing	1	100	
Braze-welting(12)	12	40	
cooling	1	30	
Total		612	

Table 54: Manifold pipe operating cycle.

Aluminum fin

Operation	Operations nbr	time (s)	Commute time (s)
cutting	1	8	13
bending	1	10	
Bending	1	20	
Total		51	

Table 63: Aluminum fin operating cycle.

Support

Operation	Operations nbr	time (s)	Commute time (s)
punching (8)	8	25	14
cuting (8)	8	20	
bending (8)	8	30	
packaging	1	40	
Total		654	

Table 55: support operating cycle.

3.3.2. Islets operating cycle calculation and cadence

After calculating the operating cycle for each component, we calculated the operating cycle for each island.

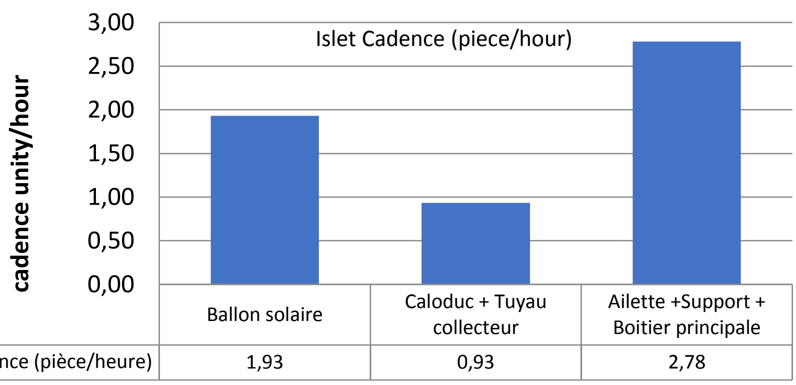


Figure 142: Islets cadence.

3.3.3. *Expected production rate*

For working hours, we have set 24h/d, and 301 days per year (365 days of the year minus holidays and a weekly day of rest [231]).

Time available/ period = 24 h/ day.

According to sales forecasts, the objective is to have 100,000 pieces per year.

Production / period= pieces /year = 100,000 /301 day = 332.22 unit / day.

So, the expected cadence = 13.84 unit/ hour.

From previous figure, we have noticed that our production chain is not balanced and that its production capacity = 1/5 da the desired capacity. So, we must first balance the production chain and then reach the expected pace.

3.3.4. Balancing of the production chain

Balancing is the distribution of sequential activities into shifts for optimal use of means and men: reducing dead time and bottlenecks.

A bottleneck is a difficulty for part of the production chain to respond as quickly as possible to increase demand. It is, therefore, a point in the production system that limits its overall performance. In the following, we will present the distribution of each islet's spots to determine the operation, which constitutes the bottleneck to treat.

storage tank

The following graph shows the distribution of the solar tank production cycle's overall operations.

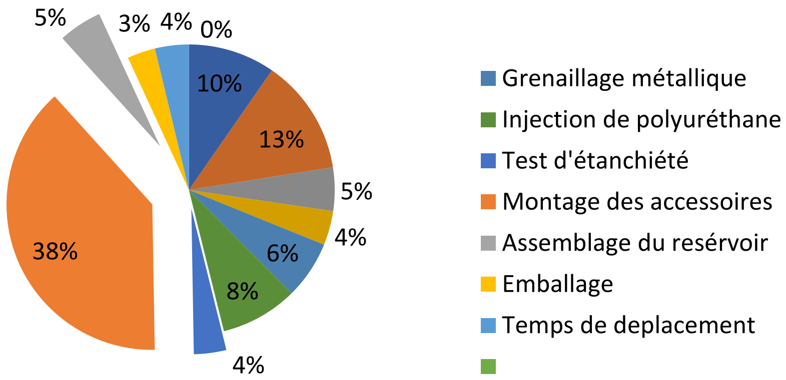


Figure 143: Each operation time (%).

Mounting accessories is a manual operation that takes 38% of the time, so to have a balance, we can double the number of operators five times.

Heat pipe and manifold pipe

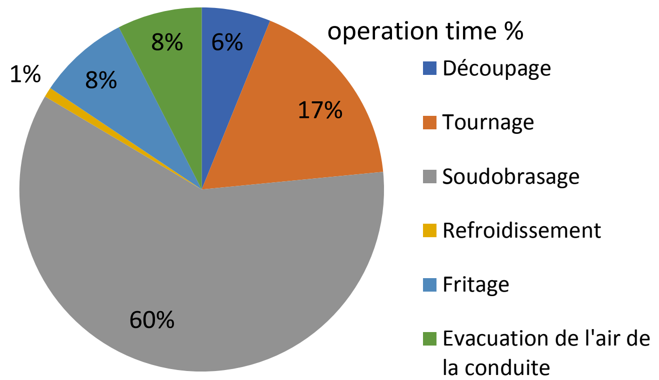


Figure 144: heat pipe operation time %.

welding is also a manual operation takes 60% of the operating time of the islet, so to minimize it, we will opt for the same solution "Double the number of operators," but this is not enough to reach the capacity = 2.78 unit/ hour so we must move to the repetition of the other shifts.
Here are the repeats achieved:
- Turning machine 3 times
- Sintering machine 2 times
- Exhaust pipe air 2 times
- Soldering 9 times

3.3.5. Rate ecalculation after balancing

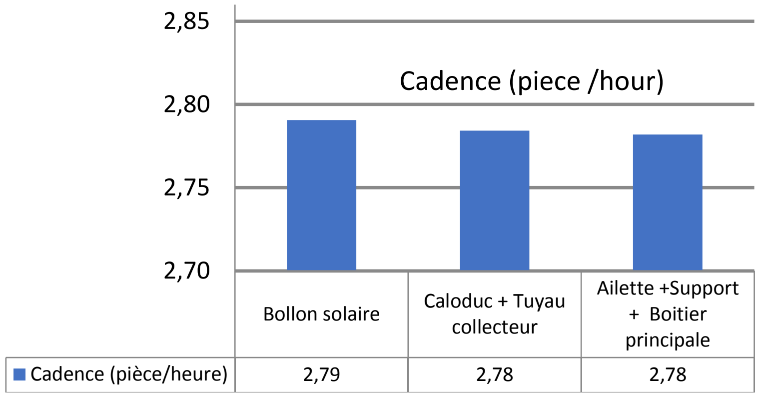


Figure 145: islet rate after balancing.

We can deduce that the production line becomes balanced through the results, and its maximum cadence is 2.78 units/ hour, so to reach the expected cadence, we must redouble this production line 5 times.

Synthesis.

Based on the sales forecasts and the calculation of the rate, we have found that our production chain is becoming able to offer the expected quantity of SWHs.

Note

The implementation of the means of production of forced circulation SWHs and single-block SWHs are almost identical. That is why we have chosen to present just that of forced circulation SWHs to avoid redundancy.

4. The layout of the production unit

4.1. General Layout

This is the general layout of buildings, services, and essential equipment. Indeed, the different premises that make up the factory are the administrative building, the manufacturing workshop, the shops and changing rooms, the reception, the infirmary, the electrical substation, and the air compressor room. Our unit has dimensions:(L*l)=310 m x 131 m, the calculation of the total area occupied for these dimensions gives 40 610 m^2.
The rules of proximity between the different premises are established to have better flexibility.
The drawing below represents the general plan of the site. One observes in the left flank of the factory entrance the administrative building in front of which is arranged a green space, a space of exhibition of the manufactured products, and parking.
Just after the administrative building is the production workshop, it is lined up raw materials and finished goods stores, changing rooms, and toilets for workers.

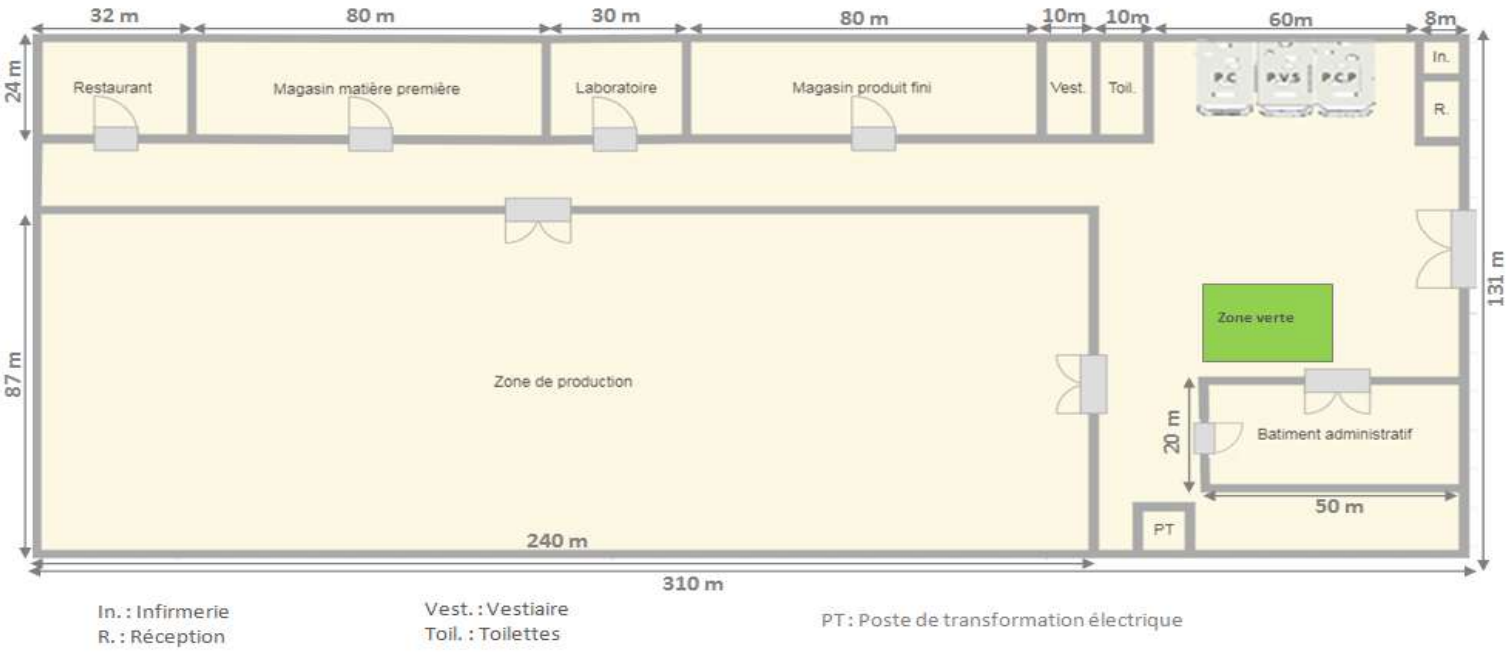


Figure 146: The general layout of the production unit.

4.2. Detailed Layout

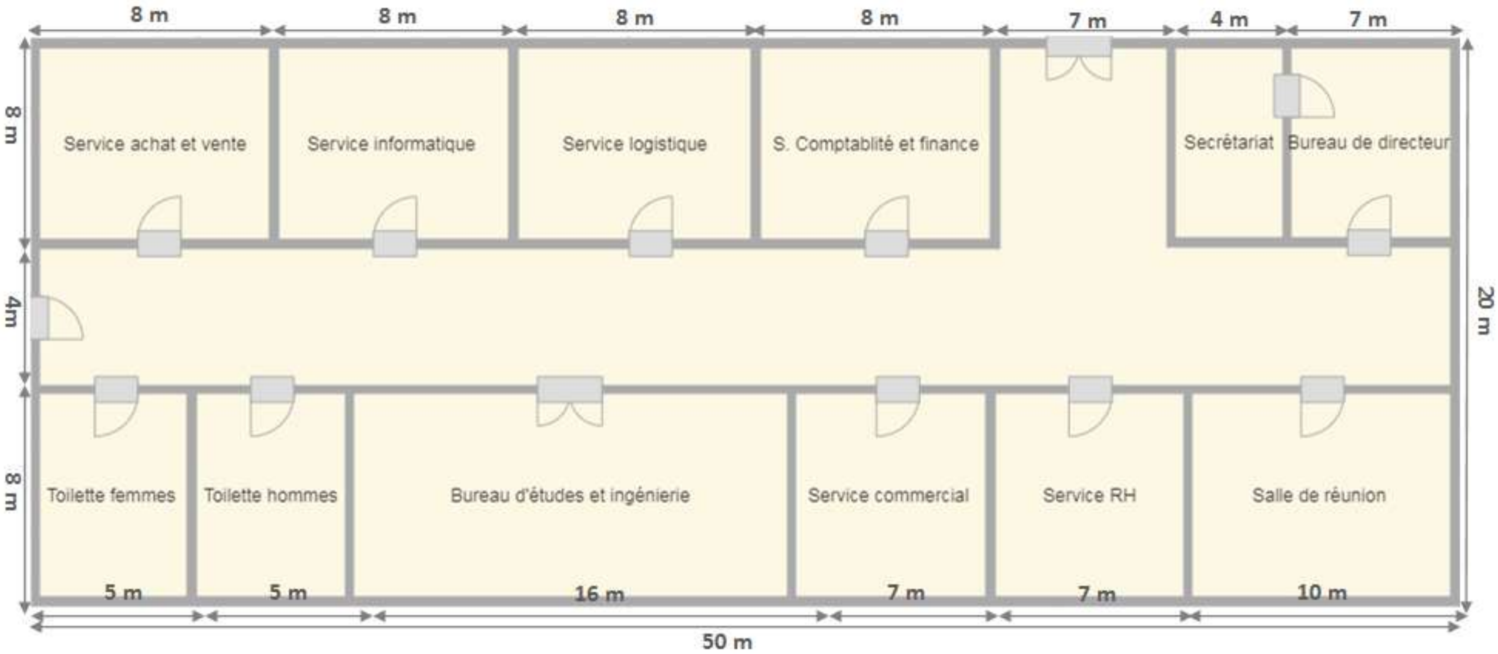
This phase is presented as a set of drawings and plans that show the location of each element. Thus, we have drawn up detailed plans of the administrative building and the manufacturing workshop.

Administrative building

The administrative building houses six (6) offices composed of:

• Office of the Director;
• Purchasing department;
• Logistics department
• Accounting and Finance
• Computer Services
• Sales Department
• Human Resources Department
• Design and engineering office;
• Director's Secretariat;
• Meeting room

Furthermore, two toilets (for men and women). At the entrance of the administrative building is



arranged a hall that will serve as a place of waiting for the visitors and displaying the information.

Figure 147: Administration building.

<u>Manufacturing workshop.</u>

This phase is presented as a set of drawings and plans that show the location of each element. Thus, we have drawn up detailed plans of the administrative building and the manufacturing workshop.

Administrative building

The administrative building houses six (6) offices composed of:

- Office of the Director;
- Purchasing department;
- Logistics department
- Accounting and Finance
- Computer Services
- Sales Department
- Human Resources Department
- Design and engineering office;
- Director's Secretariat;
- Meeting room

Furthermore, two toilets (for men and women). At the entrance of the administrative building is arranged a hall that will serve as a place of waiting for the visitors and displaying the information.

Note:

There is not much difference between the forced-circulation SWH unit's layout and that of the thermosiphon SWH. Only the "drilling" machine will be installed in the production unit of the forced-circulation ESC and not installed in the single-block ESC.

5. *Economic evaluation of the manufacturing process*

After establishing the manufacturing process and identifying the machines' characteristics and the workshop's production rate, an economic evaluation of this process will be comprehensively determined.

5.1. Investment Requirements

Investment needs are mainly based on civil engineering constructions, machinery, rolling stock, office equipment, furniture, and transport equipment.

5.1.1. Construction of civil engineering

For the different construction companies in Morocco, the average price of construction is 2000 MAD/m^2, and on which we based to estimate the cost of construction. The construction cost (area of 40,610 m^2) is 81,220,000 MAD.

5.1.2. Machines

	Machinery, Equipment and Technical Installation	Qty Forced circulation	Qty Monobloc	Unit price (MAD) HT
Machines	MABI 16-3 Rohrblitz	5	5	1 690 962,00
	Longitudinal Tig Welding Machines	5	5	68 545,68
	Hydraulic press	5	5	106 000,00
	Arc welding machine	5	5	60 556,00
	Shot Blasting machine	5	5	3 975 065,79
	Polyerethane foam injection machine	5	5	48 250,00
	TL-363 Automatic tube cutting machine	5	5	60 745,34
	CNC automatic lathes	15	15	60 745,34
	Blowtorche	30	25	179,00
	Copper tube drilling machine	5	0	161 086,42
	Filling fluid installation	5	5	2 303,23
	sintering machine	10	10	20 848,19
	Punching machine	5	5	74 503,01
	Combined bending and cutting machine COSINUS	5	5	22 180,00
	Bending machine	5	5	74 000,00
	Inverter	1	1	700 000,00
	Electrical Transformation Station	1	1	600 000,00
	Air compressor	1	1	119 990,00
	Digital Micrometer (Capacity: 0-25 mm, Accuracy: 1 µm)	10	0	2537,81
	Digital Micrometer (Capacity: 25-50 mm, Accuracy: 1 µm)	5	5	3087,81
	Digital Micrometer (Capacity: 300-500 mm, Accuracy: 1 µm)	15	15	12189,21
	Leak test machine	5	5	26 400,00
	Water leak detector	5	5	715,00
	Continuous jet sprayer with 4-meter extension	2	2	770,00
	Climatic chamber	1	1	600 000,00
	Negative Mechanical Load Test Machine	1	1	2 446,18
	Positive Mechanical Load Test Machine	1	1	36 430,00
	Thermal simulator	1	1	90 000,00
	Impact test apparatus	1	1	54 681,00
	Digital Micrometer (Capacity: 0-25 mm, Accuracy: 1 µm)	2	2	2537,81
	Digital Micrometer (Capacity: 25-50 mm, Accuracy: 1 µm)	1	0	3087,81
	Digital Micrometer (Capacity: 50-75 mm, Accuracy: 1 µm)	1	1	3806,77
	Digital Micrometer (Capacity: 300-500 mm, Accuracy: 1 µm)	1	1	12189,21
	Fiber tape measure	2	2	275,00
	Other equipements			
	Total for SWH Monobloc			34 690 253,23

Table 56: Machinery, Equipment and Technical Installation; economic.

5.1.3. Transportation

It consists mainly of liaison trucks, passenger cars, service cars, and forklifts for handling.

.

Transportation equipment's	Qty Monobloc	Unit price (MAD) HT
Truck	8	300000
Staff car (21 places)	11	339167
Front-end loader (2500 kg)	6	130000
Service car	4	130 900
Total for SWH Monobloc		7 608 437

Table 57: Transportation equipment; economic evaluation.

5.1.4. Office materials

Office material	Qty	Unit price (MAD) HT
(Desk+chair) for staff	35	5 900,00
One (desk+chair) for manager	1	22 500,00
Meeting table	1	18 630,00
Total for SWH Monobloc		247 630,00

Table 58: Office materials; economic evaluation.

5.1.5. Computer equipements

Computer equipment	Qty	Unit price (MAD) HT
Desktop Computers – HP Classes	35	6 970,00
HP Printer Copier	10	3 489,00
Total for SWH Monobloc		278 840,00

Table 59: Computer equipements; economic evaluation

5.2. Operating Requirements

Operating requirements are the requirements related to the regular activity of the business. They include raw materials, water, energy, human resources, operating equipment, and ancillary services.

5.2.1. Raw material

The tank and collector assembly will require the raw materials presented in the next table.

component	Element	Characteristics	Unit price HT	Year N	Year N+1	Year N+2
				price (MAD)	price (MAD)	price (MAD)
Storage tank	Internal reservoir	2 mm thick stainless-steel sheet	394	23 640 000,00	31 520 000,00	39 400 000,00
	External reservoir	0.7 mm thick DX51D EF steel sheet covered with Z275 galvanization and prior application of 35 µm thick RAL 7035 paint.	175	10 500 000,00	14 000 000,00	17 500 000,00
	2internal tank cover	1.8 mm thick stainless-steel sheet	18	1 080 000,00	1 440 000,00	1 800 000,00
	2external tank cover	Black UV-treated polypropylene covers	48	2 880 000,00	3 840 000,00	4 800 000,00
	metal shot-blasting	cast and treated steel	43,8	2 628 000,00	3 504 000,00	4 380 000,00
	insulation	Polyurethane	178	10 680 000,00	14 240 000,00	17 800 000,00
Manifold pipe	Central part	Cooper tube	115,2	6 912 000,00	9 216 000,00	11 520 000,00
	2nd part	Cooper tube	16,8	1 008 000,00	1 344 000,00	1 680 000,00
	20 Condenser cap	Cooper tube	145,6	8 736 000,00	11 648 000,00	14 560 000,00
Absorber	20 fins	Aluminum sheet	153,44	9 206 400,00	12 275 200,00	15 344 000,00
Support	beams	Steel DX51D coated with metal ZM195	191	11 460 000,00	15 280 000,00	19 100 000,00
	20 support plug	Nylon	240	14 400 000,00	19 200 000,00	24 000 000,00
	2 covers	Plastic	30	1 800 000,00	2 400 000,00	3 000 000,00
	insulation	Rock wool	57,6	3 456 000,00	4 608 000,00	5 760 000,00
Vaccum tube	20 leak rings	Silicon	10	600 000,00	800 000,00	1 000 000,00
	20 vaccum tube	Glass forming	1200	72 000 000,00	96 000 000,00	120 000 000,00
Heat pipe	20 Condensors	cooper	145,6	8 736 000,00	11 648 000,00	14 560 000,00

	20 Rod	cooper	1224	73 440 000,00	97 920 000,00	122 400 000,00
	20 plug	cooper	80	4 800 000,00	6 400 000,00	8 000 000,00
	20 sintring	Sintering powder	39,6	2 376 000,00	3 168 000,00	3 960 000,00
Accessories	extchanger		85,6	5 136 000,00	6 848 000,00	8 560 000,00
	1.8 Kw electrical kit includes: 1.8 Kw short electrical resistance flange, short probe holder thermostat, titanium anode, magnesium anode, flange seal 6 set screws		480	28 800 000,00	38 400 000,00	48 000 000,00
	Pressure reducer		196	11 760 000,00	15 680 000,00	19 600 000,00
	Mixing valve		540	32 400 000,00	43 200 000,00	54 000 000,00
	Non-return valve		64	3 840 000,00	5 120 000,00	6 400 000,00
	fluid		288	17 280 000,00	23 040 000,00	28 800 000,00
	Connection kit B.S		344	20 640 000,00	27 520 000,00	34 400 000,00
	Connection kit P.S		91,2	5 472 000,00	7 296 000,00	9 120 000,00
Others	Carton		8	480 000,00	640 000,00	800 000,00
	Weld Stripper		4,96	297 600,00	396 800,00	496 000,00
	Penetrant Pack		10440	10 440,00	10 440,00	10 440,00
	bolting, fittings, seals, etc.		10	600 000,00	800 000,00	1 000 000,00
Total for SWH Monobloc				363 622 440,00	484 826 440,00	606 030 440,00

Table 60: Raw material economic evaluation.

5.2.2. Water Requirements

Water is mainly used in the factory for human needs and watering the green space and its primary activities. We assume that the unit does not have a considerable need for water. Thus it will be included in the increases during the financial study.

5.2.3. Energy requirements

Energy requirements are based on electricity and fuel for the operation of vehicles.

Estimated fuel requirement:

It is considered that the truck will make a maximum of 300 km/d on Fez and some cities. As for the staff bus, the daily journey will be estimated at 50 km, which corresponds to about four journeys per day between the factory and the city center, the service car at 30 km/d, and the forklift at 10 km/d.

The truck's average fuel consumption is 0.35L/km, that of the personal coach is 0.2L/km, that of the service car 0.06L/km, and that of the forklift at 0.27 L/km.

We have 301 business days, so:

• ***Annual truck consumption***

- Forced circulation SWH: 300 *0.35*10*301= 316,050 L of diesel per year.
- SWH monobloc: 300*0.35*8*301 = 252,840 L of diesel per year.

• ***Annual consumption of transportation collective service***

- Forced circulation SWH: 50 *0.2*12*301= 36,120 1 of diesel oil per year.
- SWH monobloc: 50*0.2**301= 33 110 L of diesel oil per year.

• ***Annual forklift consumption***

- Single Block Forced Circulation CES: 10*0.27*6*301= 4876.20 L of diesel oil per year.

• ***Annual consumption of service cars***

- Single Block Forced Circulation SWH: 30*0.06 *4*301= 2167.20 L diesel per year.

Total consumption for SWH with forced circulation: 359,213.40 L of diesel oil per year.

Total consumption for single unit ESC: 292 993.40 L of diesel oil per year

The average price per liter Gasoil is 10 MAD/L.

The annual cost of diesel oil is:

Forced circulation SWH: 359 213.40 *10 =3 592 134 MAD.
SWH thermosiphon: 292 993.40 *10 = 2 929 934 MAD.

5.2.4. Electricity bills:

Electricity is consumed by production equipment, office equipment, and lighting.
Consumption of production equipment:
To calculate the consumption in kWh of the equipment, we took into consideration 3three data:
- the power of the equipment expressed in watts
- number of hours per day the equipment is operating
- the number of days per year that the equipment operates.

The formula for calculating equipment consumption is as follows:

$$[\text{operation hours}] \times [\text{operation days}] \times ([\text{apparatus power watts}] / 1000) = \text{electricity consumption kWh } [232] \quad (118)$$

The detailed calculation of electricity consumption for each year, based on the formula above Thermosiphon electricity consumptions for each year are on APENDIX.
In the table below, we have put the electricity requirements for the next three years. The tariff used to calculate the cost of electricity is from RADEFF; for industries, the tariff is approximately 0.8101 HT per kWh [233].

	Machine	Electricity consumption kWh per year		
		N	N+1	N+2
Machine	MABI 16-3Rohrblitz	60 000,00	80 000,00	100 000,00
	Hydraulic press	15 200,00	20 266,67	25 333,33
	TIG welding machine	9 000,00	12 000,00	15 000,00
	ARC welding machine	15 975,00	21 300,00	26 625,00
	Shot Blasting	600 000,00	800 000,00	1 000 000,00
	Polyurethane injection machine	3 466,67	4 622,22	5 777,78
	Aluminum sheet punching	91 666,67	122 222,22	152 777,78
	Folder cutter	171 816,67	229 088,89	286 361,11
	Copper tube drilling machine (not included for monobloc CES)	41 666,67	55 555,56	69 444,44
	Bending machine	73 333,33	97 777,78	122 222,22
	TL-363 Automatic tube cutting machine	5 653,33	7 537,78	9 422,22
	CNC lathe	15 000,00	20 000,00	25 000,00
	Sintering machine	42 000,00	56 000,00	70 000,00
	Fluid filling	53 333,33	71 111,11	88 888,89
	Continuous jet sprayer with 4-metre extension	49 123,20	49 123,20	49 123,20
	Climatic chamber	147 690,67	147 690,67	147 690,67
	Negative Mechanical Load Test Machine	33 712,00	33 712,00	33 712,00
	positive Mechanical Load Test Machine	31 304,00	31 304,00	31 304,00
	Thermal simulator	45 752,00	45 752,00	45 752,00
	Impact test apparatus	3 210,67	3 210,67	3 210,67
	Water leak setector	3 531,73	3 531,73	3 531,73
	Tank leak test machine	322,67	322,67	322,67
	Total KWh for SWH thermosiphon	1 454 221,94	1 834 080,27	2 213 938,61
	Price HT for SWH thermosiphon	1 178 115,12	1 485 851,40	1 793 587,68
Lighting	Price HT	60000	60000	60000
	Total KWh for SWH thermosiphon	1 238 115,12	1 545 851,40	1 853 587,68

Table 61: electricity consumption of the production unit.

5.2.5. *Staff salaries*

Staff	Nbr	Monthly slary (MAD)	Total salary (DH)
Manager	1	40000	40 000
Mechanical engineer (bac +5ans minimum)	2	10000	20000
Industrial ingineer (bac +5ans minimum)	2	10000	20000
Quality engineer (bac +5ans minimum)	2	10000	20000
Human resources manager (bac +5ans minimum)	1	10000	10000
Commercial manager (bac+5ans minimum)	1	10000	10000
Accounting and finance manager	1	10000	10000
Head of procurement	1	10000	10000
Head of logistic	1	10000	10000
Computer department manager	1	10000	10000
Mechanical and Maintenance Technicians	3	6000	18000
Workshop manager	6	6000	36000
Quality technician	3	6000	18000
Human resource technicians	2	6000	12000
Sales assistant	1	6000	6000
Accounting and finance technician	1	6000	6000
Procurement service technicians	2	6000	12000
Logistic technician	1	6000	6000
Compter technician	1	6000	6000
Store managers (bac+2)	6	4000	24000
Executive secratary	1	4000	4000
workers for thermosiphon SWH 14 : Islet storage tank 14 : islet heat pipe 4 : islet support and fin	480	2500	1 200 000
Guardians (Guardian Society)	12	2500	30000
Chauffeurs (Permis C)	22	3000	66000
Un technicien de surface (jardinier)	2	2500	5000
Occupational doctor	1	8804	8804
nurse	3	3200	9600
Cleaning workers	3	2500	7500
Travel allowance	10	2000	20000
Monthly premium (MAD for thermosiphon SWH	560	750	420000
Total annual for SWH thermosiphon (MAD)			24 790 848

Table 62: monthly total salaries.

Conclusion

This chapter presented A technical study focused on the manufacturing process of SWH with forced circulation and thermosiphon systems, the needs in terms of operating equipment, investment, and human resources. This study aimed to concretize, quantify, and link forward market research decisions with customer requirements.

The technical study will also allow facilitating the establishing a financial study to get an idea of the project's overall profitability.

Chapter VIII: *SHEMSY project detailed financial study*

BUSINESS PLAN

Introduction

A field trip made it possible to inquire more about the situation and have the study's data necessary. This chapter is divided into several parts: the first is devoted to the general project framework by the exhibition of a detailed description of "Sol'R-Shemsy" products, the second will be dedicated to a market study to analyze the SWH sector, and more precisely, the target customers, later a technical study presents the production process, the production rate, the layout of the unit and the necessary means such as machinery, raw materials, and qualified personnel. This chapter is closed by a financial study to assess the company's performance, liquidity, and financial equilibrium, estimating the cost price, the projected turnover, the break-even point, and other concepts, which will, in the end, have clear visibility on the profitability of the project.
Besides, in this part, the study is surrounded by the prototype previously presented, which is an individual thermosiphon technology, and also several other solar water heating variables have been included. The SHEMSY factory will produce the two technologies of solar water heaters: thermosiphon and forced circulation systems, and according to the two technologies (ETC and FPC). All products were included in the manufacturing process and the financial study with deferred capacities (150, 200, and 300L).
The choice of this variety was intended to expand the target clients and address several national needs regarding capacity and sectors aimed at tertiary residential and industrial.
All the results presented have made it possible to give figures beyond the objective of launching the SHEMSY project, which was limited only to the social solution to which the prototype presented is subject. The study proposed additional luxury and different technologies products.

1. *Moroccan target clientele study and Rivalry*

1.1. Qualitative study

Under the competition conditions and challenges, the new company's offer must find its place and meet potential customers' expectations. This exploratory study aims to understand the determinants of targeted client behaviors and assess potential demand. The questions that arise at this are why and how. Indeed, we used an easy, efficient, and meaningful method to launch an online survey offered by the Google Drive browser. Our survey form has been saved under the following link:
https://docs.google.com/forms/d/1yeBYtGopDk5vGmkYCYaNXBqJYaND6y1qUnkkGPx6CLY/edit?usp=sharing

results analysis

participants profile

The size of this cross-section makes it possible to find statistically significant results. They are made up of 52.9% of women and 47.1% of men. We note that most respondents are young people aged 18-30, with 61.8% having a high education level. We can also notice that the majority are urban (82.4%), and most people (47%) live in Fez, which will help us choose the site's first location.

The poll results

According to statistics obtained 91.1% of participants use a water heater in their home, establishment...ETC.

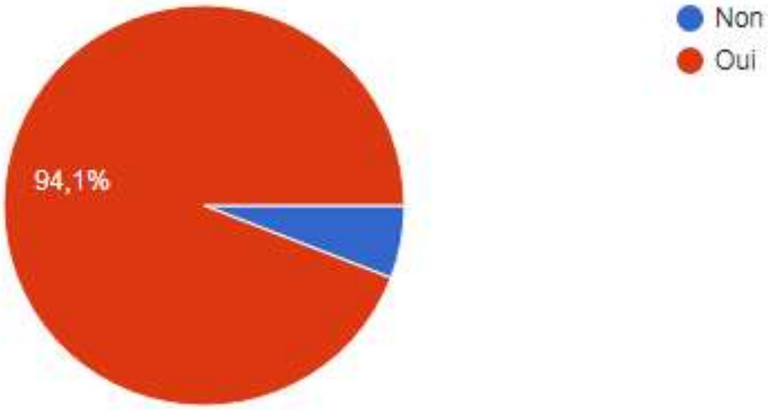


Figure 148: SWH users.

70.6% have a gas boiler of the population cross-section, and only 11.8% have a solar water heater, which shows that a significant part of homes in Morocco are increasingly gas water heater users, even as the number of deaths reported related is steadily increasing with 2346 cases of carbon monoxide (CO) poisoning[234], and 60 deaths per year [235].

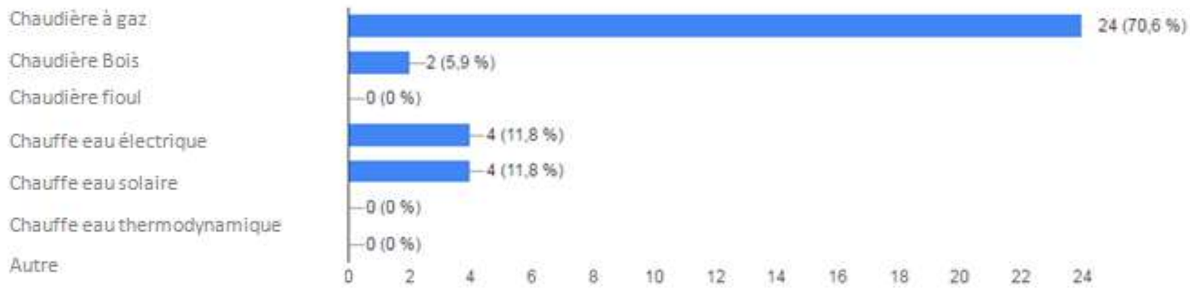


Figure 149: SWH types used.

We found that 47.1% of consumers choose their water heater under the advice of friends and family, making word-of-mouth the preferred method of marketing a new product.
61.8% are satisfied with their water heater, and 53.8% consider the price is the main reason for their choice.

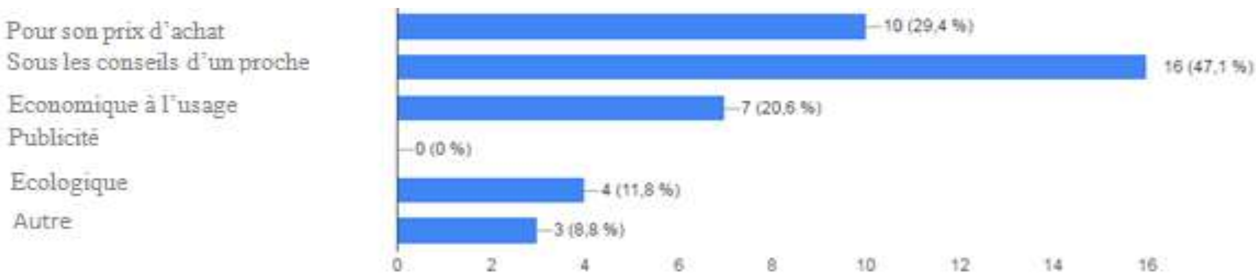


Figure 150: SWH costumer choice reasons.

The second section's objective is to know the degree of use of solar water heaters and understand the perception of future consumers on our product.

70.6% of people confirm that an ideal water heater does not release any hazardous material, and 73.5% are very interested in a new hot water solution if it guarantees stable hot water production with high efficiencies.

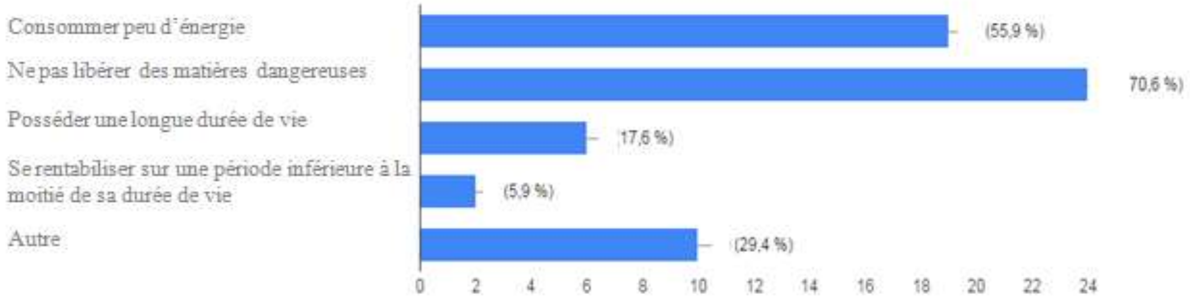


Figure 151: Ideal water heater characteristics.

Similarly, 54.3% are motivated by a solar water heater if it is economical and efficient, but 48.4% consider price the first obstacle, so the challenge is to give the best quality/price ratio.

Figure 152: SWH respondents' perceptions.

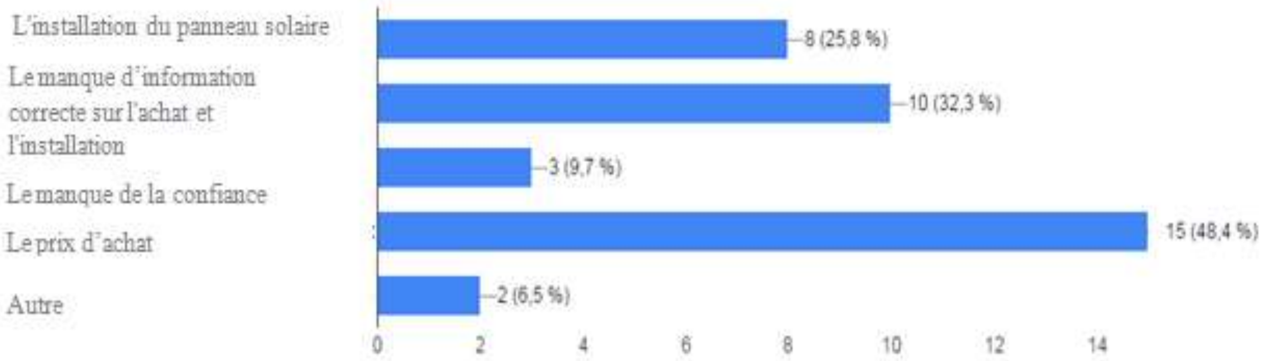


Figure 153: Barriers to use SWH.

We devoted another section to people who already have a solar water heater, 50% prove their choice by saying that the solar water heater uses renewable energy, and 44.4% because the energy produced does not generate any CO_2 emissions.

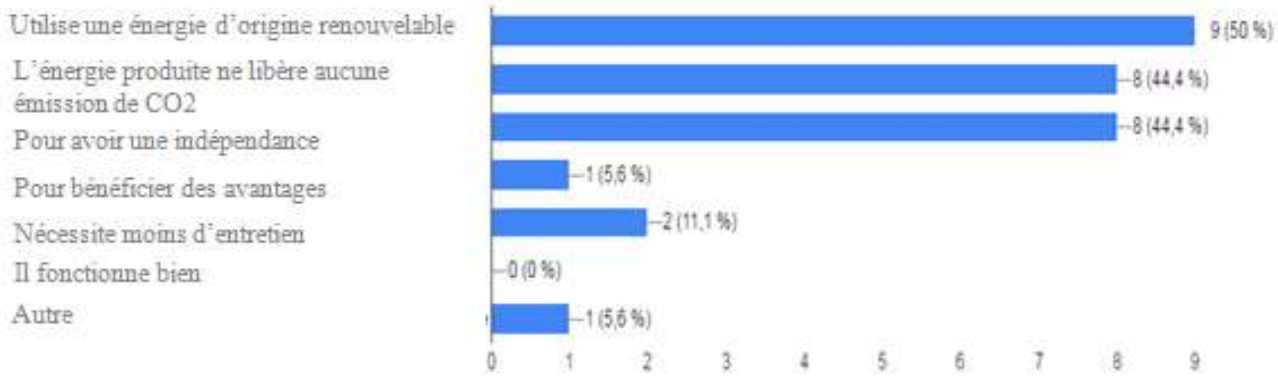


Figure 154: Why Moroccan use SWH.

We then noticed that more than half of consumers (54.5%) use flat-panel solar water heaters, but the demand for vacuum tube solar water heaters is also growing (45.5%).

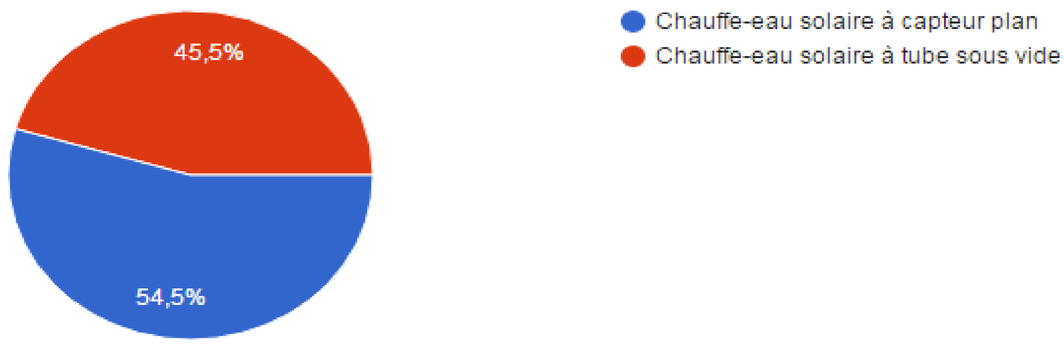


Figure 155: distribution of SWH technologies consumed in Morocco.

Regarding the potential technical problems of solar water heaters, 46.2% of respondents said that hot water loss is the most common problem encountered.

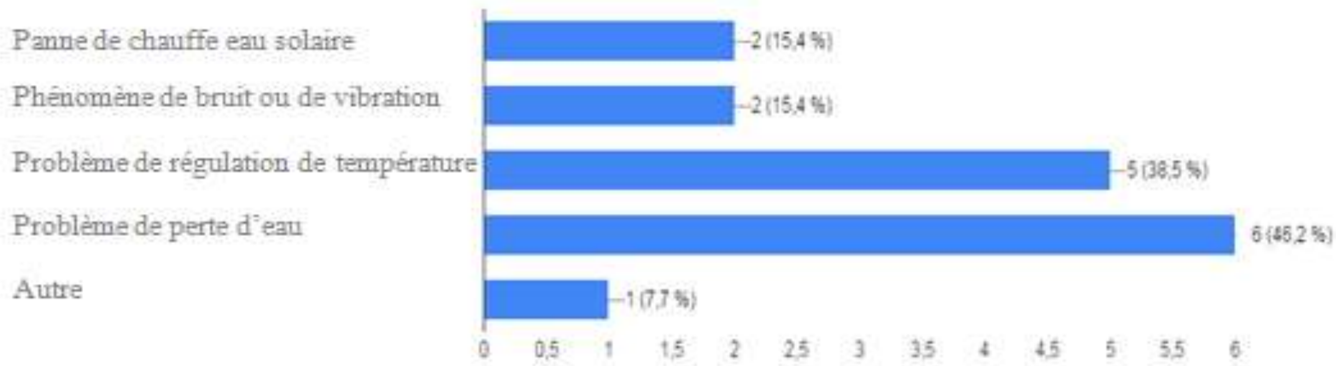


Figure 156: Consumer point of view about SWH problems.

To Evaluating the customer interest to solar vacuum tube water heater, knowing that it has a 30% higher efficiency than a collector plan; this question takes a part of the poll: "would you be interested in this type of water heater? even with a little high price?" .73.3% was worried about the exact price.

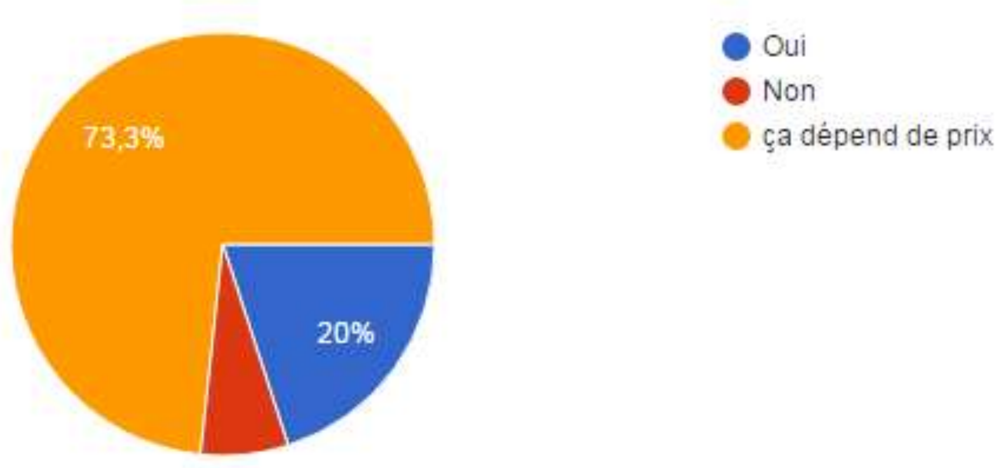


Figure 157: "would you be interested in this type of water heater? even with a little high price?".

This survey is also allowed to know the target customers' expectations and the price deemed accepted by the largest potential customers. According to the results, the expected psychological price is less than 7000 Dh/unity.

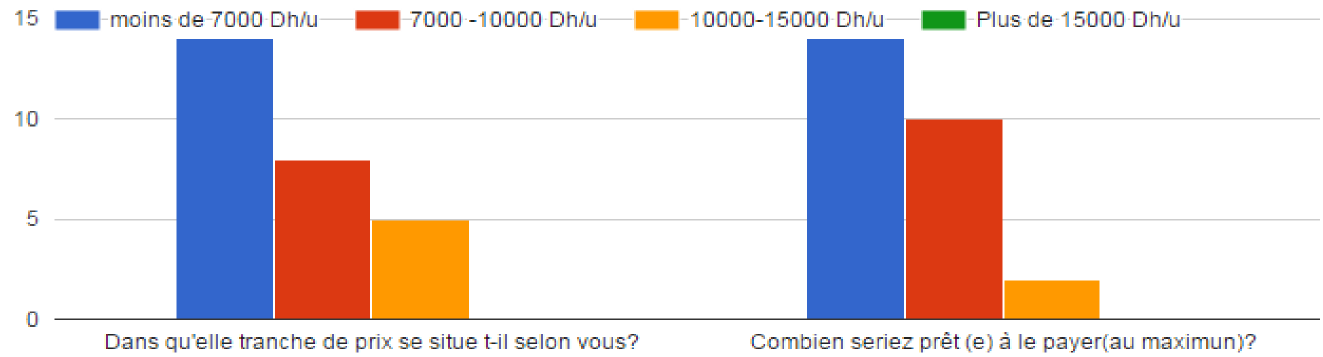


Figure 158: SWH psychological purchase price.

1.2. Quantitative study

In this part, the expected solar water vacuum tube sales in Morocco for the next three years are presented based on the qualitative study results. Planned sales for shemsy products are, therefore, shown in the table below.

Year	Expected sales (SWH number)
2020	17 600
2021	18 300
2022	20 000

Table 63: Expected sales

1.3. Rivalry study

In this part, one must have identified competitors in the Moroccan market, Their strengths and weaknesses (production and marketing capacity, sales methods, product characteristics, ETC), Their pricing policies (sales promotion policy, pricing, ETC), and The conditions granted to customers (payment conditions, delivery times, after-sales service, ETC).

Most of the actors acting in the panorama of solar thermal in Morocco are integrated companies (installation, distribution, and maintenance activities). It is estimated that there is a 50200 competitor in the market national —furthermore, two brand manufacturers focusing on flat plate collectors' technologies: EVENT SOLAR Morocco and Giordano Morocco.

Some importers also manufacture storage tanks. Solar thermal equipment is not managed by specialized companies but by installers and small companies acting as resellers from a distribution point. Concerning the installation process, solar water heaters are often installed sellers to ensure optimal installation conditions. In some cases, the salesperson can delegate the installation activity to other installers or companies. The table below present son strong concurrent in the Moroccan market.

brand	Technology
SER-GÜN	FPC
AUSTRALINOX	FPC
Imperial	FPC
BATITHERM	FPC
SOLARHEAT	FPC
TUBULAUX	ETC
CHAFFOTEAUX	FPC

Table 64: Rivaly.

The rivalry study shows that SWH in the Moroccan market is dominated by flat plate technology. However, several capacities are available starting from the 150L, wich their price presents a range from 7500 to 11300 MAD, the 200L from 8500 to 13200 MAD, and 300L prices are between 12 500 and 19500 MAD. Besides, competitors present guarantees from 5 to 10 years for systems or just the collectors.

Based on established research, we noted that competitors offer SWHs vacuum tubes, but these competitors do not manufacture the product; they only import and distribute, install, and some maintenance activities. Starting from this observation SHEMSY company will be the first to develop, innovate, and industrialize SWHs vacuum tubes "made in morocco," efficient and reliable, with a better quality/ price ratio. It will also benefit from this lack of competition at the manufacturing level to be the leader in this field.

2. Marketing strategy

To detect consumer needs and facilitate sales, we have proposed a marketing strategy to sell a product that meets customer expectations and creates a lasting relationship with them. This strategy is used to analyze the project's competitive structure, segment the market, determine targets, and determine pricing, product, distribution, and communication policy.

2.1. Porter model

The porter model provides a detailed analysis of the competitive structure of an industry. Porter highlighted five forces that interact with the company and create a broader form of competition. This analysis makes it possible to visualize the different forces at play and look for those most likely to affect the company.

Five forces can influence the products in the marketplace:

- Potential new competitors: is it easy or difficult for new entrants to start competing in the sector, what barriers exist to entry
- new competitors.
- Threat of Substitute Products: How easily can a new product or service replace itself, particularly by being cheaper.
- Buyer Bargaining Power: Are buyers in a position of strength? Unfavorable evolution of the activity of the customers with an effect on the prices.
- Risk of integration by a compelling customer who can influence prices.
- Bargaining Power of Suppliers: This is the Level of Dependence on Suppliers, some suppliers. Risk of integration by a supplier with pricing authority.
- Current Business Competition: Is there intense competition between market players or not? Is one of the players in a dominant position, or are they all of equal strength and size.

In the table below, we have determined the five forces to wear Sol'R-Shemsy product:

Porter force	SOL'R SHEMSY	Influence degree
New competitors' entry	Since the brand Sol'Rshemsy is the first made in Morocco with competitive prices and quality that meets international standards, the products have strong technological content, the Moroccan state supports the project, so the entry of new competitors to the market is not easy.	Weak
substitute products threat	SHEMSYs' products meet international standards, meet the customer's needs in Morocco with competitive prices. However, several companies market CES in Morocco, so gas water heaters are widely used by Moroccans. therefore, the threat of substitute products more at least Strong	strong
Negotiating power-purchasers	SHEMSYs' prices will be varied between a minimum of 5000 DH, and a maximum of 14000 DH.the prices are competitive all social classes.	weak
Negotiating power-suppliers	The raw material suppliers are national and international, and their negotiating power is strong.	Strong
Intra-sector competition	All solar water heaters on the Moroccan market are manufactured abroad in Europe, China, or the United States or are mounted in Morocco. We are the first company to manufacture a new Moroccan solar water heaters brand with a competitive price and high quality that meets international standards, so we have a competitive advantage over competitors.	weak

Table 65: forces that can influence SHEMSY project.

2.2. Market segmentation and targeting

2.2.1. Market segmentation

Market segmentation analyzes a market to break it down into homogeneous subsets (market segments). It is about identifying different and homogeneous groups of customers in the same market, based on specific criteria, rather than addressing an average customer.

Segmentation criteria		relevance
housing type	-apartment, building, villa -factory, hotel	High to medium
Power purchase	-salary< 2500 MAD - salary [2500 ;5000] - salary rang [5000 ;10000] - salary rang [10000 ;20000] - salary >20000 MAD	High
Climatic zone	-Southern and Sahara regions - The western regions -Northern Morocco - Internal regions	High to medium
Selling price	SHEMSY products prices: < 6,000 MAD basic model [6000; 10000] MAD middle segment [10,000;14000] MAD Premium	High to medium
Family number	-family of 2 persons -family of 4 -Family 6 people -family more than 6 persons	Medium to low
Quantity purchased	- Products most in demand by customers	Medium to low
Le statut d'utilisateur et sa fidélité	-customer loyalty to products	Medium to low
Consumption patterns and use situations	-The product consumed in the long term	Medium to low

Table 66: the segmentation criteria adopted in SHEMSY project.

SHEMSYs' segments

The segmentation strategy of our customers is a differentiation strategy. The proposed products are adapted to each targeted segment. For example, solar water heaters medium segment are mainly oriented for segment 2. Our company targets different market segments to meet the specific needs of consumer groups better, this strategy has allowed us to better fight against competition.

Products / Clients	<6 000 MAD Basic model	[6 000; 10 000] MAD Middle segment	[10 000; 12 000] MAD premium
Segment 1: buyers earn from 2500 to 5000 MAD	Segment1		
Segment 2: buyers earn from 5000 to 10000 MAD		Segment 2	
Segment 3 : buyers earn more than 10000 MAD			Segment 3

Table 67: Clients segments

2.2.2. Targeting

Targeting is a strategic choice based on the segmentation chosen: Which segment(s) or portion of the segment should be targeted according to the marketing strategy?

The segments we will target to strengthen our marketing strategy are the three segments. The project is national, aiming to satisfy the global market (low-end, mid-range, and high-end).

2.3. Strategic Objectives

- Be known: We aim to launch a new brand «made in Morocco» of solar vacuum tube water heaters in the Moroccan market, so we must follow a marketing strategy to inform customers of our products' existence.
- Improve the image: In this case, the objective of the marketing strategy will be to improve the quality of our offer and the image of our society by participating in sports or cultural events and helping associations, etc.
- Improving customer satisfaction: Improving customer satisfaction is another typical marketing strategy objective. Companies are increasingly convinced of this factor's importance in retaining loyalty and, consequently, in developing sales.
- Building customer loyalty: Strengthen the relationship with our customers to create a relationship of trust by Offering impeccable quality service and making offers evolve according to competing offers, to show the customer the added value of products.
- Differentiate from the competition: the project is in a competitive environment. A differentiation marketing strategy must be chosen r to distinguish ourselves in the market (by offering additional services, based on innovation, etc.).

2.4. Marketing Mix

The marketing mix is the whole offer proposed to its market. It initially includes the 4 P's: Product, Price, Place, Promotion.

The marketing mix is the set of operational areas in which strategies need to be developed. It obeys a principle of coherence between the four Ps: this principle makes all its strength.

2.4.1. Products policy

This is the first component of the marketing mix; it is essential for the following reasons:

Experience shows that one can rarely compensate for the inadequacy of a product to its market using the other components of the Mix because one can rarely do good marketing with a lousy product. Decisions on the choice of products for sale involve significant investments. The choices relating to the other components of the Mix are subject to the product's characteristics being sold. The definition of a product policy generally logically precedes the choice of the other components of operational marketing.

To position in sustainable development, it is necessary to offer a viable alternative with the advantages of solar energy to meet the customers' needs through the manufacture and marketing of solar water heaters that use the technique of vacuum tubes.

This technology is recognized for its exceptionally high efficiency. Each solar panel installed can reduce from 150 to 300kg CO_2 each year. More than 75% of the solar energy captured is returned and usable via solar water heating: about 1500 Wh with a correct sunlight level.

The solar panels by vacuum tubes are the key to the immediate energy savings and are exceptionally and efficient by their design.

Two significant families of SWH systems are proposed as products:

- The first is the «Monobloc» family, using water height to naturally circulation the fluid.
- The second is the "forced Circulation" family with a circulator to cause the heat transfer fluid circulation.

On the one hand, the single-piece solar water heater is one of the most used types. The solar collectors and the storage tank are placed on the outside, on the same chassis. The tank follows a horizontal shape and place on the top of the tubes or panels. It is the simplest and by far the cheapest and advises for very sunny areas. The single-piece thermosiphon requires no circulation pump or regulator, which makes it easy to install, can be transported anywhere, and requires no maintenance.

On the other hand, the forced circulation system is more complicated, but offers the most excellent installation flexibility and facilitates a harmonious integration into the building and guarantees a strong and continuous thermal efficiency. The pump allows to dissociate more capture and storage but generates a price a little high.

2.4.2. The Packaging

The packaging is the set of material elements that, without being inseparable from the product itself, are sold with it to allow or facilitate its protection, transport, storage, presentation in linear, its identification, and its use by the customers.

Better packaging can be the main element in differentiating our product from the market because the customer values it.

the main functions of a packaging are:

• Technical packaging functions

-Protection and conservation of the product.

-the convenience of use.

-Ease of transport and storage.

-Environmental protection (eco-friendly packaging).

• Package communication functions

-Consumer information.

-visual impact.

-Brand identification and recognition.

-Impulse to purchase.

2.4.3. Pricing Policy

"The customer is king": this famous expression is especially true for setting a price. Today, consumers are not only paying close attention to market prices (especially in times of low purchasing power) but are also becoming more and more informed. It is thus able to compare the prices charged for the same product.

Price is an essential part of marketing. It can be set in several ways. It will also depend on the marketing objectives: profitability to be obtained, market shares to be conquered in the short or long term, the positioning to be defined.

In order to set the "fair price," it is necessary to know its customers and the type of use (for a single house, apartment, factory, hotel, swimming pool, etc.), its competitors (CHAFFOTEAUX, TUBULAUX, etc.), and its costs. Three complementary approaches must, therefore, be undertaken:

Demand analysis (clients)

Thus, in pricing, we (project leaders) must ask our potential customers to measure: their knowledge of market prices: As mentioned earlier, the consumer is increasingly informed about market prices. It is a question of his knowledge of the prices charged.

The psychological price is the price that is commercially acceptable to the most significant number of potential customers of the company. To determine this, two questions must be asked of customers:

*In what price range do you think it is?

*How much would be willing to pay for it (maximum)?

Analysis of the results will determine the price acceptable to the most significant number of customers.

Analysis of competition

A customer analysis is a prerequisite but not sufficient. It is also necessary to analyze the prices charged by the competition.

Therefore, if the price is higher than the competition, the customer must be offered a "more competitive." That is to say, a service, a discernible customer advantage, and which "justifies" the price difference. Furthermore, this price must correspond to the expectations of the customer...
In our case, we decided to align ourselves with our competitors by adopting prices relatively equal to those on the market by adding differentiation margins (up or down).
<u>the cost price calculation</u>
It is essential to know precisely the cost price because, otherwise, the company would risk selling "at a loss." The cost price is the sum of the company's costs to market the product at all levels from its manufacture, distribution, and promotion.
These costs include:
Direct costs (fixed or variable): purchase of goods and/or raw materials- remuneration (employees, cashiers, wind power, associates), use of subcontractors, maintenance of machinery and equipment (transport materials, security system, computer crates, etc.) depreciation of machinery, etc.
Indirect costs (fixed or variable): market research, advertising, commissions... - general and financial costs (rent, electricity, insurance...), research and development costs (development of new models based on new materials) etc.
In our case of business creation, the exact cost price can only be calculated after having established all the financial forecasts (forecast income statement) in the business plan.
2.4.4. Distribution Policy
To distribute products means to bring them to the right customers, with the right assortment, in adequate quantity, in the right quantity, at the right time, and with the services necessary for their sale, consumption, and, if necessary, maintenance: the right product at the right time in the right place. A distribution channel is a process that, passing through a greater or lesser number of external or internal intermediaries, allows a product to be delivered to the final consumer.
From the producer to the final customer, distribution channels may be more or less long; that is, they may have more or fewer intermediaries. There are three main types of distribution circuits:
Direct Channel
There is no external intermediary: the producer sells directly to the final consumer (stationary, with representatives or by mail).
This type is suitable for:
- products resulting from artisanal manufacture (tailors, carpenters, etc.) or an agricultural production (eggs, poultry, market sales, etc.)
- highly developed industrial products (machine tools controlled by a factory in manufacturer, complex equipment used by hospitals, computers...).
Short Channel
There is an external intermediary between the producer and the end consumer. This type is suitable for:
- in the sale of expensive products: automobiles, boats, audio-visual devices, household appliances, furniture, etc.,
- in the sale of products manufactured by small industrial enterprises to be sold geographically: beverage factories, small wine producers (agricultural co-operatives).
Long channel
There are at least two external intermediaries between the producer and the final consumer. The extended circuit is commonly used for food, cleaning products, textiles, hardware, small electrical equipment... in general, products of mass consumption.

Product Distribution Sol'R-Shemsy

For SHEMSY brand, the sale is carried out directly to the product's final consumer through non-stores established by the company in all Moroccan regions.

The most efficient channel is the direct channel to master the distribution circuit and benefit from a considerable margin to better quantitative and qualitative knowledge of the market.

After creating the factory, it's preferred that the products be market to set up the first point of sale as a pilot sample to a motivating region (Casablanca) to measure consumer reactions around the new "made in Morocco" brand.

2.4.5. Communications Policy

Each of these tools is more or less effective depending on the product type to be promoted, the target's nature, the message's content to be conveyed, and the budget available.

For our products, we seek to establish external communication: display, radio spot, car dressing, leaflets, brochures, advertising on the place of sale, arrange and designate at the level of the points of sale. In addition to this, promotion actions: raffle, price reduction (balance), animation (music and light games, etc.); this will allow the company to win a place on the market and to be always in contact with its customers.

Our promotion policy seeks to develop a positive image of our products by developing a positive word of mouth and the use of social networks such as Facebook, Twitter, etc. , and advertising on magazines and cities.

The importance attached to the promotion is due to its loyalty for its products and stimulating any act of new product launch.

3. Financial study

3.1. development of initial funding plan

The initial funding plan is presented in the form of a table consisting of two parts:

• In the left part, the project's sustainable financing needs: The investments to be made are the costs of the establishment, land, and development; buildings; production equipment and equipment; transport equipment; start-up costs; working capital, etc.

• In the right part, the amount of sustainable financial resources that must be provided to finance all company needs of the same nature: The financing to be provided is equity (net contributions of partners or partners); subsidies; medium- and long-term credits; short-term credits.

3.1.1. Sustainable Needs

3.1.1.1. Establishment Fees

The costs of setting up the company (consulting fees, registration fees, first publicity costs, etc.) are part of the expenses incurred for the benefit of the company for a long period

The negative certificate: 230 MAD

Fiscal stamp: 750 MAD

Deposit of statutes: 200 MAD

Registration in the trade register: 350 MAD

Registration fee for forced circulation system: 1,700,000 MAD

Registration fee for monobloc system : 1,540,000 MAD

Advertising costs: 20,000 MAD

3.1.1.2. Investments

Investments in fixed assets also include items related to land, buildings, technical facilities, equipment, and tools owned by the company.

Investments	Forced circulation SWH	Thermosiphon SWH
Establishment Fees	1 721 530	1 561 530
Construction company (2000 / m²)	81 220 000	81 220 000
Machinery and Equipment	35 525 046	34 690 253
Vehicule supplier	8 547 604	7 608 437
Office equipments supplier	247 630	247 630
Computer supplier	278 840	278 840

Table 68: investments MAD.

3.1.1.3. working capital requirement

It represents the cash flow required for the business's start-up to finance the settlement gap between revenue and expenditure.

The simplified expression of the WCN is: [236]

$$\text{WCN (BFR)} = \text{Stocks} + \text{accounts receivable} - \text{accounts payables} \quad (119)$$

- Average stock of raw materials (in number of days purchased HT) (1) = number of days in stock x Purchases / 360
- Average stock of finished products (in number of days of turnover HT) (2) = Annual turnover HT X Number of days of turnover HT / 360
- Average outstanding customer receivables TTC (3) = Customer payment deadline x Annual turnover HT x 1.VAT rate / 360
- Average outstanding of suppliers payablesc TTC (4) = Payment deadline for suppliers x Purchase HT x 1.VAT rate / 360

The conditions of settlement:

Number of days stock of raw material = 21 days

Number of days in-stock finished product = 10 days

Client Lead Time = 30 days

Time obtained from suppliers = 45 days

WCN (working capital needs) : thermosiphon SWH

	YEAR 1	YEAR 2	YEAR 3
WCN (BFR)			
Stocks HT (necessary permanent level for the business activity) (1) + (2)	34 420 857,32	45 894 273,43	57 367 689,54
accounts receivable; customers TTC (3)	47 554 373,96	63 405 831,95	79 257 289,94
accounts payables; suppliers TTC (4)	54 543 366,00	72 723 966,00	90 904 566,00
WCN	27 431 865,28	36 576 139,38	45 720 413,47

Table 69: WCN thermosiphon SWH case MAD.

3.1.2. Sustainable Resources

They correspond to equity, depreciation and provisions, financial debts other than current bank loans. In our case, the own capital in cash corresponds to 170,000,000 MAD for forced circulation SWHs and 154,000,000 for monobloc SWHs, without any financing debt.

Initial Financial plan (MAD)			
Sustainable financial needs (A)	amount	Sustainable resources (P)	amount
incorporable Immobilizations	**1 561 530**	Own funds	154 000 000
• establishment fees		• social capital or personal	
Negative company (certificate)	230	Personal assets	154 000 000
Fiscal stamps	750	Financial depts	
Deposing the artical	200	• other financial depts	-
Listed at the trad register	350	Credit institution	
Registration fees	1 540 000		
Advertising coasts	20 000		
Tangible fixed assets	**124 045 160**		
• built-up land			
23218. Constructions	81 220 000		
• Machinery, equipment and tools - finance leases			
2331. Machinery, equipment and tools - finance leases	34 690 253		
• transport materials			
2340. transport materials	7 608 437		
• provide office furniture and equipment			
2351. office furniture	247 630		
2352. computer furniture	278 840		
• other Tangible fixed assets			
2380. others Tangible fixed assets			
WCN	27 431 865		
Treasury	**961 444**		
Total needs	154 000 000	Total des resources	154 000 000

Table 70: the initial financing plan for thermosiphon SWH.

The WCN is positive (27 431 865,28 MAD for SWH thermosiphon); This is partly because the purchase of goods constitutes a significant part of the operating cycle. In this context, the working capital requirement is mainly used to cover the amount of cash needed to finance the difference between the payment from suppliers and the cash from the products' sale.

3.2. Development of the forecast income statement

The forecast income statement is a financial table presented in a list reflecting the level of economic activity over the accounting year. It summarizes all the income and expenses of an enterprise to result in a positive (a profit) or negative (a loss) result.

The forecast income statement must contain essential variables, such as:

• The projected turnover,
• Forecast expenses,
• Forecast depreciation,
• Projected taxes and charges.

3.2.1. Projected turnover

As an essential part of the business plan, the forecasted turnover summarizes all company sales over the financial forecast horizon (usually three years).

• In the first place, it is essential to calculate the cost, which corresponds to the sum of all the direct and indirect costs incurred by the enterprise in producing a good or offering a service, about the number of goods produced or services rendered[237]. To determine this, we used the following formula:

The cost =sum of charges/Quantity produced (120)

Cost for SWH Thermosiphon :6 604,77 MAD

The second step is to set the selling price; once our cost price is identified, it is crucial to set a selling price adapted to the company's sound management. Having an acceptable selling price is the first step of profitability, which makes it possible to achieve a margin on each sale and to have a profit indispensable to the investment, therefore [238]:

Selling price = cost price + gross margin (121)

During a meeting with our employees, we set the gross margin at 20% of the cost price and therefore, the selling price of the forced circulation SWHs (200 L) = 12 599,26 MAD per unit and the selling price of the thermosiphon SWHs (200 l) =7 925,73 MAD per unit.

• Turnover is calculated by the following formula[239]:

Turnover = Unit selling price H.T x Quantity sold (122)

Thus, the following table presents the turnover for the next three years:

YEAR	thermosiphon SWHs (200 l) MAD
N	475 543 739,61
N+1	634 058 319,48
N+2	792 572 899,35

Table 71: turnover for three next years (MAD).

3.2.2. Forecasted coasts.

3.2.2.1. Consumable Purchases

This account includes all purchases intended to be stored and which are identifiable and consumed by the company.

YEAR	thermosiphon SWHs (200 l) MAD
N	592 174 440,00
N+1	363 622 440,00
N+2	789 562 440,00

Table 72: raw material coast's needs.

3.2.2.2. External Expenses

External expenses are generally purchases paid by the company to third parties.

YEAR	thermosiphon SWHs (200 l) MAD
N	1 298 115,12
N+1	1 605 851,40
N+2	1 913 587,68

Table 73: water and electricity charges.

Fuel:

The annual fuel cost for SWH thermosiphon 200l is: 2 929 934.00 MAD.

3.2.2.3. Staff costs

They correspond to the remuneration paid to the company's personnel, return for the work performed, and the social security costs associated with this remuneration and the various allowances and bonuses allocated.

Staff Salary:

	thermosiphon SWHs
Annual salary mass (MAD)	19 510 848
Travel allowance (MAD)	240 000
Annual primium (MAD)	5 040 000
Total (MAD)	24 790 848

Table 74: staff salary costs.

Social security charges

	Salary mass	Ration	Amount MAD
CNSS	24 790 848,00	16,60%	4 115 280,77
AMO	24 790 848,00	3,50%	867 679,68
Total contributions			4 982 960,45

Table 75: social security charge, thermosiphon SWH case.

3.2.3. Forecast Depreciation

A capital asset is an investment that the company will use sustainably; for our case, the depreciable capital assets are:

Investments	Depreciation period (year)
Transport materiel	5
building	25
Machinery, equipment and tools	10
Office furniture	10
Computer furniture	3
Preliminary fees	3

Table 76: depreciable elements.

Depreciation charges shall be recognized at the close of each financial year provided for the forecast. It is calculated by the following formula[240]:

$$\text{Depreciations charges} = \text{Original value} \times (1/\text{Expected useful period in years}) \quad (123)$$

Investments	**price**	**Depreciation ratio**	**N**	**N+1**	**N+2**
Preliminary fees	1 561 530,00	33,33%	520 510,00	520 510,00	520 510,00
Transport materiel	7 608 437,00	20,00%	1 521 687,40	1 521 687,40	1 521 687,40
building	81 220 000,00	4%	3 248 800,00	3 248 800,00	3 248 800,00
Machinery, equipment…	34 690 253,23	10%	3 469 025,32	3 469 025,32	3 469 025,32
Office furniture	247 630,00	10%	24 763,00	24 763,00	24 763,00
Computer furniture	278 840,00	33,33%	92 946,67	92 946,67	92 946,67
TOTAL per year			8 877 732,39	8 877 732,39	8 877 732,39

Table 77: depreciation charges ; thermosiphon SWH case.

3.2.4. Estimated taxes and charges

SHEMSY project company will be exempt from taxes.

Forcast annual income statements			
I: INCOME	**year N**	**year N+1**	**year N+2**
*salles revenue (H.T)	475 543 739,61	634 058 319,48	792 572 899,35
Total incomes (H.T)	475 543 739,61	634 058 319,48	792 572 899,35
II: EXPENSES (H.T)			
*consumable purshases			
Raw materials	363 622 440,00	484 826 440,00	606 030 440,00
*external expanses			
Water, electricity	1 298 115,12	1 605 851,40	1 913 587,68
fuel	2 929 934,00	2 929 934,00	2 929 934,00
*others external expanses			
advertising	10 000,00	10 000,00	10 000,00
Postal and telecommunication coasts	45 000,00	51 000,00	60 000,00
Certification coasts (ISO 9001, Solar Keymark)	629 300,00	144 600,00	144 600,00
*staff Expanses			
Gross salaries (including social contribution charges)	29 773 808	29 773 808	29 773 808
*depreciation charges			
Operating allocations to depreciation of tangible capital assets	8 877 732,39	8 877 732,39	8 877 732,39
TOTAL EXPENSES (H.T)	407 186 329,96	528 219 366,24	649 740 102,51
PRE-TAX INCOME (I-II)	68 357 409,65	105 838 953,25	142 832 796,84
INCOME TAX	-	-	-
NET TAX INCOME (31%)	68 357 409,65	105 838 953,25	142 832 796,84

Table 78: forecast annual income statements: thermosiphon SWH (200L) case.

3.3. Development of forecast income statement with the interim management balances

Intermediate management balances (MIS) make it possible to analyze the enterprise’s income by breaking it down into several essential indicators (value-added, gross operating surplus, operating income, pre-tax net income, retained earnings, self-financing capacity). It’s provides information on the activity of an enterprise and the formation of its profit (or deficit).

forecast income statement with the interim management balances						
	Year 1		Year 2		Year 3	
Final products sales	475 543 739,61		634 058 319,48		792 572 899,35	
Saled products						
Stocked products						
Operating subsidies						
A – operating products	475 543 739,61	100%	634 058 319,48	100%	792 572 899,35	100%
Purchases(including sub-contracting)	363 622 440,00		484 826 440,00		606 030 440,00	
Stocks variation						
External coasts	4 283 049,12		4 596 785,40		4 913 521,68	
1 – sub-total	367 905 489,12		489 423 225,40		610 943 961,68	
B – Added value = A - 1	107 638 250,49	22,63%	144 635 094,08	22,81%	181 628 937,68	22,92%
2 - Gross salaries(including social contributioncharges)	29 773 808,45		29 773 808,45		29 773 808,45	
C – gross operating surplus = B - 2	77 864 442,04	16,37%	114 861 285,64	18,12%	151 855 129,23	19,16%
3- Depreciation charges, provisions and other	8 877 732,39		8 877 732,39		8 877 732,39	
D – operating incom = C - 3	68 986 709,65	14,51%	105 983 553,25	16,72%	142 977 396,84	18,04%
4- financial products						
5 - Interest on medium and long-term borrowings						
6- banck fees						
E – gross pre-tax incom = D + 4 - (5 + 6)	68 986 709,65	14,51%	105 983 553,25	16,72%	142 977 396,84	18,04%
7 – income tax	-					
8 - Dividend						
F1 – net income non-distributed = E - (7 + 8)	68 986 709,65	14,51%	105 983 553,25	16,72%	142 977 396,84	18,04%
F2 – net self-financing = F1 + 3	77 864 442,04	16,37%	114 861 285,64	18,12%	151 855 129,23	19,16%
Repayment of the load						
Cach flow balance	77 864 442,04	16,37%	114 861 285,64	18,12%	151 855 129,23	19,16%

Table 79: forecast income statement with interim management balances: thermosiphon SWH case

3.4. Financial statement

The financial statement is a document that summarizes the company's goods. Called "assets" (land, buildings, transportation equipment, office equipment, and development, etc.) and its resources called "liabilities" (equity, reserves, investment grants, etc.), it is a company photograph that makes it possible to carry out a business evaluation.

Simplified forecast statement			
	Year 1	Year 2	Year 3

ASSETS			
Fixed assets at capital	125 606 690,23	-	-
- depreciation	- 8 877 732,39	- 8 877 732,39	- 8 877 732,39
Stocks	34 420 857,32	45 894 273,43	57 367 689,54
-Provision			
Customers receivables	47 554 373,96	63 405 831,95	79 257 289,94
-Provision			
Créances diverses			
Disponibilities	78 825 886,53	147 271 855,91	281 104 978,66
TOTAL ASSETS	277 530 075,65	247 694 228,90	408 852 225,74

LIABILITIES			
Social capital	154 000 000,00	-	-
Reserves		68 986 709,65	174 970 262,90
Net income	68 986 709,65	105 983 553,25	142 977 396,84
Investment subsidies			
Provision for risks and charges			
browings			
Other operating depts			
Daily bank leading			
Operating suppliers	54 543 366,00	72 723 966,00	90 904 566,00
TOTAL LABILITIES	277 530 075,65	247 694 228,90	408 852 225,74

Table 80: financial statement: thermosiphon SWH case.

3.5. break-even (profitability threshold)

The break-even point is the minimum level of activity at which a business becomes profitable. The break-even point consists of defining the level of turnover, which allows, thanks to the margin achieved, to have the means to pay the fixed charges. It is carried out in two steps:

- The variable cost margin rate must first be calculated, comparing this variable cost margin to sales[241]:

$$\text{contribution margin rate} = (\text{contribution margin}/\text{turnover}) \times 100 \qquad (124)$$

- Next, divide fixed charges by the margin rate on variable costs (contribution margin rate). [67]

$$\text{Break-even point (profitability)} = \text{Fixed charges}/\text{contribution margin rate} \qquad (125)$$

- neutral (dead point) is a break-even data. It is no longer a financial figure but a period expressed in many days, months, or years over which it is necessary to be profitable. It is defined by the following ratio [241]:

$$\text{neutral (daily)} = \text{Break-even (profitability)}/(\text{Annual turnover}/360) \qquad (126)$$

For a 3-year forecast, it is imperative to calculate the break-even point (profitability) for each year by decreasing and showing the neutral position (dead point) in terms of turnover and the number of days worked per year to explain the factual measure project.

	N	N+1	N+2
Forecast turnover (MAD)	755 955 741,62	1 007 940 988,83	1 259 926 236,03
Fixed expenses (DH)	44 759 001,87	44 759 001,87	44 759 001,87
Variable expenses (DH)	597 167 111,68	794 884 655,48	992 605 199,28

Variable expense margin (DH)	158 788 629,94	213 056 333,34	267 321 036,75
Margin rate on variable expenses	0,21005	0,21138	0,21217
Break-even point (DH)	213 087 199,43	211 748 845,47	210 956 239,89
Neutral position (day)	102,89	76,68	61,11
Quality neutral position	16 912,67	16 806,45	16 743,54

Table 81: break-even point and neutral calculation: thermosiphon SWH case.

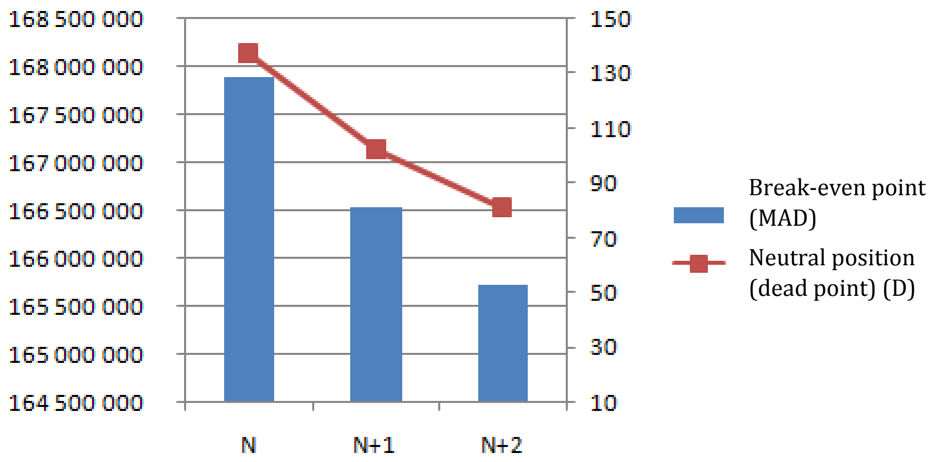


Figure 159: Break-even point (profitability) and neutral for thermosiphon case.

When the company reaches a turnover of 167,886,277.43 MAD, which corresponds to 137 business days and 22,548 pieces sold, all its expenses will be covered.

4. The company judicial framework

After drawing up a market study, technical study, and a financial study of the Sol'R-Shemsy project, the choice of a legal form for the future company is essential to determine a judicial framework relevant for the future company.

4.1. The selection criteria

The main criteria for choosing a legal form are:

- Share capital >300000 MAD
- Number of partners: shareholders, IRESEN, Others in private sector
- Associate Liability: limited contribution.
- Quality of Associates: legal entity.
- Decision-making authority

Since the Sol'R-Shemsy project's share capital is considerable, the number of partners is more than two (private, public), the responsibility of the partners is limited to contributions. After having better studied the existing legal forms, it's concluded that the most relevant form for the future company is the simplified stock company (SAS) because its creation and operation are more flexible than other legal forms, particularly the SA.

Conclusion

This chapter made it possible to concretize the technical data of the project previously studied, presenting significant figures and interpretations. It was necessary to start with a market study that made it possible to collect, process, and analyze its various components. Indeed, it offered the opportunity to have an idea on the Moroccan market: the needs of customers, potential customers, competitors, their strengths, and their weaknesses, and check that there is indeed an available customer base—moreover, solvent for the product which is about to be placed on the market. A marketing strategy was then established to segment the market and determine a price, product, distribution, and communication policy to clearly define the objectives. After this market assessment, a financial study is required. This part demonstrates the process, which consists of studying the company's feasibility on the financial level based on economic and financial forecasts to confirm the project's results are profitable like all indicators obtained. This pre-investment study made it possible to propose a financial design for the project and assess its behavior during its production qualitatively. All the financial profitability indicators studied have provided favorable results and confirm the need to set up this local solar water heater manufacturing unit. Finally, a legal form's choice was an essential step in a detailed and complete study for the Sol'R-Shemsy product. SOl'R SHEMSY project concerns solar water heaters with the vacuum tube and glass plane with forced circulation (150 l, 200 l, 300 l) and thermosiphon (150 l, 200 l, 300 l). In this report, only solar water heaters with a capacity of 200 l with a vacuum tube(forced circulation and thermosiphon) are treated.

Chapter IX: *implementation of a quality management system; SHEMSY SWH.*

Introduction

Quality is a prerequisite for the success and sustainability of organizations immersed in a highly competitive economic environment, marked by the intensity and speed of technological and commercial developments. In this context, the Sol'R-Shemsy project is to manufacture and market solar water heaters that meet European and international standards and the market's best quality/price ratio. In this context, this chapter «Design of quality management system for the company manufacturing the product «Sol'R-Shemsy».This chapter will be structured as follows:
The first part will present the objectives, scope, and principles of the quality management system. To present the right quality management system design based on the requirements of ISO 9001-V2015.
The present chapter is to understand the organization's context and expectations and the development of quality policy and objectives. By identifying company processes and their interactions using process mapping and process sheets to achieve expectations, a risk management approach that can impact its processes will be developed. Identifying and providing the necessary resources to the establishment, implementing, updating, and improving these processes, such as human resources, infrastructure, and documented information... Then control the products (from the reception of the raw material to the finished product). The measurement means used during quality control to improve product quality. Furthermore, finally evaluate the company's performance by organizing internal audits, management review, and improvement opportunities based on the culture of continuous improvement within the company, management of non-compliant products, and planning and implementation of corrective actions. Finally, the chapter will be closed by a presentation of the ISO 9001-V2015 certification process and the "Sol'R-Shemsy" product certification process according to European standards.

1. General presentation of the quality management system

A quality management system includes how the company identifies its objectives and determines the processes and resources needed to achieve the expected results [242].
Implementing a QMS compliant with ISO 9001 is the primary condition for obtaining the ISO 9001 certificate.

1.1. The objective

The QMS manages the processes and their interactions, the resources required to deliver value and results to relevant stakeholders. It allows management to optimize the use of resources taking into account the short-term and long-term consequences of their decision. A quality management system provides the means to identify actions to address the expected and unexpected consequences in realizing the product and service [242]. The present quality management system study applies to the company's activities relating to thermosyphon and forced circulation vacuum tubes solar water heaters production.

1.2. Quality Management Principles

To implement a quality management system more efficiently, the understanding and implementation of seven quality management principles are essential. They are as follows[243]:

Client Focus

The main objective of quality management is to meet customers' requirements and strive to meet their expectations.

Leadership

At all levels, managers establish goals and guidelines and create conditions in which staff is involved in achieving their quality objectives.

Staff Involvement

Competent, empowered, and involved staff at all levels of the organization is essential to enhance the organization's ability to create and deliver value.

Process Approach

Consistent and predictable results are achieved more effectively and efficiently when activities are understood and managed as correlated processes operating as a coherent system.

Improvement

Improvement is essential for an organization to maintain its current performance levels, respond to any changes in the internal and external context, and create new opportunities.

Evidence-Based Decision Making

Decisions based on the analysis and evaluation of data and information are more likely to produce the expected results.

Management of Stakeholder Relations

To achieve sustainable performance, organizations manage their relationships with the parties interested parties, such as service providers.

1.3. Design of the quality management system

To design a QMS compliant with ISO 9001 version 2015, all the ISO 9001 standard requirements that we must follow and the deliverables that must achieved to obtain an ISO 9001 certification are determined.

2. Quality Management System Design ISO 9001-V2015

The quality management system design focuses on identifying and describing processes and their interactions using process mapping and process sheets, policy development, and quality objectives. The risks management that may affect the company's processes operation, and then identify the resources needed to establish, implement, update, and improve the QMS. Then, the realization of the operational activities that serve to control the purchasing process and the production process, from the reception phase of the raw materials until the finished products' delivery.

Finally, the assessment of the company's performance focuses on internal audits and the management review to assess the progress of all the company's activities.

2.1. Organizational Context

2.1.1. Understanding the organization and its context

the company vision and mission

As mentioned since the beginning of this report, the main project objective is to produce and market a heater - "Made in Morocco" solar vacuum tube water that complies with European standards. At the best quality/price of the market and a competitive price for society, its development strategy is based on quality, professionalism, and compliance with prevailing standards. True to this strategy, the company aims to obtain the European standards' certification in force on its products and the ISO 9001 certification on its quality management system

Company organization

The company is organized into departments and services according to a well-researched organizational chart. The responsibilities and authorities of the company's personnel shall be defined in the following documents:

• Job cards: These documents define the tasks, responsibilities, responsibilities, and authorities and the competency profile required for the function; the HR department is responsible for preparing these cards.

• Processes, procedures, and instructions that define the responsibilities, authorities, and interfaces between the people responsible for performing the tasks that contribute to an activity or process's performance.

The SQM animation is ensured by a quality manager whose mission is to ensure that the processes necessary for the company's operation are established, implemented, and continuously improved and report to the Branch on the proper functioning of the QMS and any need for improvement.

2.1.2. Understanding of stakeholder needs and expectations

stakeholders' needs and expectations relevant to the company under the QMS that may directly or indirectly impact production, company operations, or product compliance, are identified.

2.1.3. Quality Management System Process

Process Identification

Process identification is essential to implement a simple and efficient system, so it is a requirement of ISO 9001-V2015.

We have three broad categories of processes[244]:

Management or management processes (strategy)

They reflect the business plan. Management expresses the purpose of the organization, its policy, and the objectives to be achieved. Such as:

- The business strategy
- The quality approach (quality management)
- Internal communication
- External communication …

The implementation processes (business line)

They relate directly to the manufacture of the product or the preparation and provision of the service. They include all activities from the integration of the client's need for the satisfaction of those needs. Such as:

- the commercial activities
- the development
- the production or manufacture or realization of the product
- the after-sales service …

The support processes (support)

They are essential to the implementation of other processes. They bring the necessary means to carry out the processes without directly impacting the product delivered or the service provided to customers. Support processes are very close to specific functions. Whether it is training, IT, people management

The determination of all the company's processes is an act of management. It reflects the transversal vision of the company as conceived by management.

The number of processes must be limited. Process mapping is often referred to as a graphical representation of all processes in the company.
The company’s leading processes and their interactions were established according to a level 2 process mapping.
• Management processes: Steering process.
• Delivery processes: Commercial, Production, and Logistics.
• Support processes: Procurement Process, Human Resources, Quality Control, Industrial Equipment Maintenance, Financial Resources, and Information System.

Processes description
The description of the processes through the process sheets allows all the company actors to understand their meaning and purpose. As such, resources and how they are implemented will be identified and accepted by all. [244] This operation is essential because it must:
• Unambiguous understanding of the purpose of the process;
• Situate the process in its environment;
• Identify internal customers and suppliers of the process;
• Define the interactions between processes;
The "process sheets" constitute a micro-mapping. A complete level 2 mapping cannot adequately describe all interactions; otherwise, it becomes incomprehensible. For this reason, the worksheet is an advantageous way to describe and document process characteristics. It also provides additional information necessary for the fullest possible understanding of how this process works
The description of a process should include the following:
• The Process Driver
• The purpose of the process
• Process inputs and their suppliers.
• Key processes in interactions
• Documented information associated with the process
• Process resources
• Process outputs and their customers.
• Process objectives, including monitoring indicators to measure and monitor the operation and effectiveness of its objectives.
Process Interactions
The interactions between the SQM processes are identified at the process sheets level, which explains, on the one hand, the process inputs and their sources (suppliers) and, on the other hand, the outputs and their destinations (customers). A detailed description of the interactions is established to clarify the benefits of the interactions between the SQM processes.

Process management
We have defined 11 processes, each assigned to a pilot who can be designated by management.
The table below shows the drivers of the processes we proposed in the process sheets:

Process	**Pilot**
Steering process	Executive Director
SQM animation process	Quality Manager
Business process	Business Leader
Production Process	Production Manager
Logistics Process	Logistics Lead
Human Resources Processes	Human Resources Manager

Procurement Process	Procurement Lead
Information system process	Information System Manager
Process Maintenance of industrial equipment	Maintainer
Financial Resource Processes	Financial Resources Manager
Quality Control Process	Quality Manager

Table 82: List of Process Drivers.

Procedures

The description of the processes will lead to evaluate the nature and number of procedures that will be written. All the procedures related to the level 2 mapping processes are drafted.

A procedure sheet "documents" a process in more or less detail. The procedure can be documented. It must always include:

• What: what needs to be done (what the activity is about)

• Who: Specifying the different responsibilities (Executor, Auditor, and Lead); • How: how the procedure is handled (how this activity takes place)

The following table lists the QMS Procedure Sheets we have prepared:

Pilotage	Risk management procedure
Quality Management	"Internal audit management" procedure
	"Management Review" procedure
Documented information	"Documented information control" procedure
Quality Control	"Control of corrective actions" procedure
	"Control of Non-compliant Product" procedure
Commercial	"Customer Order Management" procedure
	"Customer Complaint Processing" procedure
Production	Produce Single Block and Forced Circulation Solar Water Heater Procedure
	"Product identification and traceability" procedure
Purchase	Purchase, Selection, and Evaluation Procedure
HR	suppliers»
	Personal Recruitment Procedure
Maintenance of industrial equipment	"Personal Training" procedure
Information system	Maintenance Procedure

Table 83: the QMS Procedure Sheets

3. Leadership

3.1. Leadership and Commitment

3.1.1. Management Commitment

Management is explicitly committed to implementing the quality management system and the continuous improvement of its efficiency. This translates into:

• The definition of a quality management policy in line with the company's vision and strategic orientations;

• The establishment of measurable objectives and their implementation at all levels of the company;

• The provision of the necessary resources to implement the QMS and continuous improvement of its efficiency;

• Conducting executive reviews.

3.1.2. *Client Orientation*

In order to ensure mastery of the determination of customer requirements and expectations and a better understanding of the market, the company must ensure, as part of the management and commercial processes, Ongoing customer listening based on the following listening sources:

• Strategic Intelligence
• The Market Watches
• Business visits
• Customer satisfaction surveys
• Competitive intelligence
• Organizing marketing events
• national and international trade shows, etc.

All the customer expectations identified are analyzed by the processes concerned with studying the feasibility of their implementation.

3.2. *Development of quality policy*

We have defined the company's quality policy in line with its strategic orientations, the expectations of customers, and taking into account the normative, legal, and regulatory requirements relating to the product. The quality policy is broken down into measurable objectives at all appropriate levels and communicated to all staff. Management ensures that staff understands the quality policy through the results obtained and through internal audits.

3.3. *Roles and Responsibilities and Authorities within the Company*

The responsibilities and authorities of each of the functions listed in the general organizational chart must be described in the job cards. These shall be communicated, after validation, to the persons concerned. The responsibilities and authorities of each person impacting quality are also defined at the level of SQM documents such as process sheets, procedures, instructions, etc... . Process pilots must be designated by management. Key missions include:

• Actively listen to external and/or internal customers of the process
• Ensure smooth process operations.
• Inform and sensitize process stakeholders on company quality policy and customer requirements.
• Identify any deviations from the process and address identified malfunctions.
• Ensure compliance with process procedures and instructions by all stakeholders concerned.
• Initiate corrective and/or preventive actions as required.
• Identify opportunities for process improvement.
• Review process documents and update as required.
• Collect information for calculation and monitoring of process indicators.
• Inform the SQM of the evolution of the process (indicators, no compliance, the progress of corrective and preventive actions,..).
• Prepare the necessary elements to ensure process analysis at the Executive Review level.
• Accountable to management for the operation of the process.

4. *Planning*

4.1. *Risk Management*

According to ISO 31000:2009 – Risk Management – Principles and Guidelines, the risk is newly defined as “the effect of uncertainty on objectives” and is further noted that “A risk is often characterized by reference to potential events and consequences or a combination of both” [245].

Risk Management is the discipline that seeks to identify, assess, and prioritize risks related to an organization's activities. regardless of the nature or origin of these risks, to address them methodically in a coordinated and cost-effective manner, reduce and control the probability of the feared events, and reduce the potential impact of such events [246].

4.1.1. Identification of risks

A company is inherently risky, and it is impossible to cancel out all sources of risk altogether. Therefore, identification will play a strategic role in risk management and allow the company to deal with factors that may prevent its objectives and, consequently, its performance.
The identification of risks is to answer the following question:
- What can go wrong in society?

To answer the previous question, we have identified the risks that can prevent the manufacturing company's operation of the product Sol'R-Shemsy. The types of risks identified are:

• Strategic Risks
• Political/Legal Risks
• Economic Risks
• Financial risks
• Cultural Hazards
• Risks related to climatic conditions
• Operational Risks

4.1.2. Risk Analysis

Risk analysis involves analyzing and predicting the consequences of the identified risks on the company's purpose. [247] Identifying risk consequences is an essential step in management as it facilitates the assessment of each risk.

4.1.3. Risk Assessment

The objective of the risk assessment is to assess each risk's criticality according to its probability of occurrence and its level of impact on the company's activities, based on the list of identified risks and its consequences[247].
The chosen method, which must be simple and adapted to society, must allow:

• Estimating the probability of occurrence of the risk,
• Estimating the severity of the risk (potential impact on costs, timeframes, and performance…),
• Calculating the criticality of the risk.

To determine the priority risks to be addressed, we used the criticality grid, which highlights the risks deemed unacceptable to consider priority actions to reduce their probability or severity.
To develop this grid, the following parameters must first be calculated:
Probability: this risk occurrence frequency.

P	Probability	Definition
1	Very rare	1 time every (5 years and older)
2	Rare	1 time per 1 year
3	Infrequent	1 time per 3 months
4	Frequent	1 time per week

Table 84: risk occurrence frequency.

Severity: measures the effects and level of impact on society's targets. (It has more or less critical consequences).

S	Severity	Definition
1	Minor	Minimal impact
2	Significant	Visible damage
3	Grave	Significant damage
4	Critique	irreversible damage

Table 85: risk impact Severity.

Based on the probability and severity rating scales (tables above) and the estimated consequences of the identified risks on the company's activities, we calculated each of these risks' criticality to represent a mapping of each type of risk.
These mappings allowed us to determine which risks were not acceptable graphically using the following scale:

<table>
<tr><th colspan="2">C = P X S</th><th>Risk level</th><th>Definition</th></tr>
<tr><td>1</td><td>1</td><td rowspan="5">Acceptable risk</td><td rowspan="5">Low critical or well-controlled risk. Non-priority actions.</td></tr>
<tr><td>2</td><td>1</td></tr>
<tr><td>3</td><td>1</td></tr>
<tr><td>1</td><td>2</td></tr>
<tr><td>1</td><td>3</td></tr>
<tr><td>1</td><td>4</td><td rowspan="5">Risk under vigilance</td><td rowspan="5">Risk is present under surveillance. Actions to be taken to reduce criticality.</td></tr>
<tr><td>2</td><td>2</td></tr>
<tr><td>2</td><td>3</td></tr>
<tr><td>3</td><td>2</td></tr>
<tr><td>4</td><td>1</td></tr>
<tr><td>2</td><td>4</td><td rowspan="6">Risk not acceptable</td><td rowspan="6">Risk requiring priority processing. Essential security actions.</td></tr>
<tr><td>3</td><td>3</td></tr>
<tr><td>3</td><td>4</td></tr>
<tr><td>4</td><td>2</td></tr>
<tr><td>4</td><td>3</td></tr>
<tr><td>4</td><td>4</td></tr>
</table>

Table 86: Risk Mapping Interpretation.

4.1.4. Action Plan

The Risk Action Plan provides a response strategy. In other words, for each risk, the following questions must be answered:
-What can we do to reduce this risk?
-What is the cost and time to complete each preventive action related to this risk?
The Risk Response (Planning) Plan is an ongoing process of taking into account and risk treatment (mitigation, vigilance, acceptance), as and when as they appear. This step is sometimes referred to as "Mitigation Strategy for risks." [247]
The main strategies for addressing potential risks are, in order of cost and time:

Criticality	Level risk	Priority=C*T Execution time (T): (1) short-term, (2) medium-term, (3) long-term. Cost (C): (1) Low, (2) Medium and (3)High.		Decision	
8	Unacceptable risk	1	Strong priority	Mitigation or reduction	Reduce risk to an acceptable threshold
9		2			
12		3	Medium priority	Mitigation or reduction	
		4			
16		6	Low priority	Mitigation or reduction	
		9			
4	Risk under vigilance	1	Strong priority	Mitigation or reduction	
		2			
		3	Medium priority	Monitoring without mitigation action	Risk monitoring without reduction action
6		4			
		6	Low priority	Acceptance	Accept the risk you have to live under these conditions.
		9			
1	Acceptable risk	1	Strong priority	Mitigation or reduction	Reduce risk to an acceptable threshold
		2			
2		3	Medium priority	Acceptance	Accept the risk you have to live under these conditions.
		4			
3		6	Low priority	Acceptance	Accept the risk you have to live under these conditions.
		9			

Table 87: Risk Prevention Action Decision.

4.1.5. Risk Monitoring

Some risks may disappear, others may appear, or others may be considered initially as low, which could quickly become unacceptable. For each risk, the following questions must be answered[247]:

-Have risk reduction actions reduced risks in deadlines and budgets?

- Does the overall risk increase or decrease?

-Given the resources allocated to risk control, have we achieved maximum possible mitigation?

This step's purpose is to update the initial list of risks already known, to take into account the evolution of the situation of each risk. To monitor the treated risks, we recalculated the criticality of the residual risks after the completion of the action plan, thus drawing the new mapping of residual risks.

4.1.6. Risk Control

Risk control consists of monitoring the risk analysis at a frequency determined in the risk management plan.

The proposed methods for risk control are:

• Visual inspection
• Statistical process control
• Sampling
• The Poka-yoke
• Experience Plan
• Etc.

4.1.7. Feedback from experience

At the end of each year, management must analyze and synthesize the risk management approach. This approach aims to capitalize on the know-how and experience acquired to benefit all the actors in society's processes[247].

To this end, the risk documents (risk management procedure, risk identification and assessment sheet, action plan, etc.) drawn up continuously during the year should be formalized and finalized. These documents ensure the traceability of the risks encountered, the actions taken, and the results obtained.

4.1.8. Incident Management

An incident can be defined as an occurrence, condition, or situation during a work activity that could have resulted in injury, illness, health problems, or death to an employee or damage to production equipment[248].
In order to control incidents that may involve hazardous substances on people and material of the company, incident report is prepared.

4.2. Quality Objectives

the quality objectives represent the company’s quality targets and performance indicators based on the quality policy defined and planned previously.

4.3. Planning for Changes

Any changes that may affect the QMS are planned and implemented to maintain consistency and ensure stability. Changes are input to management review.

5. Support

5.1. Human Resources & Competence

Each company relies on its human capital to accompany it in its request for distinction and continuous improvement. We do this by ensuring that any person performing work that affects compliance with product requirements is competent based on their initial, continuing, professional training, experience, and know-how.
The requesting department expresses its need for human resources. The HR department is responsible for drawing up a job description that defines the tasks, responsibilities, responsibilities, and authorities required for the function.
The provision of the skills best suited to the company's needs and their development are described in the "personal recruitment" procedure.
Training is a means of valuing the company's internal wealth. Indeed, it enables the maintenance and development of skills capital and facilitates its permanent adaptation to change. The arrangements for identifying, planning, implementing, and evaluating the effectiveness of training actions are described in the "Personal Training" procedure.
To evaluate the effectiveness of the training organized within the company, we have developed a hot evaluation sheet. This assessment is made after the training, or the employee returns to his or her post. It is a question of evaluating the trainer's qualities, or the training body on the pedagogy, the tools used, the material conditions, the response to expectations, ...).
A cold evaluation sheet was drawn up, evaluating the concrete and operational contributions of the training actions held over the evaluation period. It takes place during individual interviews.
To enable staff to develop appropriate levels of quality issues awareness. Awareness-raising actions must be regularly carried out by management.
This awareness includes:
• The importance of compliance with the SMQ's quality policy, procedures, and requirements;
• The importance of each person's activity and how staff contribute to
the achievement of SQM objectives;
• Roles and responsibilities to ensure compliance with the requirements of the
SQM and continuous performance improvement;

• Potential consequences of deviation from specified procedures.

5.2. Infrastructure

The company must provide all the necessary means (buildings, workspaces, installations, equipment, tools, hardware, software, etc.) to obtain compliance with the produces and maintain the safety of personnel. The plant level's maintenance process ensures the maintenance of industrial equipment, materials, and tools.

Maintenance management and workflow within the factory are described in the procedure "Maintenance of Industrial Equipment."

Information System, Telephony and Network Management is managed through the Information Systems process and is described in the "Information System Management" procedure.

5.3. Awareness & Communication

Internal Communication

The staff at all levels is the essence of the company, and that a total involvement on the part of the company allows using their skills for the benefit of the company, it is for this reason we have determined the arrangements to communicate internally, in particular concerning:

• The quality policy,
• Responsibilities and authorities,
• The importance of compliance with the quality policy and SQM procedures,
• Progress on objectives,
• The performance indicators,
• Results of audits and customer satisfaction surveys,
• Conclusions and actions decided during management reviews.

To make this communication more concrete, we proposed to have a paper communication poster posted in all production workshops see.

The effectiveness of internal communication is assessed through internal audits.

5.4. Documented Information

Documented information is QMS data that must be controlled and documented by the organization to ensure its processes' efficiency.

The documented information required by the quality management system must be controlled to ensure[244]:

• They are available and suitable for use, when and where they are needed;
• They are adequately protected (from loss of confidentiality, inappropriate use, or loss of integrity).

The establishment of an ISO 9001 QMS requires the implementation of documented information. Using documentation, it is possible to communicate and demonstrate the compliance of processes, products, and services. Besides, it is a means of retaining and sharing organizational knowledge, disseminating and preserving company experiences

5.4.1. Structure of Documented Information

The QMS documents required of the company are defined and structured according to the pyramid described below:

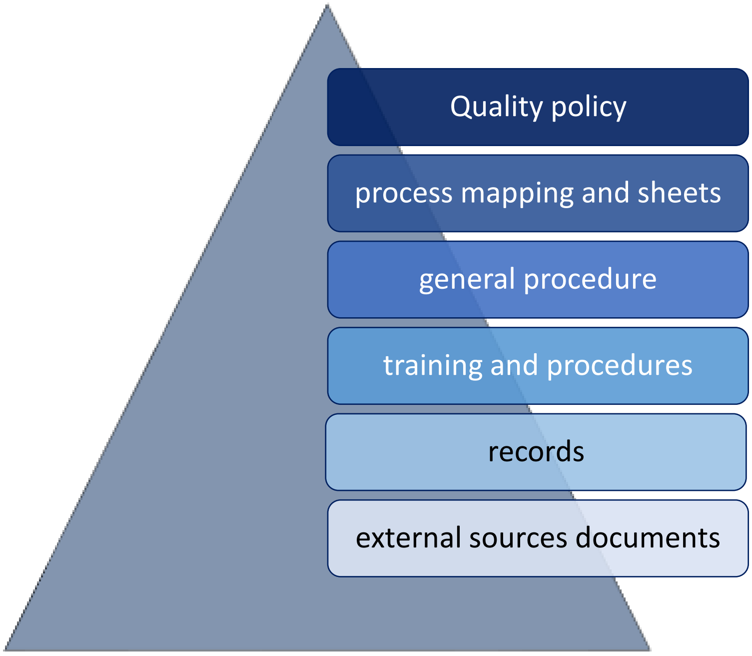


Figure 160: Structure of the company's documentary system

5.4.2. Mastering documented information

Documented information of internal or external origin must be identified and controlled.

Documented information retained as evidence of compliance must be protected from unintentional alteration.

The control of documented information is described in the "Documented Information Control" procedure, which defines the procedures for identifying, storing, protecting, accessibility, retaining, and disposal of documented QMS information.

6. Carrying out Operational Activities

6.1. Product and Service Requirements

The company's business process commercializes the products that will be manufactured by our factory. The procedures for determining and reviewing product requirements are defined within the "Commercial" Process. The procedures for processing orders and contracts are managed by the "Customer Order Management" procedure.

Any feedback gathered during business visits is taken into account and analyzed for better communication with the customer. The salesperson receives customer complaints. The "Customer Complaints Processing" procedure defines the procedures for handling complaints, in this case, the receipt, registration, and processing of complaints.

6.2. Control of products and services provided by external providers

The "Procurement" process ensures the provision of goods and services under the specified requirements on time.

Suppliers of products that affect our products' quality are selected and evaluated based on predefined criteria in the "Purchase, Selection, and Evaluation of Suppliers" procedure.

We have developed a supplier identification questionnaire to collect the general information of each supplier and its quality assurance data to control the products and services provided by external suppliers.

Procurement documents clearly describe the data and specifications for the product ordered. Products and services provided by external suppliers shall be verified upon receipt following the purchase specifications established with the suppliers using the supplier evaluation sheet, which is used to assess the supplier in terms of time, price, and quantity of goods requested.

6.2.1. Identification of the characteristics to be checked

To carry out a control of the products supplied by the external suppliers, we have determined the characteristics that impact the quality of the finished product to be checked during the reception phase, the means of control necessary to guarantee the quality of the products supplied by external suppliers.

The means of controlling their characteristics and the necessary quantity are shown in the following table:

Means of control	**characteristics**	**Need (quantity)**
Digital micrometer	Capacity: 0-25 mm	2
	Accuracy: 1 µm	
Digital micrometer	Capacity: 25-50 mm	1
	Accuracy: 1 µm	
Digital micrometer	Capacity: 300-500 mm	1
	Accuracy: 1 µm	
Digital micrometer	Capacity: 50-75 mm	1
Means of control	Accuracy: 1 µm	
Digital micrometer	capacity 10 meters	2

Table 88: Means of product control provided by external suppliers.

6.2.2. Control of products supplied by external suppliers

The control of the products supplied by external suppliers is carried out during the reception phase of the materials by the purchasing department in coordination with the quality department. This control consists of randomly taking a sample of size «n» from a batch of size «N» and to decide, at the end of this check, whether this batch is acceptable or not. This decision is determined by a maximum number of defective 'R' found in the sample that must not be exceeded in deciding to accept the lot[249].

the exact sample size according to ISO 2859-1, the lot acceptance criterion, and the lot rejection criterion based on three parameters: the lot size, the AQL acceptable quality level, and the NIG general inspection level, are defined. The NQA and NIG are mainly determined by a standard agreement between the supplier and the customer.

6.2.3. Acceptance Control Report

Upon receipt of the products supplied by external suppliers, we have established a control sheet for the reception of the raw materials and the sub-This is used to decide whether to accept or reject a lot based on the characteristics of the raw materials already identified.

6.3. Production Control and Service Delivery

All processes, whatever they are, cannot produce precisely the same product; all operators well know this, and it is one of the main problems that regulators face every day.

This variability is unavoidable, and we must be able to "live with it." Regardless of the machine studied, the observed characteristic is always dispersion in the characteristic (Measurable or not measurable). These variations come from the entire production process. The analysis of manufacturing processes allows dissociating 5 elementary elements source of this dispersion[250]. The 5 M generally refers to these five fundamental causes responsible for dispersion (variability) and therefore of non-quality.

6.3.1. Identification of process characteristics to be controlled

To better control the manufacturing processes, we have first determined the production steps in the procedure "Produce single-piece vacuum tube and forced circulation solar water heaters." Then we identified the manufacturing steps that need to be controlled during production; see: Solar Tank Manufacturing Process Control Points, Heat Pipe Manufacturing Process Control Points, Aluminum Fin Manufacturing Process Control Points, Heat Pipe Manifold Manufacturing Process Control Points, Support Manufacturing Process Control Points.

Identifying the characteristics to be checked is based on the importance of the characteristic for the satisfaction of the end customer, so we have selected the process characteristics strongly correlated to the expected functions of the finished product. These characteristics (measurable and not measurable) and the means used to control them are established.

The following table represents the process of quality control means:

Means of control	Characteristics	Needs (quantity)
Digital micrometer	Capacity 300- 500mm	15
	Accuracy: 1 µm	
Digital micrometer	Capacity 0-25mm	10
	Accuracy: 1 µm	
Digital micrometer	Capacity 25-50mm	5
	Accuracy: 1 µm	
Barometer	Capacity: 0 to 3500 mmHg (0-3,99 Bar)	5
	Accuracy:0.015%	
Water leak detector	comes with a 1.2 m detection cable	5
Cleaner	3 500 ml aerosols	20 per month
Red penetrator		
White Developer		

Table 89: Means for controlling manufacturing processes.

6.3.2. Conduct of Controls

a. Control of measurable characteristics

The measurable characteristics of the manufacturing process to be controlled are:

• Monitoring the diameter of the inner solar tank tank
• Monitoring the diameter of the external solar tank tank
• Solar Tank Inner Cover Diameter Monitoring
• Condenser diameter monitoring
• Inlet & Outlet diameter collector monitoring
• Fin diameter monitoring

We performed the normality test, the stability, and capability test for all the previous characteristics we determined.

To document and record the quality control of the products being manufactured, we have developed a control sheet of each shift's products.

Control sheet for the diameter of the inner solar tank tank.

Control sheet for the diameter of the external solar tank tank.

Diameter control sheet for inner solar tank covers.

Condenser diameter control sheet.

Manifold Inlet & Outlet Diameter Check Sheet.

Control sheet for the diameter of the fin.

- **Normality Test**

To control the manufacturing process, we must first check that the random variations often follow a bell curve: the customary law.

Indeed, many tests (capability test, stability test, etc.) assume the distributions' normality to be applicable. This is why we have to check whether the actual data we collected in the sampling phase follows the ordinary law or not. In non-normality, we looked for a method to make our data follow the bell curve. It is the Cox-Box transformation.

- **Capability Test**

The capability is measured by the ratio between the requested performance and the actual performance of a Process. It measures the ability to produce parts within the tolerance range set out in the specifications[249]. There are two indicators to determine the capability of a process:

Dispersion indicators Cp

This indicator compares the expected process performance (tolerance interval). Furthermore, the performance was obtained on it (dispersion). To calculate this indicator, we used the following relation: [9]

Cp= Tolerance interval/ short-term dispersion of the process= IT/ (6 6CT) (73)

Cpk is the centering indicator around the target. It compares the distance from the nearest control limit to the target with half scatter.

To calculate Cpk, we used the following relation[249]:

Cpk= Distance (Nearest Mean/Limit)/ (1/2)Short-term dispersion of the process= Dist(M/LlpP) / 3 6 CT (74)

Interpretation of Capability Indicators

After having calculated the indicators Cp and Cpk, the results obtained must be interpreted; generally, a process is capable if:

Cpk is more significant than 1.33, and Cp is more significant than 1.33

The following tables present interpretations of all possible causes of the calculated Cp and Cpk indicators:

Cp indicator interpretation		
value	Graphic Description	Interpretation of the Cp
Cp<0,67	Dispersion greater than the interval.	More than 5% of defects are generated. 100% control is probably necessary.
0,67<Cp<1	Dispersion slightly greater than the interval.	We generate between 0.0063% and 5% default. You have to look at long-term capability to know whether this is just a “one-time” or “sustainable” situation. If it is sustainable, more control is needed.
1<Cp<1,33	Dispersion slightly smaller than the interval.	
1,33<Cp<1,67	Dispersion low in relation to the interval.	Very few defects are generated. It is simply a matter of controlling the process over time and correcting special causes as they arise.
1,67<Cp<2	Very low dispersion.	
2<Cp	Dispersion more than 2 times smaller than the interval.	

Table 90: Interpretation of indicator Cp [12], [13].

Cpk indicator interpretation		
Value	Graphic Description	Cpk Interpretation
Cpk<0,67	The process is very biased.	Even if our dispersion would be minimal, the excessive decentralization puts us in a situation at risk. 100% control is without
0,67<Cpk<1	Decentralization is relatively low.	doubt necessary.
Cpk> = 1	The process is perfectly centered.	The situation is very dependent on our value as Cp. Nevertheless, even if it is good, some

Table 91: Interpretation of indicator Cpk [12], [13];

- **Stability test**

Control Map Calculation

The purpose of the control maps is to monitor that the process's variations are not more significant than the "normal" variations. Therefore, before setting up a control card,
what are these variations. Knowing the natural variability of the process, we can then calculate the control maps adapted to the characteristic. The use of control cards motivates operators and supervisors to improve the process and thus reduce the process's natural variability. Once this variability has decreased, the maps will need to be recalculated and further improved. We then enter the continuous improvement phase[249].

Measurable process characteristics such as inner solar tank diameter, condenser diameter etc… are monitored by the Medium/Wide Control Map, which consists of establishing two control maps:

- Averages map to monitor setpoint setting
- Area map to monitor machine dispersion

For each control board, we must calculate the average values and lower and upper control limits.
Measurable Characteristics Control Maps are established for different tests:
Capacity test/diameter stability of the inner solar tank tank, capacity test/diameter stability of the outer solar tank, capacity test/diameter stability of the inner solar tank covers, Capability/Diameter Stability Test Capability/Diameter Stability Test Inlet & Outlet, Capability/Diameter Stability Test.

ccontrol of non-measurable characteristics (attributes)

Where the specifications to be checked are not measurable, an attribute check shall be carried out. This latter mode of control consists of assigning two possible values: Compliant 1; Non-compliant 0. Compliance depends on the established acceptance criteria. Implementation is based on the sampling strategy, as is the case with measurement control cards at the sampling level and the determination of control limits.

The unmeasurable process characteristics to be controlled are:

• Monitoring the state of the solar inner tank welding
• Indoor Tank Blasting Condition Monitoring
• Indoor Solar Tank Tank Polyurethane Injection Condition Monitoring
• Solar Tank Inner Tank Leak Monitoring
• Monitoring of the state of solar tank welding
• Monitoring of the state of welding of the lid with the inner solar tank tanks
• Monitoring of condenser sintering
• Heat pipe rod sintering monitoring
• Heat Pipe Water Leak Monitoring
• Monitoring of the welding state of the manifold pipe

To document and record the products' quality control during manufacture, we proposed the control sheet of the products during the manufacture of the non-measurable characteristics.

- Solar Tank Interior Welding Condition Monitoring Sheet.
- Indoor Tank Blasting Condition Monitoring Sheet.
- Solar Tank Inner Tank Polyurethane Injection Condition Monitoring Sheet.
- Solar Tank Inner Tank Leak Test Sheet.
- Solar Tank Exterior Welding Condition Monitoring Sheet.
- Cover Welding Condition Monitoring Sheet with Solar Tank Inner Tanks.
- Condenser Sintering Monitoring Sheet.
- Heat Pipe Sintering Monitoring Sheet.

- Heat Pipe Water Leak Monitoring Sheet.
- Collector Pipe Welding Condition Monitoring Sheet.

We have checked these non-measurable characteristics by an NP control map (Schwartz map), which allows tracking the number of non-conforming units.

For this map, the samples must all be of the same size; the number of non-conforming units is np; This is the product of sample size 'n,' with the proportion of non-conforming units' p'

We then choose to estimate p by the proportion of non-compliant units in all "m" samples of size "n". By scoring neither the number of non-conforming units in sample "i," the proportion "p" of non-conforming units is calculated as follows:

Interpretation of Extended/Medium Control Map [249]

6.3.3. Process Control Report

Depending on the sampling that has been done, it must be decided whether production can be accepted or if it is to be triaged. To make this decision, it is necessary to take into account the capability of the process expressed by the PC. The decision table (Table 92) gives the rules to apply. In low short-term capability (Cp 1.33), production must be systematically sorted to obtain the correct result. In case of outstanding short-term capability (Cp > 1.67), one can produce without sorting even if one finds a point out of control. In the intermediate cases (1.33 Cp 1.67), production is only sorted in cases where there is a point out of control. [249] The decision table is shown below :

	Cp value observed on previous charts		
The last point on the control board indicates:	Cp less than 1,33	Cp between 1,33 and 1,67	Cp greater than 1.67
The process is "under control."	Unit Control (100% Sort)	ACCEPT pieces	ACCEPT pieces
The process becomes "out of control," BUT all individual sample values are within tolerances	IDENTIFY and CORRECT the special cause		
	Unit Control (100% Sort)	SORT the components since the last "under control" point of the Control Board	ACCEPT piece
The process becomes "out of control," AND one or more individual sampling values are out of tolerance.	IDENTIFY and CORRECT the special cause		
	Unitary control (100% Sort)	SORT components since the last item under control» of the control board	

Table 92:production decision.

6.4. Control of Finished Product

The final product control is carried out in compliance with the manufacturing standards of solar water heaters. We started with a study of different European and international standards for the manufacture of solar water heaters to determine the relevant standards for our products.

After studying the European and international standards for solar water heaters' manufacture and their characteristics in chapter 4, EN 12975 and EN 12976 are chosen to control and certify the products.

6.4.1. Identification of the characteristics to be checked

The control team shall take a sample size "n" and carry out the control based on the tests of the standards mentioned in the preceding paragraph. The tests to validate the finished product and means used are detailed in chapter 4.

6.4.2. Conduct of Controls

the requirements for running the test, the flowchart process, and the symptoms that may appear after each test are determined in chapter 4.

High-Temperature Resistance Test, Exposure Test, External Thermal Shock Test, Internal Thermal Shock Test, Rain Penetration Test, Gel Resistance Test, Mechanical Load Test, Internal Pressure Test, Shock Resistance Test (optional).
To better evaluate the tests' results, the team responsible must carry out a final inspection corresponding to the disassembly of all the solar water heaters tested; all detected anomalies must be documented and accompanied by photographs.

6.4.3. Control Report

For the decision concerning the acceptance or rejection of solar water heaters, we have proposed a final product control sheet that decides whether to accept or reject the controlled water heater and document the final inspection with the test photos.

6.5. Mastering the means of measurement

To improve the quality of the products, it is necessary to ensure that the characteristics of the processes controlled by measure or by attributes can be checked with sufficient precision. Indeed, it is useless to control the production process's characteristics with means of control that are not capable; this creates the risk of rejecting compliant parts. To solve this, it is proposed to use the R & R pledge, a statistical tool used to measure a measuring system's performance in terms of repeatability and reproducibility. This test qualifies as a measurement system by calculating a percentage that indicates the total variations in the measurement process. The lower the percentage, the more accurate the measurements are. [251]
Repeatability R (of the measurement results): the close agreement between the results of successive measurements of the same measured quantity or characteristic, carried out under all the same measuring conditions (same operator, same instrument, same environment, same measurement time).
Reproducibility R (of the measurement results): the close agreement between the results of measurements of the same measured size or characteristic, carried out by varying the measuring conditions.

6.6. Product Identification and Traceability

All products are identified, from receipt to delivery using appropriate devices. The identification and traceability of products are managed by the “Product identification and traceability” procedure.

7. Performance Evaluation

7.1. Monitoring, Measurement, Analysis, and Evaluation

<u>Customer Satisfaction Survey</u>
To ensure the continuous improvement of the efficiency of the quality management system,
the company monitors the customer's perception of the level of meeting these requirements. The customer satisfaction survey results are analyzed, and appropriate action plans are put in place to take into account and address customer dissatisfaction and/or recommendations for improvement. The "Customer Complaints Handling" procedure also allows you to listen to the customer and react to satisfy him continually.

7.2. Internal Audit

The company conducts internal audits to determine whether the QMS:
Complies with planned provisions and requirements of ISO 9001; Is implemented and maintained effectively. The responsibilities and arrangements for planning, conducting internal audits, reporting on results, and dealing with non-compliances arising from audits are defined in the

"Internal Audit" procedure. Internal audits shall be conducted either by a qualified internal auditor, independent of the activities to be audited or by a qualified external auditor.

7.3. Management Review

Executive reviews are held once a year; This is an opportunity for the Executive to ensure that the quality management system remains relevant, adequate, and useful. The management review includes an assessment of opportunities for improvement and the need make changes to the QMS, including the quality policy and associated objectives. The QMR prepares for the Executive Review Meeting, and the input elements include[244]:

- Progress of actions decided upon following previous management reviews
- changes in external and internal issues relevant to the quality management system;
- information on the performance and efficiency of the quality management system;
- adequacy of resources;
- the effectiveness of the actions implemented in the face of risks and opportunities.

Decisions are taken, and actions are planned at the end of each management review, and these concerns:

- Improving the efficiency of the QMS and its processes;
- Improvement of the product concerning the customer's requirements;
- The need for resources.

These decisions and actions must necessarily lead to an action plan. Management review reports are prepared and maintained by the QMR and disseminated to all relevant officials. The conduct of the management review is defined in the "management review" procedure.

8. Improvement

8.1. Non-Compliance and Corrective Action

Non-conforming products control

The company must ensure that output items that do not meet the requirements
are identified and controlled to prevent their unintentional use or supply.
The company may process non-compliant output items by:

- Correction;
- Isolation, confinement, return or suspension of supply of goods and services;
- Informing the client;
- Obtaining an Override Acceptance Authorization.

Corrective Actions

The procedure "Control of Corrective Actions" provides for the review of non-conformities, the determination of the causes of non-compliance, the assessment of the need to undertake actions, the implementation, and the registration of actions undertaken.
The sources for initiating corrective actions are:

- Internal and external audits;
- Measuring and monitoring customer satisfaction;
- Process measurement and monitoring;
- Control of nonconformities, including customer complaints;
- Data analysis output elements;
- Output data from executive reviews.

Corrective actions are reviewed for their effectiveness to decide on the closure of corrective action sheets or the implementation of other more relevant actions.

8.2. Continuous improvement

To continuously increase its competitiveness and performance, the company must be part of a dynamic of continuous improvement based on the Quality Policy, QMS objectives, audit results and measurement, monitoring arrangements, data analysis, corrective actions, and management review. Corrective actions are taken to eliminate the actual and/or potential causes of non-compliance. The procedures «Control of the product Non-compliant, «Control of actions corrective» defines the rules for the management of nonconformities and the methods used to initiate corrective or improvement actions

9. ISO 9001 Sol'R-Shemsy product certification

After the quality management system design, the ISO 9001 certification approach will be presented in this section.

9.1. ISO 9001-V2015

The ISO 9001 standard specifies requirements aimed primarily at giving confidence in an organization's products and services and thus increasing customer satisfaction. It can also be expected that its appropriate implementation will benefit the organization, such as better internal communication, better understanding, and greater control over its processes[244].

9.2. ISO 9001-V2015 Certification

ISO 9001 version 2015 certification is a method to demonstrate that the company's QMS complies with ISO 9001. Being certified means that, at the end of the process, an external auditor will regularly come to audit the company's processes and verify compliance with the QMS requirements of ISO 9001. The certification represents national and international recognition of the quality of work because ISO 9001 ensures acceptable management practices, quality assurance of products or services, and customer satisfaction. The requirements of the standard constitute a standard that is internationally recognized.

How to obtain ISO 9001 certification?

An ISO 9001 certification process, in general, takes 18 months. However, this period depends on several factors, such as the size, the area of activity of the organization, the commitment and motivation of staff, etc.

The Figure below shows the steps for ISO 9001 certification:

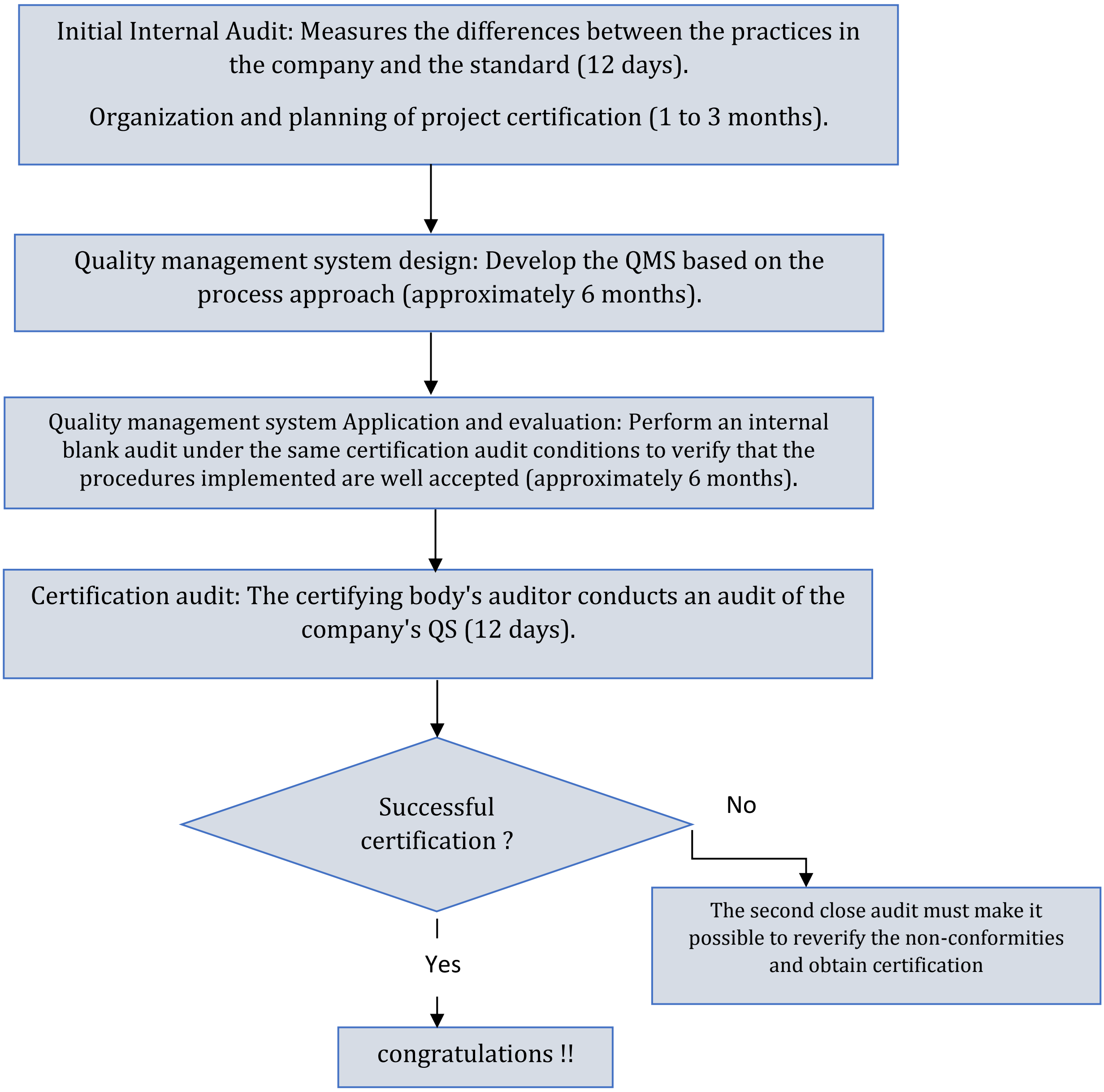


Figure 161: ISO 9001 certification process [26].

To obtain ISO 9001 certification, the quality manager must contact a certifying body in Morocco to begin the certification process. For more specified certifications, especially about solar water heaters, chapter 4 presents all details about certifications, standards, and necessary tests and requirements. The test procedures are also explained and fixed for the solar water heater. Chapter 4 makes a zoom on the keymark certification recommended for SOL'R SHEMSY project; the procedure to obtain this certificate is exhibited. Also, all certification tests body recommended is mentioned.

Conclusion

This chapter developed a quality management platform following current standards; This involved a presentation of the objectives, scope, and principle of a quality management system. Following an elaborate design of the quality management system of the predictive manufacturing Sol'R-Shemsy product based on ISO 9001-V2015 standard requirements, the organization's context, the needs, and expectations, in setting policy and quality objectives. These results were achieved by identifying processes and a risk management platform determination that can impact the processes and the company's performance to finally develop the documented human resources, infrastructure, and information management procedures.

To guarantee the quality of the products, it was essential to define a product validation approach from the raw materials' receipt to the delivery of the finished product and control the measurement means used in the quality control. Finally, the ISO 9001 certification process was presented.

This chapter has provided a forecasted production unit's processes management guide to guarantee the quality, which is one of the project's main objectives.

7.General conclusion and perspectives

7.1. General conclusion

This thesis project aims to develop the concept of technological adaptation, projecting the SWH. The project was finalized to present a high-performance, certifiable product adapted to the Moroccan context (technical, climatic, economic, and social).

Through this project, several preliminary studies have been carried out to situate the problem, evaluating the strategic, economic, and political failures surrounding it and the economic and environmental impacts and benefits this project can bring.

The study of the generalization of thermosiphons in Morocco allowed us to achieve a new regional climate zoning evaluating the residential concentration in the different Moroccan climatic zones. The study addresses different needs related to three significant buildings in Morocco: modern Moroccan houses, villas, and buildings with a demand for a hot water sanitary variant from standard to luxurious. The dynamic thermal simulations by TRNsys made it possible to generate all the energy gains by climate zones generated by covering all the Moroccan domestic hot water needs. The results show that large-scale integration of TSWH into Moroccan residences could provide up to 70% of thermal energy loads. An economic assessment was also carried out, taking into account gas water heaters and two different scenarios, with and without state subsidies for gas. Approximately 1250 Million USD as national economies can be achieved. The environmental effects were also assessed to achieve the aims of this work and to evaluate the CO_2 emissions avoided due to this environmentally friendly solution. 3.644 million tons of CO_2 can be avoided, and 220,377 million m3 of butane saved nationally.

The second study aims to compare passive building envelope solutions and active solutions (integrating solar water heaters. The comparison is made based on energy bill reductions and economically based on investments and investment return times. In this study's framework, the evaluation took on another dimension detailing the SWH system; This is by comparing the two technologies (ETC and FPC) and evaluating the storage technique for the chosen collective building; the individual and collective heating systems. The study took several parallel directives to judge the system with the same technological variants but under different configurations. Furthermore, evaluate it against other energy retrofit solutions for buildings; this made it possible to highlight the importance of adopting the solar water heating project and the meter a priority over other solutions given the importance of energy and economic gains.

This project also enabled the mastery of the different materials used to manufacture solar water heaters in order to be able to carry out the technical and economic studies and to make a rational choice for the SWH SHemsy. All these studies made it possible to finally present the optimal solution adapted to the different aspects that surround the project.

Two different variants of the solution were presented through the project: an entry-level low-pressure solar water heater and another much more efficient high-pressure variant. The product respects the launch's commitment and is presented at a very social price that does not exceed MAD 5000. On the other hand, the overall performance of the SWH has been studied and presented in this report. The product guarantees a very satisfactory operation with a national

average annual solar fraction of 80%, ensuring warm water with a temperature of 60°C in all the kingdom's varied climatic conditions (the six climatic zones).
The product was accompanied by the realization of an experimental platform dedicated to scientific research studies. The system presents forced circulation solar water heaters with two types of solar thermal collectors (ETC and FPC). A weather station was also installed to present a complete installation: technique and weather. The achievements of the SOL'R SHEMSY project were complemented by the proposal of a control system dedicated to forced circulation systems, in order to monitor performance and control operation.

To control the parameters of the project, a manufacturing procedure of the product has been proposed with an identification of the totality of the technical, human, and financial means necessary for the installation of the production unit.

This thesis project presents a complete proposal of the realization and the detailed technical and scientific studies to the economic studies previewed by presenting a complete business plan of the project established based on all the elements previously presented and a market study studying the behavior and needs of the Moroccan consumer.

To improve the project, a proposal was made for the production quality management system to fix the control methodology installed in the production unit for a product of the desired sound quality.

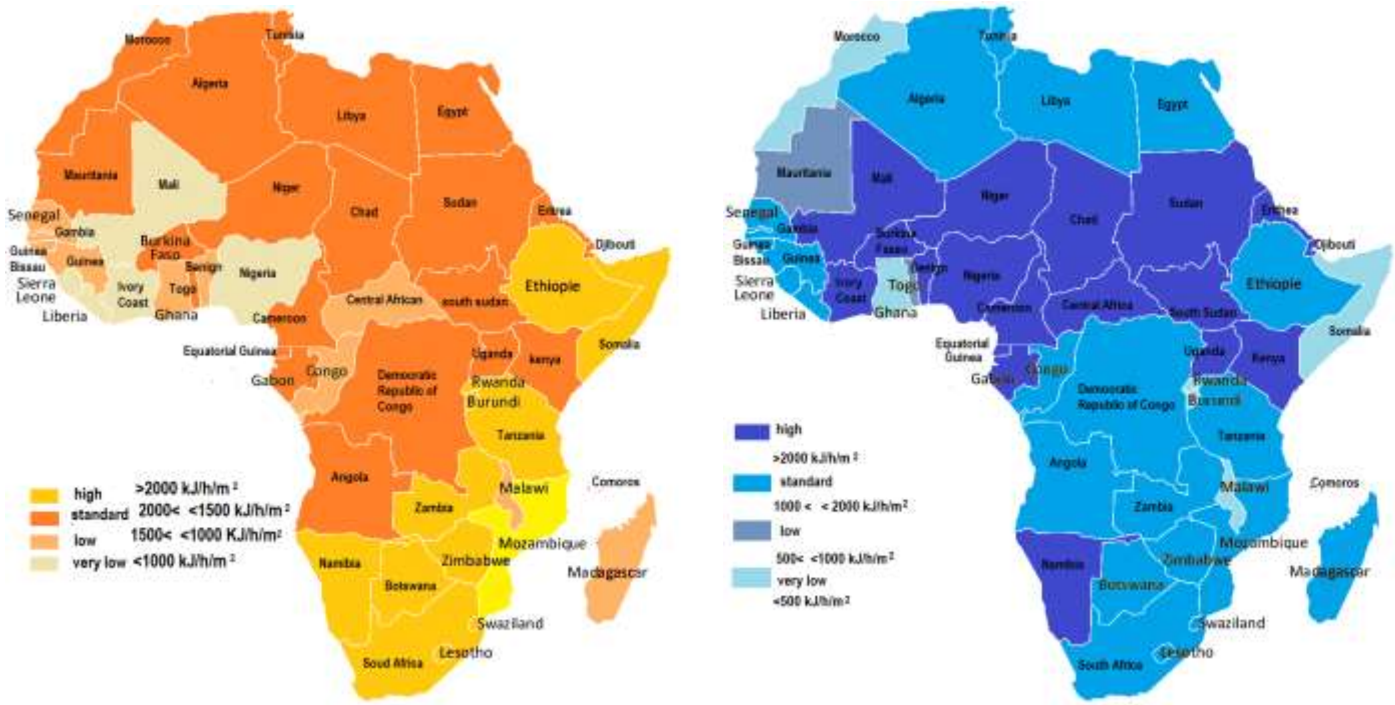
7.2. Perspectives

As part of the prospects for the continuity of this project:
The continuity of scientific research studies to produce an innovative prototype, to bring innovation to the prototype presented in the first phase of the realization, guaranteeing a quality improvement of performance and yields. Presenting a better version of the product compliant with European standards and competitive ready to find a place on the Moroccan market.

The Continuity of the studies concerning the control system to present new variants much more intelligent will allow to calculate and follow more parameter; the energy bill thus consumes predicting the model of the load profiles linked to the user for more optimization and performance.

The continuation of studies on the prototype also presents a significant perspective of this thesis project by carrying out the various experimental tests to validate all the dynamic studies and simulations presented in this report. Exploit the experimental platform perform and finalize for scientific research studies and validation of digital studies previously performed.

The perspectives of this thesis project are not limited to geographical boundaries. However, aim to conduct a range of technical and simulation, energy, environmental, and economic studies on all African countries to assess this product's adaptability to the conditions and contexts of other countries. This perspective is based on the importance of this continent's solar potential in terms of the quantity and quality of solar energy available. The figure below shows a mapping of quality energy potential in Africa, and that has been developed and carried out as part of this thesis project.



(a) (b)

Figure 162: (a) The solar exergy distribution for a representative day of august (summer).

The studies will take this project to another dimension that exceeds national needs' satisfaction, presenting a proposal of export of the product SHEMSY.

References

[1] « GIEO-Maroc-Ouverture-Economique-2020 Pages 51 - 84 - Text Version | AnyFlip ». http://anyflip.com/xdsqf/tvll/basic/51-84 (consulté le oct. 18, 2020).

[2] « INDICATEURS DE SUIVI DU DÉVELOPPEMENT HUMAIN : NIVEAU & TENDANCES À L'ÉCHELLE NATIONALE ET RÉGIONALE 2012-2017 », *Observatoire National du Développement Humain*. http://www.ondh.ma/fr/publications/indicateurs-suivi-developpement-humain-niveau-tendances-lechelle-nationale-et-regionale (consulté le oct. 18, 2020).

[3] H.-J. Beerfeltz, « Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (BMZ) », *Voluntaris*, vol. 1, nº 1, p. 18‑20, 2013, doi: 10.5771/2196-3886-2013-1-18.

[4] « GUIDE-CHAUFFE-EAU-SOLAIRES.pdf ». .

[5] « Global Energy & CO2 Status Report 2018 », *IEA Webstore*. https://webstore.iea.org/global-energy-co2-status-report-2018 (consulté le oct. 18, 2020).

[6] « World Energy Balances 2018 », *IEA Webstore*. https://webstore.iea.org/world-energy-balances-2018 (consulté le oct. 18, 2020).

[7] REN21, « RENEWABLES 2020 GLOBAL STATUS REPORT ». https://www.ren21.net/gsr-2020 (consulté le oct. 18, 2020).

[8] « Global CO2 emissions in 2019 – Analysis », *IEA*. https://www.iea.org/articles/global-co2-emissions-in-2019 (consulté le oct. 18, 2020).

[9] J. Krämer, « Global Trends in Renewable Energy Investment 2020 », *Frankfurt School*. https://www.fs-unep-centre.org/global-trends-in-renewable-energy-investment-2020/ (consulté le oct. 18, 2020).

[10] D. Coady, I. Parry, N.-P. Le, et B. Shang, « Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates », *IMF Working Papers*, vol. 19, nº 89, p. 1, 2019, doi: 10.5089/9781484393178.001.

[11] « gsr_2020_full_report_en_compressed-254-289.pdf ». .

[12] « Rapport du CESE_transition énergétique (1).pdf ». .

[13] « RESING_evaluation_PROMASOL_rapport_final (1).pdf ». .

[14] « ESTIF - Solar Thermal Markets in Europe - Trends and Market Statistics - SUMMARY », *Google Docs*. https://docs.google.com/forms/d/e/1FAIpQLSfkqU9Yy0_tmFJXlOAZxM5aHnS8qv3uSEFoU6bPjc5ksO6IXg/viewform?usp=embed_facebook (consulté le oct. 18, 2020).

[15] A. Bennouna, *Trois décennies d'énergie solaire thermique au Maroc*. 2019.

[16] P. Lumiar, « Mapping flexibility of urban energy systems », p. 4.

[17] « Renewables 2019 Global Status Report ». https://wedocs.unep.org/handle/20.500.11822/28496 (consulté le oct. 18, 2020).

[18] « Base de données du commerce extérieur du Maroc ». https://services.oc.gov.ma/DataBase/CommerceExterieur/ (consulté le oct. 18, 2020).

[19] « (PDF) Trois décennies d'énergie solaire photovoltaïque au Maroc ». https://www.researchgate.net/publication/337731175_Trois_decennies_d'energie_solaire_photovoltaique_au_Maroc (consulté le oct. 18, 2020).

[20] N. Dimassi et L. Dehmani, « Natural Convection of a Solar Wall in a Test Room under Tunisian Climate », *ISRN Renewable Energy*, vol. 2012, p. 1‑9, 2012, doi: 10.5402/2012/573176.

[21] I. M. Michaelides, W. C. Lee, D. R. Wilson, et P. P. Votsis, « Computer simulation of the performance of a thermosyphon solar water-heater », *Applied Energy*, vol. 41, nº 2, p. 149‑163, janv. 1992, doi: 10.1016/0306-2619(92)90042-A.

[22] B. Carlsson, M. Meir, J. Rekstad, D. Preiß, et T. Ramschak, « Replacing traditional materials with polymeric materials in solar thermosiphon systems – Case study on pros and cons based on

a total cost accounting approach », *Solar Energy*, vol. 125, p. 294‑306, févr. 2016, doi: 10.1016/j.solener.2015.12.005.
[23] S. Kalogirou et C. Papamarcou, « Modelling of a thermosyphon solar water heating system and simple model validation », *Renewable Energy*, vol. 21, p. 471‑493, nov. 2000, doi: 10.1016/S0960-1481(00)00086-0.
[24] C. Tecchio, J. L. G. Oliveira, K. V. Paiva, M. B. H. Mantelli, R. Gandolfi, et L. G. S. Ribeiro, « Thermal performance of thermosyphons in series connected by thermal plugs », *Experimental Thermal and Fluid Science*, vol. 88, p. 409‑422, nov. 2017, doi: 10.1016/j.expthermflusci.2017.06.021.
[25] Z. Xu, Y. Zhang, B. Li, C.-C. Wang, et Q. Ma, « Heat performances of a thermosyphon as affected by evaporator wettability and filling ratio », *Applied Thermal Engineering*, vol. 129, p. 665‑673, janv. 2018, doi: 10.1016/j.applthermaleng.2017.10.073.
[26] L. L. Vasiliev, L. P. Grakovich, M. I. Rabetsky, L. L. Vassiliev, et A. S. Zhuravlyov, « Thermosyphons with innovative technologies », *Applied Thermal Engineering*, vol. 111, p. 1647‑1654, janv. 2017, doi: 10.1016/j.applthermaleng.2016.07.101.
[27] S. Kumar, A. Dubey, et G. N. Tiwari, « A solar still augmented with an evacuated tube collector in forced mode », *Desalination*, vol. 347, p. 15‑24, août 2014, doi: 10.1016/j.desal.2014.05.019.
[28] R. H. E. Hassanien, M. Li, et Y. Tang, « The evacuated tube solar collector assisted heat pump for heating greenhouses », *Energy and Buildings*, vol. 169, p. 305‑318, juin 2018, doi: 10.1016/j.enbuild.2018.03.072.
[29] M. A. Essa et N. H. Mostafa, « Theoretical and experimental study for temperature distribution and flow profile in all water evacuated tube solar collector considering solar radiation boundary condition », *Solar Energy*, vol. 142, p. 267‑277, janv. 2017, doi: 10.1016/j.solener.2016.12.035.
[30] P. M. E. Koffi, H. Y. Andoh, P. Gbaha, S. Touré, et G. Ado, « Theoretical and experimental study of solar water heater with internal exchanger using thermosiphon system », *Energy Conversion and Management*, vol. 49, nº 8, p. 2279‑2290, août 2008, doi: 10.1016/j.enconman.2008.01.032.
[31] A. Zerrouki, A. Boumedien, N. Said, et B. Tedjiza, « Input/output test results and long-term performance prediction of a domestic thermosiphon solar water heater in Algiers, Algeria », *Renewable Energy*, vol. 25, nº 1, p. 153‑161, janv. 2002, doi: 10.1016/S0960-1481(00)00157-9.
[32] R. Tang, Y. Cheng, M. Wu, Z. Li, et Y. Yu, « Experimental and modeling studies on thermosiphon domestic solar water heaters with flat-plate collectors at clear nights », *Energy Conversion and Management*, vol. 51, nº 12, p. 2548‑2556, déc. 2010, doi: 10.1016/j.enconman.2010.04.015.
[33] I. Zeghib et A. Chaker, « Simulation of a solar domestic water heating system », *Energy Procedia*, vol. 6, p. 292‑301, 2011, doi: 10.1016/j.egypro.2011.05.033.
[34] R. L. Shrivastava, Vinod Kumar, et S. P. Untawale, « Modeling and simulation of solar water heater: A TRNSYS perspective », *Renewable and Sustainable Energy Reviews*, vol. 67, p. 126‑143, janv. 2017, doi: 10.1016/j.rser.2016.09.005.
[35] « Influence of the DHW load profile on the fractional energy savings: a case study of a solar Combi-system with TRNSYS simulations », *Fuel and Energy Abstracts*, vol. 43, nº 3, p. 200, mai 2002, doi: 10.1016/S0140-6701(02)85844-1.

[36] K. Tanha, A. S. Fung, et R. Kumar, « Performance of two domestic solar water heaters with drain water heat recovery units: Simulation and experimental investigation », *Applied Thermal Engineering*, vol. 90, p. 444‑459, nov. 2015, doi: 10.1016/j.applthermaleng.2015.07.038.

[37] A. Hobbi et K. Siddiqui, « Optimal design of a forced circulation solar water heating system for a residential unit in cold climate using TRNSYS », *Solar Energy*, vol. 83, nº 5, p. 700‑714, mai 2009, doi: 10.1016/j.solener.2008.10.018.

[38] S. Chen et J. Yang, « Loop thermosyphon performance study for solar cells cooling », *Energy Conversion and Management*, vol. 121, p. 297‑304, août 2016, doi: 10.1016/j.enconman.2016.05.043.

[39] A. Brusly Solomon *et al.*, « Performance enhancement of a two-phase closed thermosiphon with a thin porous copper coating », *International Communications in Heat and Mass Transfer*, vol. 82, p. 9‑19, mars 2017, doi: 10.1016/j.icheatmasstransfer.2017.02.001.

[40] T. Kousksou, P. Bruel, G. Cherreau, V. Leoussoff, et T. El Rhafiki, « PCM storage for solar DHW: From an unfulfilled promise to a real benefit », *Solar Energy*, vol. 85, nº 9, p. 2033‑2040, sept. 2011, doi: 10.1016/j.solener.2011.05.012.

[41] S. Rezvani, P. A. Bahri, T. Urmee, G. F. Baverstock, et A. D. Moore, « Techno-economic and reliability assessment of solar water heaters in Australia based on Monte Carlo analysis », *Renewable Energy*, vol. 105, p. 774‑785, mai 2017, doi: 10.1016/j.renene.2017.01.005.

[42] L. Sokka *et al.*, « Environmental impacts of the national renewable energy targets – A case study from Finland », *Renewable and Sustainable Energy Reviews*, vol. 59, p. 1599‑1610, juin 2016, doi: 10.1016/j.rser.2015.12.005.

[43] T. Bouhal *et al.*, « Impact of load profile and collector technology on the fractional savings of solar domestic water heaters under various climatic conditions », *International Journal of Hydrogen Energy*, vol. 42, nº 18, p. 13245‑13258, mai 2017, doi: 10.1016/j.ijhydene.2017.03.226.

[44] A. Allouhi, A. Jamil, T. Kousksou, T. El Rhafiki, Y. Mourad, et Y. Zeraouli, « Solar domestic heating water systems in Morocco: An energy analysis », *Energy Conversion and Management*, vol. 92, p. 105‑113, mars 2015, doi: 10.1016/j.enconman.2014.12.055.

[45] B. Muhammad, « Energy consumption, CO2 emissions and economic growth in developed, emerging and Middle East and North Africa countries », *Energy*, vol. 179, p. 232‑245, juill. 2019, doi: 10.1016/j.energy.2019.03.126.

[46] T. Kousksou *et al.*, « Renewable energy potential and national policy directions for sustainable development in Morocco », *Renewable and Sustainable Energy Reviews*, vol. 47, p. 46‑57, juill. 2015, doi: 10.1016/j.rser.2015.02.056.

[47] « Site institutionnel du Haut-Commissariat au Plan du Royaume du Maroc », *Site institutionnel du Haut-Commissariat au Plan du Royaume du Maroc*. https://www.hcp.ma (consulté le oct. 19, 2020).

[48] L. El-Katiri, « The Road to Marrakech: Key Issues for COP22 », p. 11.

[49] « AMEE | AGENCE MAROCAINE POUR L'EFFICACITÉ ENERGÉTIQUE ». https://www.amee.ma/fr/agence-marocaine-pour-efficacite-energitique (consulté le oct. 19, 2020).

[50] S. A. Klein *et al.*, « Mathematical Reference », p. 434.

[51] A. de Gracia *et al.*, « Experimental set-up for testing active and passive systems for energy savings in buildings – Lessons learnt », *Renewable and Sustainable Energy Reviews*, vol. 82, p. 1014‑1026, févr. 2018, doi: 10.1016/j.rser.2017.09.109.

[52] X. Sun, Z. Gou, et S. S.-Y. Lau, « Cost-effectiveness of active and passive design strategies for existing building retrofits in tropical climate: Case study of a zero energy building », *Journal of Cleaner Production*, vol. 183, p. 35‑45, mai 2018, doi: 10.1016/j.jclepro.2018.02.137.

[53] A. K. Athienitis, G. Barone, A. Buonomano, et A. Palombo, « Assessing active and passive effects of façade building integrated photovoltaics/thermal systems: Dynamic modelling and simulation », *Applied Energy*, vol. 209, p. 355‑382, janv. 2018, doi: 10.1016/j.apenergy.2017.09.039.

[54] M. N. Addy, E. Adinyira, et J. Ayarkwa, « Identifying and weighting indicators of building energy efficiency assessment in Ghana », *Energy Procedia*, vol. 134, p. 161‑170, oct. 2017, doi: 10.1016/j.egypro.2017.09.554.

[55] S. Mahmoud, T. Zayed, et M. Fahmy, « Development of sustainability assessment tool for existing buildings », *Sustainable Cities and Society*, vol. 44, p. 99‑119, janv. 2019, doi: 10.1016/j.scs.2018.09.024.

[56] S. Lidelöw, T. Örn, A. Luciani, et A. Rizzo, « Energy-efficiency measures for heritage buildings: A literature review », *Sustainable Cities and Society*, vol. 45, p. 231‑242, févr. 2019, doi: 10.1016/j.scs.2018.09.029.

[57] Y. Wang, J. Kuckelkorn, D. Li, et J. Du, « Evaluation on distributed renewable energy system integrated with a Passive House building using a new energy performance index », *Energy*, vol. 161, p. 81‑89, oct. 2018, doi: 10.1016/j.energy.2018.07.140.

[58] F. Bougiatioti et A. Michael, « The architectural integration of active solar systems. Building applications in the Eastern Mediterranean region », *Renewable and Sustainable Energy Reviews*, vol. 47, p. 966‑982, juill. 2015, doi: 10.1016/j.rser.2015.03.030.

[59] C. Vassiliades, A. Michael, A. Savvides, et S. Kalogirou, « Improvement of passive behaviour of existing buildings through the integration of active solar energy systems », *Energy*, vol. 163, p. 1178‑1192, nov. 2018, doi: 10.1016/j.energy.2018.08.148.

[60] A. S. Vieira, R. A. Stewart, R. Lamberts, et C. D. Beal, « Residential solar water heaters in Brisbane, Australia: Key performance parameters and indicators », *Renewable Energy*, vol. 116, p. 120‑132, févr. 2018, doi: 10.1016/j.renene.2017.09.054.

[61] C. Garnier, T. Muneer, et J. Currie, « Numerical and empirical evaluation of a novel building integrated collector storage solar water heater », *Renewable Energy*, vol. 126, p. 281‑295, oct. 2018, doi: 10.1016/j.renene.2018.03.041.

[62] « Integrated energy performance optimization of a passively designed high-rise residential building in different climatic zones of China | Request PDF ». https://www.researchgate.net/publication/323250569_Integrated_energy_performance_optimization_of_a_passively_designed_high-rise_residential_building_in_different_climatic_zones_of_China (consulté le oct. 19, 2020).

[63] X. Chen, H. Yang, et W. Zhang, « Simulation-based approach to optimize passively designed buildings: A case study on a typical architectural form in hot and humid climates », *Renewable and Sustainable Energy Reviews*, vol. 82, p. 1712‑1725, févr. 2018, doi: 10.1016/j.rser.2017.06.018.

[64] P. L. Simona, P. Spiru, et I. V. Ion, « Increasing the energy efficiency of buildings by thermal insulation », *Energy Procedia*, vol. 128, p. 393‑399, sept. 2017, doi: 10.1016/j.egypro.2017.09.044.

[65] K. Biswas, A. Desjarlais, D. Smith, J. Letts, J. Yao, et T. Jiang, « Development and thermal performance verification of composite insulation boards containing foam-encapsulated vacuum insulation panels », *Applied Energy*, vol. 228, p. 1159‑1172, oct. 2018, doi: 10.1016/j.apenergy.2018.06.136.

[66] R. Ji, Z. Zhang, Y. He, J. Liu, et S. Qu, « Simulating the effects of anchors on the thermal performance of building insulation systems », *Energy and Buildings*, vol. 140, p. 501‑507, avr. 2017, doi: 10.1016/j.enbuild.2016.12.036.

[67] V. Shekar et M. Krarti, « Control strategies for dynamic insulation materials applied to commercial buildings », *Energy and Buildings*, vol. 154, p. 305‑320, nov. 2017, doi: 10.1016/j.enbuild.2017.08.084.

[68] D. M. Nguyen, A.-C. Grillet, Q.-B. Bui, T. M. H. Diep, et M. Woloszyn, « Building bio-insulation materials based on bamboo powder and bio-binders », *Construction and Building Materials*, vol. 186, p. 686‑698, oct. 2018, doi: 10.1016/j.conbuildmat.2018.07.153.

[69] I. Cetiner et A. D. Shea, « Wood waste as an alternative thermal insulation for buildings », *Energy and Buildings*, vol. 168, p. 374‑384, juin 2018, doi: 10.1016/j.enbuild.2018.03.019.

[70] L. Aditya *et al.*, « A review on insulation materials for energy conservation in buildings », *Renewable and Sustainable Energy Reviews*, vol. 73, p. 1352‑1365, juin 2017, doi: 10.1016/j.rser.2017.02.034.

[71] Y. Wang, M. Iskandar Jobli, C. Zheng, X. Yang, et K. Li, « Thickness of Building External Insulation in Chongqing Based on Intermittent Heating Supply », *Procedia Engineering*, vol. 205, p. 2755‑2761, 2017, doi: 10.1016/j.proeng.2017.09.873.

[72] E. Küçüktopcu et B. Cemek, « A study on environmental impact of insulation thickness of poultry building walls », *Energy*, vol. 150, p. 583‑590, mai 2018, doi: 10.1016/j.energy.2018.02.153.

[73] T. Gao, T. Ihara, S. Grynning, B. P. Jelle, et A. G. Lien, « Perspective of aerogel glazings in energy efficient buildings », *Building and Environment*, vol. 95, p. 405‑413, janv. 2016, doi: 10.1016/j.buildenv.2015.10.001.

[74] A. Ghosh et T. K. Mallick, « Evaluation of optical properties and protection factors of a PDLC switchable glazing for low energy building integration », *Solar Energy Materials and Solar Cells*, vol. 176, p. 391‑396, mars 2018, doi: 10.1016/j.solmat.2017.10.026.

[75] A. Ghosh et T. K. Mallick, « Evaluation of colour properties due to switching behaviour of a PDLC glazing for adaptive building integration », *Renewable Energy*, vol. 120, p. 126‑133, mai 2018, doi: 10.1016/j.renene.2017.12.094.

[76] S. Lu, Z. Li, Q. Zhao, et F. Jiang, « Modified calculation of solar heat gain coefficient in glazing façade buildings », *Energy Procedia*, vol. 122, p. 151‑156, sept. 2017, doi: 10.1016/j.egypro.2017.07.335.

[77] S. A. Klein *et al.*, « Standard Component Library Overview », p. 92.

[78] L. M. Ayompe, A. Duffy, S. J. McCormack, et M. Conlon, « Validated TRNSYS model for forced circulation solar water heating systems with flat plate and heat pipe evacuated tube collectors », *Applied Thermal Engineering*, vol. 31, nº 8‑9, p. 1536‑1542, juin 2011, doi: 10.1016/j.applthermaleng.2011.01.046.

[79] K. Ahmed, P. Pylsy, et J. Kurnitski, « Monthly domestic hot water profiles for energy calculation in Finnish apartment buildings », *Energy and Buildings*, vol. 97, juin 2015, doi: 10.1016/j.enbuild.2015.03.051.

[80] P. K. Vishwakarma, P. K. Shahi, S. B. Rai, et A. Bahadur, « Low temperature optical collector based on non-thermally coupled level of Ho3+ and defect level of Zn2+ in Yb3+:Y2Ti2O7 phosphor », *Journal of Physics and Chemistry of Solids*, vol. 142, p. 109445, juill. 2020, doi: 10.1016/j.jpcs.2020.109445.

[81] L. Kumar, M. Hasanuzzaman, et N. A. Rahim, « Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review », *Energy*

Conversion and Management, vol. 195, p. 885‑908, sept. 2019, doi: 10.1016/j.enconman.2019.05.081.
[82] Pr. K. Abdenacer et S. Nafila, « Impact of temperature difference (water-solar collector) on solar-still global efficiency », *Desalination*, vol. 209, nº 1‑3, p. 298‑305, avr. 2007, doi: 10.1016/j.desal.2007.04.043.
[83] V. G. Belessiotis et E. Papanicolaou, « History of Solar Energy », in *Comprehensive Renewable Energy*, Elsevier, 2012, p. 85‑102.
[84] J.-C. Sabonnadière, Éd., *Renewable energies*. Hoboken, NJ: ISTE Ltd/John Wiley & Sons, 2009.
[85] B. Marsden, « Superseding Steam: the Napier and Rankine Hot-air Engine », *Trans. Newc. Soc.*, vol. 76, nº 1, p. 1‑22, 2006, doi: 10.1179/175035206X105186.
[86] C. Silvi, « Italian Contribution to CSP with Flat or Almost Flat Reflectors », in *Proceedings of the ISES Solar World Congress 2011*, Kassel, Germany, 2011, p. 1‑11, doi: 10.18086/swc.2011.06.12.
[87] A. Segal, « Solar energy at high temperatures; researches at the Weizmann Institute of Science, Israel; 25 years of success », *Renewable Energy and Environmental Sustainability*, vol. 1, p. 1, 2016, doi: 10.1051/rees/2016001.
[88] M. H. Mohamed, A. Z. El-Sayed, K. F. Megalla, et H. F. Elattar, « Modeling and performance study of a parabolic trough solar power plant using molten salt storage tank in Egypt: effects of plant site location », *Energy Syst*, vol. 10, nº 4, p. 1043‑1070, nov. 2019, doi: 10.1007/s12667-018-0298-4.
[89] J. C. G. Pereira, J. C. Fernandes, et L. Guerra Rosa, « Mathematical Models for Simulation and Optimization of High-Flux Solar Furnaces », *Mathematical and Computational Applications*, vol. 24, nº 2, p. 65, juin 2019, doi: 10.3390/mca24020065.
[90] O. Farges, J. J. Bézian, et M. El Hafi, « Global optimization of solar power tower systems using a Monte Carlo algorithm: Application to a redesign of the PS10 solar thermal power plant », *Renewable Energy*, vol. 119, p. 345‑353, avr. 2018, doi: 10.1016/j.renene.2017.12.028.
[91] B. Lohani *et al.*, « INTERNATIONAL ORGANISATIONS », p. 251.
[92] R. Taylor, « Solar Thermal Technology & Applications », p. 68.
[93] A. Kylili, P. A. Fokaides, A. Ioannides, et S. Kalogirou, « Environmental assessment of solar thermal systems for the industrial sector », *Journal of Cleaner Production*, vol. 176, p. 99‑109, mars 2018, doi: 10.1016/j.jclepro.2017.12.150.
[94] T. R. Bajracharya et S. R. Shakya, « Solar Water Heater Systems », p. 9, 2003.
[95] A. Jamar, Z. a. A. Majid, W. H. Azmi, M. Norhafana, et A. A. Razak, « A review of water heating system for solar energy applications », *International Communications in Heat and Mass Transfer*, vol. C, nº 76, p. 178‑187, 2016, doi: 10.1016/j.icheatmasstransfer.2016.05.028.
[96] S. Tadvi, Vishal R Jain, et Keyur Thakkar, « A Review: Solar Water Heating Systems », 2014, doi: 10.13140/2.1.1910.5281.
[97] J. A. Duffie et W. A. Beckman, « Solar Engineering of Thermal Processes », p. 928.
[98] G. Colangelo, E. Favale, P. Miglietta, et A. de Risi, « Innovation in flat solar thermal collectors: A review of the last ten years experimental results », *Renewable and Sustainable Energy Reviews*, vol. 57, p. 1141‑1159, mai 2016, doi: 10.1016/j.rser.2015.12.142.
[99] Y. Tian et C. Y. Zhao, « A review of solar collectors and thermal energy storage in solar thermal applications », *Applied Energy*, vol. 104, p. 538‑553, avr. 2013, doi: 10.1016/j.apenergy.2012.11.051.

[100] Q. Mao, H. Chen, et Y. Yang, « Energy Storage Performance of a PCM in the Solar Storage Tank », *J. Therm. Sci.*, vol. 28, nº 2, p. 195‑203, avr. 2019, doi: 10.1007/s11630-019-1076-x.

[101] W. Rached, « Arkerna France, Colombes (FR) », p. 4, 2011.

[102] M. P. Beck, Y. Yuan, P. Warrier, et A. S. Teja, « The thermal conductivity of alumina nanofluids in water, ethylene glycol, and ethylene glycol + water mixtures », *Journal of Nanoparticle Research*, vol. 12, nº 4, p. 1469‑1477, mai 2010, doi: 10.1007/s11051-009-9716-9.

[103] P. V. Quiles, F. J. Aguilar, et S. Aledo, « Analysis of the Overheating and Stagnation Problems of Solar Thermal Installations », *Energy Procedia*, vol. 48, p. 172‑180, 2014, doi: 10.1016/j.egypro.2014.02.022.

[104] K. Chopra, V. V. Tyagi, A. K. Pandey, et A. Sari, « Global advancement on experimental and thermal analysis of evacuated tube collector with and without heat pipe systems and possible applications », *Applied Energy*, vol. 228, p. 351‑389, oct. 2018, doi: 10.1016/j.apenergy.2018.06.067.

[105] A. Shafieian, M. Khiadani, et A. Nosrati, « A review of latest developments, progress, and applications of heat pipe solar collectors », *Renewable and Sustainable Energy Reviews*, vol. 95, p. 273‑304, nov. 2018, doi: 10.1016/j.rser.2018.07.014.

[106] J. Gao, A. Li, X. Xu, W. Gang, et T. Yan, « Ground heat exchangers: Applications, technology integration and potentials for zero energy buildings », *Renewable Energy*, vol. 128, p. 337‑349, déc. 2018, doi: 10.1016/j.renene.2018.05.089.

[107] M. Taki, A. Rohani, et M. Rahmati-Joneidabad, « Solar thermal simulation and applications in greenhouse », *Information Processing in Agriculture*, vol. 5, nº 1, p. 83‑113, mars 2018, doi: 10.1016/j.inpa.2017.10.003.

[108] A. J. Slemmons, L. Gatos, P. J. Newgard, et R. City, « 54 FIBER-REINFORCED CONCRETE SOLAR COLLECTOR », p. 5.

[109] D. Carbonell, M. Y. Haller, et E. Frank, « Potential Benefit of Combining Heat Pumps with Solar Thermal for Heating and Domestic Hot Water Preparation », *Energy Procedia*, vol. 57, p. 2656 ‑2665, 2014, doi: 10.1016/j.egypro.2014.10.277.

[110] Anonymous, « Harmonised Standards », *Internal Market, Industry, Entrepreneurship and SMEs - European Commission*, juill. 05, 2016. https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards_en (consulté le oct. 19, 2020).

[111] D. J. Close, « The performance of solar water heaters with natural circulation », *Solar Energy*, vol. 6, nº 1, p. 33‑40, janv. 1962, doi: 10.1016/0038-092X(62)90096-8.

[112] « (PDF) The International Standards for Solar Thermal Collectors and Components as a Medium of Quality Assurance ». https://www.researchgate.net/publication/294860567_The_International_Standards_for_Solar_Thermal_Collectors_and_Components_as_a_Medium_of_Quality_Assurance (consulté le oct. 19, 2020).

[113] « On the Measurement of the Istantaneous Efficiency of Solar Thermal Collectors with a Modified EN 12975 Test Facility | Request PDF ». https://www.researchgate.net/publication/263719952_On_the_Measurement_of_the_Istantaneous_Efficiency_of_Solar_Thermal_Collectors_with_a_Modified_EN_12975_Test_Facility?_sg=VoSk8hYXRdIQuuC_3bG-KbomHsiB5V3xG4tl2fOL95tQehvmGeYnbDSZNz3MU7QTRCKWjD28b7xzZ-0 (consulté le oct. 19, 2020).

[114] « 04/02124 Collector test method under quasi-dynamic conditions according to the European standard EN 12975-2 », *Fuel and Energy Abstracts*, vol. 45, nº 4, p. 292, juill. 2004, doi: 10.1016/S0140-6701(04)94711-X.

[115] A. Kurdia, J. Gomes, G. Pius, P. Ollas, et O. Olsson, *Quasi-Dynamic Testing of a Novel Concentrating Solar Collector According to ISO 9806:2013*. 2018.
[116] « European Standards ». http://www.estif.org/solarkeymarknew/the-solar-keymark-scheme-rules/8-manufacturers/2-european-standards (consulté le oct. 19, 2020).
[117] G.-P. Vicente et R. Anthony, « A reliability test installation for water heating solar systems: Requirements and design according to the European norm 12976 », 2015, p. 91‑123.
[118] B. Ehrismann, « Assessment of the possibility of incorporating solar thermal cooling into EN 12977 series Task Report 5.3.4 », p. 17.
[119] G. Fraisse, Y. Bai, N. Le-Pierres, et T. Letz, « Comparative Study of Various Cesi Optimization Criteria and Proposition of a Global Evaluation Approach », in *Proceedings of ISES World Congress 2007 (Vol. I – Vol. V)*, D. Y. Goswami et Y. Zhao, Éd. Berlin, Heidelberg: Springer Berlin Heidelberg, 2008, p. 2007‑2012.
[120] J. E. Nielsen, « EUROPEAN SOLAR THERMAL STANDARDS AND SOLAR KEYMARK CERTIFICATION », p. 4.
[121] H. Drück, S. Fischer, et H. Müller-Steinhagen, « Solar Keymark Testing of Solar Thermal Products », in *Proceedings of ISES World Congress 2007 (Vol. I – Vol. V)*, Berlin, Heidelberg, 2009, p. 2094‑2099, doi: 10.1007/978-3-540-75997-3_425.
[122] I. M. Sims, S. M. Carnachan, T. J. Bell, et S. F. R. Hinkley, « Methylation analysis of polysaccharides: Technical advice », *Carbohydrate Polymers*, vol. 188, p. 1‑7, mai 2018, doi: 10.1016/j.carbpol.2017.12.075.
[123] Y. Bendvavid, « Description et validation de la version solaire de CSTBât et de son interface: rapport de stage du 2 avril au 31 août 1991 - Search results - Pascal and Francis Bibliographic Databases », présenté à Description et validation de la version solaire de CSTBât et de son interface: rapport de stage du 2 avril au 31 août 1991, 1991, Consulté le: oct. 19, 2020. [En ligne]. Disponible sur: http://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=6463815.
[124] M. E. Zayed *et al.*, « Applications of cascaded phase change materials in solar water collector storage tanks: A review », *Solar Energy Materials and Solar Cells*, vol. 199, p. 24‑49, sept. 2019, doi: 10.1016/j.solmat.2019.04.018.
[125] F. S. Javadi, H. S. C. Metselaar, et P. Ganesan, « Performance improvement of solar thermal systems integrated with phase change materials (PCM), a review », *Solar Energy*, vol. 206, p. 330‑352, août 2020, doi: 10.1016/j.solener.2020.05.106.
[126] H. Huang, Y. Xiao, J. Lin, T. Zhou, Y. Liu, et Q. Zhao, « Improvement of the efficiency of solar thermal energy storage systems by cascading a PCM unit with a water tank », *Journal of Cleaner Production*, vol. 245, p. 118864, févr. 2020, doi: 10.1016/j.jclepro.2019.118864.
[127] W. Wu *et al.*, « A novel composite PCM for seasonal thermal energy storage of solar water heating system », *Renewable Energy*, vol. 161, p. 457‑469, déc. 2020, doi: 10.1016/j.renene.2020.06.147.
[128] A. Dahash, F. Ochs, M. B. Janetti, et W. Streicher, « Advances in seasonal thermal energy storage for solar district heating applications: A critical review on large-scale hot-water tank and pit thermal energy storage systems », *Applied Energy*, vol. 239, p. 296‑315, avr. 2019, doi: 10.1016/j.apenergy.2019.01.189.
[129] S. Işık et C. Yıldız, « Improving thermal energy storage efficiency of solar collector tanks by placing phase change materials in novel finned-type cells », *Thermal Science and Engineering Progress*, vol. 19, p. 100618, oct. 2020, doi: 10.1016/j.tsep.2020.100618.

[130] Q. Mao et Y. Zhang, « Thermal energy storage performance of a three-PCM cascade tank in a high-temperature packed bed system », *Renewable Energy*, vol. 152, p. 110‑119, juin 2020, doi: 10.1016/j.renene.2020.01.051.

[131] Q. Mao, H. Chen, et Y. Yang, « Energy Storage Performance of a PCM in the Solar Storage Tank », *J. Therm. Sci.*, vol. 28, nº 2, p. 195‑203, avr. 2019, doi: 10.1007/s11630-019-1076-x.

[132] S. Koohi-Fayegh et M. A. Rosen, « A review of energy storage types, applications and recent developments », *Journal of Energy Storage*, vol. 27, p. 101047, févr. 2020, doi: 10.1016/j.est.2019.101047.

[133] H. Asgharian et E. Baniasadi, « A review on modeling and simulation of solar energy storage systems based on phase change materials », *Journal of Energy Storage*, vol. 21, p. 186‑201, févr. 2019, doi: 10.1016/j.est.2018.11.025.

[134] A. J. White, J. D. McTigue, et C. N. Markides, « Analysis and optimisation of packed-bed thermal reservoirs for electricity storage applications », *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, vol. 230, nº 7, p. 739‑754, nov. 2016, doi: 10.1177/0957650916668447.

[135] K. Aramaki et T. Shimura, « Corrosion protection of metals and oxidized metals by ultrathin two-dimensional polymer coatings prepared by chemical modification of three types of Self-Assembled monolayers », *BOSHOKU GIJUTSU*, vol. 65, nº 3, p. 95‑102, 2016.

[136] M. Tammaro, A. W. Mauro, C. Montagud, J. M. Corberán, et R. Mastrullo, « Hot sanitary water production with CO2 heat pumps: Effect of control strategy on system performance and stratification inside the storage tank », *Applied Thermal Engineering*, vol. 101, p. 730‑740, mai 2016, doi: 10.1016/j.applthermaleng.2016.01.094.

[137] A. Riemer, S. Leuders, M. Thöne, H. A. Richard, T. Tröster, et T. Niendorf, « On the fatigue crack growth behavior in 316L stainless steel manufactured by selective laser melting », *Engineering Fracture Mechanics*, vol. 120, p. 15‑25, avr. 2014, doi: 10.1016/j.engfracmech.2014.03.008.

[138] V. Maurice, H. Peng, L. H. Klein, A. Seyeux, S. Zanna, et P. Marcus, « Effects of molybdenum on the composition and nanoscale morphology of passivated austenitic stainless steel surfaces », *Faraday Discuss.*, vol. 180, nº 0, p. 151‑170, juill. 2015, doi: 10.1039/C4FD00231H.

[139] S.-J. Kim, S.-K. Jang, et J.-I. Kim, « Electrochemical properties and corrosion protection of stainless steel for hot water tank », *Korean J. Chem. Eng.*, vol. 21, nº 3, p. 739‑745, mai 2004, doi: 10.1007/BF02705514.

[140] A. Solé, L. Miró, C. Barreneche, I. Martorell, et L. F. Cabeza, « Corrosion of metals and salt hydrates used for thermochemical energy storage », *Renewable Energy*, vol. 75, p. 519‑523, mars 2015, doi: 10.1016/j.renene.2014.09.059.

[141] J. Tao, S. Hu, J. Kong, et Y. Zhang, « Effect of process temperature on the microstructures and properties of enamels coated on Ti-bearing substrate RT360 », *Ceramics International*, vol. 43, nº 8, p. 6276‑6285, juin 2017, doi: 10.1016/j.ceramint.2017.02.032.

[142] A. V. Ryabova, E. A. Yatsenko, V. V. Khoroshavina, et L. V. Klimova, « Glass-Enamel Corrosion-Resistant Coatings for Steel Pipelines », *Glass Ceram*, vol. 74, nº 7, p. 282‑287, nov. 2017, doi: 10.1007/s10717-017-9980-6.

[143] J. Yan, J. Yu, et B. Ding, « Mixed Ionic and Electronic Conductor for Li-Metal Anode Protection », *Adv. Mater.*, vol. 30, nº 7, p. 1705105, févr. 2018, doi: 10.1002/adma.201705105.

[144] Laboratoire d'Electrochimie, Catalyse et Environnement, Faculté des Sciences, Université Ibn Zohr, Agadir, Maroc. et N. Zidane, « Evaluation of the Corrosion of AZ31 Magnesium Alloy Used

as Sacrificial Anode for Cathodic Protection of Hot-Water Tank Storage Containing Chloride », *Int. J. Electrochem. Sci.*, p. 29‑44, janv. 2018, doi: 10.20964/2018.01.36.

[145] H. Yang *et al.*, « Recent progress and perspective on lithium metal anode protection », *Energy Storage Materials*, vol. 14, p. 199‑221, sept. 2018, doi: 10.1016/j.ensm.2018.03.001.

[146] S. ed-Dîn Fertahi *et al.*, « Thermo-mechanical strength analysis for energy storage improvement of horizontal storage tanks integrating evacuated tube collectors », *International Journal of Hydrogen Energy*, vol. 42, nº 49, p. 29370‑29383, déc. 2017, doi: 10.1016/j.ijhydene.2017.10.016.

[147] P. E. Schweitzer Philip A., *Corrosion of Linings & Coatings: Cathodic and Inhibitor Protection and Corrosion Monitoring*, 0 éd. CRC Press, 2006.

[148] T. Bellezze, M. Malavolta, A. Quaranta, N. Ruffini, et G. Roventi, « Corrosion behaviour in concrete of three differently galvanized steel bars », *Cement and Concrete Composites*, vol. 28, nº 3, p. 246‑255, mars 2006, doi: 10.1016/j.cemconcomp.2006.01.011.

[149] J. D. Waters, R. O. Knoeppel, et G. Pfendt, « (54) WATER-RESISTANT PORCELAN ENAMEL COATINGS AND METHOD OF MANUFACTURING SAME », p. 11.

[150] S. Kim, J. W. Kim, et J. H. Kim, « Enhancement of corrosion resistance in carbon steels using nickel-phosphorous/titanium dioxide nanocomposite coatings under high-temperature flowing water », *Journal of Alloys and Compounds*, vol. 698, p. 267‑275, mars 2017, doi: 10.1016/j.jallcom.2016.12.027.

[151] A. K. Guin, B. P. Mallik, et S. Shreepathi, « Electrochemical and mechanical studies on influence of curing agents on performance of epoxy tank linings », *Progress in Organic Coatings*, vol. 78, p. 340‑347, janv. 2015, doi: 10.1016/j.porgcoat.2014.07.014.

[152] W. Villasmil, L. J. Fischer, et J. Worlitschek, « A review and evaluation of thermal insulation materials and methods for thermal energy storage systems », *Renewable and Sustainable Energy Reviews*, vol. 103, p. 71‑84, avr. 2019, doi: 10.1016/j.rser.2018.12.040.

[153] F. Domhagen et B. Adl-Zarrabi, « Influence of oxidation on radiative heat transfer in polyurethane insulation used for district heating pipes », *Energy Procedia*, vol. 132, p. 309‑314, oct. 2017, doi: 10.1016/j.egypro.2017.09.735.

[154] N. I. Vatin, I. I. Pestryakov, S. T. Sultanov, O. T. Ogidan, Y. A. Yarunicheva, et A. P. Kiryushina, « Water vapour by diffusion and mineral wool thermal insulation materials », *Инженерно-строительный журнал*, nº 5 (81), 2018, Consulté le: oct. 22, 2020. [En ligne]. Disponible sur: https://elib.spbstu.ru/dl/2/j19-56.pdf/info.

[155] G. Deshmukh, P. Birwal, R. Datir, et S. Patel, « Thermal Insulation Materials: A Tool for Energy Conservation », *J Food Process Technol*, vol. 08, nº 04, 2017, doi: 10.4172/2157-7110.1000670.

[156] S. Cai, B. Zhang, et L. Cremaschi, « Review of moisture behavior and thermal performance of polystyrene insulation in building applications », *Building and Environment*, vol. 123, p. 50‑65, oct. 2017, doi: 10.1016/j.buildenv.2017.06.034.

[157] R. Brown, S. Russell, S. May, F. Regan, et J. Chapman, « Reproducible Superhydrophobic PVC Coatings; Investigating the Use of Plasticizers for Early Stage Biofouling Control: Reproducible Superhydrophobic PVC Coatings… », *Adv. Eng. Mater.*, vol. 19, nº 7, p. 1700053, juill. 2017, doi: 10.1002/adem.201700053.

[158] B. Stawarczyk, N. Lümkemann, M. Eichberger, et T. Wimmer, « Made in China PVC/Pet/PP/PE/BOPP Film Plastic Sheet for Aluminium/Glass/Mable », *Dentistry Journal*, vol. 5, nº 4, 2017.

[159] B. R. Negri, M. C. P. Soares, A. C. L. Lisboa, et J. R. Bartoli, « Low-Cost Solar Heating Reservoir Manufactured by Double-Coating a Water Tank with Polymeric Materials », *Materials Proceedings*, vol. 2, nº 1, p. 14, avr. 2020, doi: 10.3390/CIWC2020-06784.
[160] A. R. J. Hussain, A. A. Alahyari, S. A. Eastman, C. Thibaud-Erkey, S. Johnston, et M. J. Sobkowicz, « Review of polymers for heat exchanger applications: Factors concerning thermal conductivity », *Applied Thermal Engineering*, vol. 113, p. 1118‑1127, févr. 2017, doi: 10.1016/j.applthermaleng.2016.11.041.
[161] M. Omidi, M. Farhadi, et M. Jafari, « A comprehensive review on double pipe heat exchangers », *Applied Thermal Engineering*, vol. 110, p. 1075‑1090, janv. 2017, doi: 10.1016/j.applthermaleng.2016.09.027.
[162] L. Evangelisti, R. De Lieto Vollaro, et F. Asdrubali, « Latest advances on solar thermal collectors: A comprehensive review », *Renewable and Sustainable Energy Reviews*, vol. 114, p. 109318, oct. 2019, doi: 10.1016/j.rser.2019.109318.
[163] R. Agathokleous, G. Barone, A. Buonomano, C. Forzano, S. A. Kalogirou, et A. Palombo, « Building façade integrated solar thermal collectors for air heating: experimentation, modelling and applications », *Applied Energy*, vol. 239, p. 658‑679, avr. 2019, doi: 10.1016/j.apenergy.2019.01.020.
[164] M. S. Buker et S. B. Riffat, « Building integrated solar thermal collectors – A review », *Renewable and Sustainable Energy Reviews*, vol. 51, p. 327‑346, nov. 2015, doi: 10.1016/j.rser.2015.06.009.
[165] A. A. Hawwash, A. K. Abdel Rahman, S. A. Nada, et S. Ookawara, « Numerical Investigation and Experimental Verification of Performance Enhancement of Flat Plate Solar Collector Using Nanofluids », *Applied Thermal Engineering*, vol. 130, p. 363‑374, févr. 2018, doi: 10.1016/j.applthermaleng.2017.11.027.
[166] H. Bhowmik et R. Amin, « Efficiency improvement of flat plate solar collector using reflector », *Energy Reports*, vol. 3, p. 119‑123, nov. 2017, doi: 10.1016/j.egyr.2017.08.002.
[167] A. Allouhi et M. Benzakour Amine, « Effect analysis on energetic, exergetic and financial performance of a flat plate collector with heat pipes », *Energy Conversion and Management*, vol. 195, p. 274‑289, sept. 2019, doi: 10.1016/j.enconman.2019.04.081.
[168] K. Chopra, A. K. Pathak, V. V. Tyagi, A. K. Pandey, S. Anand, et A. Sari, « Thermal performance of phase change material integrated heat pipe evacuated tube solar collector system: An experimental assessment », *Energy Conversion and Management*, vol. 203, p. 112205, janv. 2020, doi: 10.1016/j.enconman.2019.112205.
[169] S. Gholipour, M. Afrand, et R. Kalbasi, « Improving the efficiency of vacuum tube collectors using new absorbent tubes arrangement: Introducing helical coil and spiral tube adsorbent tubes », *Renewable Energy*, vol. 151, p. 772‑781, mai 2020, doi: 10.1016/j.renene.2019.11.068.
[170] E. Bellos et C. Tzivanidis, « A review of concentrating solar thermal collectors with and without nanofluids », *J Therm Anal Calorim*, vol. 135, nº 1, p. 763‑786, janv. 2019, doi: 10.1007/s10973-018-7183-1.
[171] R. Dobriyal, P. Negi, N. Sengar, et D. B. Singh, « A brief review on solar flat plate collector by incorporating the effect of nanofluid », *Materials Today: Proceedings*, vol. 21, p. 1653‑1658, 2020, doi: 10.1016/j.matpr.2019.11.294.
[172] R. Sekhar Dondapati, R. Agarwal, V. Saini, G. Vyas, et J. Thakur, « Effect of Glazing Materials on the Performance of Solar Flat Plate Collectors for Water Heating Applications », *Materials Today: Proceedings*, vol. 5, nº 14, p. 27680‑27689, 2018, doi: 10.1016/j.matpr.2018.10.002.

[173] S. Föste, A. Pazidis, R. Reineke-Koch, B. Hafner, D. Mercs, et C. Delord, « Flat Plate Collectors with Thermochromic Absorber Coatings to Reduce Loads During Stagnation », *Energy Procedia*, vol. 91, p. 42‑48, juin 2016, doi: 10.1016/j.egypro.2016.06.169.

[174] J. Takadoum, « Black coatings: a review », *Eur. Phys. J. Appl. Phys.*, vol. 52, nᵒ 3, p. 30401, déc. 2010, doi: 10.1051/epjap/2010155.

[175] « Les absorbeurs : matériaux et modèles ». https://www.lepanneausolaire.net/les-absorbeurs-materiaux-modeles.php (consulté le oct. 22, 2020).

[176] S. Ashman et S. G. Kandlikar, « A Review of Manufacturing Processes for Microchannel Heat Exchanger Fabrication », in *ASME 4th International Conference on Nanochannels, Microchannels, and Minichannels, Parts A and B*, Limerick, Ireland, janv. 2006, p. 855‑860, doi: 10.1115/ICNMM2006-96121.

[177] T. Beikircher, M. Möckl, P. Osgyan, et G. Streib, « Advanced solar flat plate collectors with full area absorber, front side film and rear side vacuum super insulation », *Solar Energy Materials and Solar Cells*, vol. 141, p. 398‑406, oct. 2015, doi: 10.1016/j.solmat.2015.06.019.

[178] G. Martínez-Rodríguez, A. L. Fuentes-Silva, et M. Picón-Núñez, « Solar thermal networks operating with evacuated-tube collectors », *Energy*, vol. 146, p. 26‑33, mars 2018, doi: 10.1016/j.energy.2017.04.165.

[179] A. Papadimitratos, S. Sobhansarbandi, V. Pozdin, A. Zakhidov, et F. Hassanipour, « Evacuated tube solar collectors integrated with phase change materials », *Solar Energy*, vol. 129, p. 10‑19, mai 2016, doi: 10.1016/j.solener.2015.12.040.

[180] G. Shao *et al.*, « Microstructure, radiative property and thermal shock behavior of TaSi2–SiO2-borosilicate glass coating for fibrous ZrO2 ceramic insulation », *Journal of Alloys and Compounds*, vol. 663, p. 360‑370, avr. 2016, doi: 10.1016/j.jallcom.2015.10.003.

[181] G. J. LEVERMORE et G.J.LEVERMORE, *Building Energy Management Systems: An Application to Heating, Natural Ventilation, Lighting and Occupant Satisfaction*. Routledge, 2013.

[182] T. Salsbury et B. Chen, « A New Sequencer Controller for Multistage Systems of Known Relative Capacities », *HVAC&R Res.*, vol. 8, nᵒ 4, p. 403‑428, oct. 2002, doi: 10.1080/10789669.2002.10391298.

[183] W. Ait Ahmed, M. Aggour, et F. Bennani, « Automating a solar water heating system », *Journal of Energy Systems*, vol. 1, p. 56‑64, nov. 2017, doi: 10.30521/jes.330414.

[184] Kiam Heong Ang, G. Chong, et Yun Li, « PID control system analysis, design, and technology », *IEEE Transactions on Control Systems Technology*, vol. 13, nᵒ 4, p. 559‑576, juill. 2005, doi: 10.1109/TCST.2005.847331.

[185] K. J. Åström, T. Hägglund, et A. Wallenborg, « Automatic Tuning of a Digital Controller », *IFAC Proceedings Volumes*, vol. 25, nᵒ 14, p. 285‑290, juill. 1992, doi: 10.1016/S1474-6670(17)50749-1.

[186] Q. Bi *et al.*, « Advanced controller auto-tuning and its application in HVAC systems », *Control Engineering Practice*, vol. 8, nᵒ 6, p. 633‑644, juin 2000, doi: 10.1016/S0967-0661(99)00198-7.

[187] Ya-Gang Wang, Zhi-Gang Shi, et Wen-Jian Cai, « PID autotuner and its application in HVAC systems », in *Proceedings of the 2001 American Control Conference. (Cat. No.01CH37148)*, Arlington, VA, USA, 2001, p. 2192‑2196 vol.3, doi: 10.1109/ACC.2001.946075.

[188] T. I. Salsbury, « A SURVEY OF CONTROL TECHNOLOGIES IN THE BUILDING AUTOMATION INDUSTRY », *IFAC Proceedings Volumes*, vol. 38, nᵒ 1, p. 90‑100, 2005, doi: 10.3182/20050703-6-CZ-1902.01397.

[189] A. I. Dounis et C. Caraiscos, « Advanced control systems engineering for energy and comfort management in a building environment—A review », *Renewable and Sustainable Energy Reviews*, vol. 13, nº 6‑7, p. 1246‑1261, août 2009, doi: 10.1016/j.rser.2008.09.015.

[190] D. D. Kukolj, S. B. Kuzmanović, et E. Levi, « Design of a PID-like compound fuzzy logic controller », *Engineering Applications of Artificial Intelligence*, vol. 14, nº 6, p. 785‑803, déc. 2001, doi: 10.1016/S0952-1976(02)00014-3.

[191] « 1. Quizz SOUDAGE », *Site de nicolaspernot-sii !* http://nicolaspernot-sii.jimdofree.com/les-sciences-de-l-ingénieur-en-pt/quizz-de-cours/ (consulté le oct. 22, 2020).

[192] S. Graupner et D. Gmach, « Supervisory control as pattern for integrated IT management », in *2012 IEEE Network Operations and Management Symposium*, Maui, HI, avr. 2012, p. 947‑952, doi: 10.1109/NOMS.2012.6212013.

[193] S. Wang et Z. Ma, « Supervisory and Optimal Control of Building HVAC Systems: A Review », *HVAC&R Res.*, vol. 14, nº 1, p. 3‑32, janv. 2008, doi: 10.1080/10789669.2008.10390991.

[194] S. Liu et G. P. Henze, « Experimental analysis of simulated reinforcement learning control for active and passive building thermal storage inventory », *Energy and Buildings*, vol. 38, nº 2, p. 148‑161, févr. 2006, doi: 10.1016/j.enbuild.2005.06.001.

[195] A. Keblawi, N. Ghaddar, et K. Ghali, « Model-based optimal supervisory control of chilled ceiling displacement ventilation system », *Energy and Buildings*, vol. 43, nº 6, p. 1359‑1370, juin 2011, doi: 10.1016/j.enbuild.2011.01.021.

[196] Z. Ma et S. Wang, « Supervisory and optimal control of central chiller plants using simplified adaptive models and genetic algorithm », *Applied Energy*, vol. 88, nº 1, p. 198‑211, janv. 2011, doi: 10.1016/j.apenergy.2010.07.036.

[197] T. Y. Chen, « Real-time predictive supervisory operation of building thermal systems with thermal mass », *Energy and Buildings*, vol. 33, nº 2, p. 141‑150, janv. 2001, doi: 10.1016/S0378-7788(00)00078-5.

[198] D. Ippoliti et X. Zhou, « A self-tuning self-optimizing approach for automated network anomaly detection systems », in *Proceedings of the 9th international conference on Autonomic computing - ICAC '12*, San Jose, California, USA, 2012, p. 85, doi: 10.1145/2371536.2371551.

[199] S. Liu et G. P. Henze, « CALIBRATION OF BUILDING MODELS FOR SUPERVISORY CONTROL OF COMMERCIAL BUILDINGS », p. 8.

[200] G. Henze et J. Schoenmann, « Evaluation of Reinforcement Learning Control for Thermal Energy Storage Systems », *HVAC&R Res.*, vol. 9, nº 3, p. 259‑275, juill. 2003, doi: 10.1080/10789669.2003.10391069.

[201] Z. Yu et A. Dexter, « Online tuning of a supervisory fuzzy controller for low-energy building system using reinforcement learning », *Control Engineering Practice*, vol. 18, nº 5, p. 532‑539, mai 2010, doi: 10.1016/j.conengprac.2010.01.018.

[202] T. Tobi et T. Hanafusa, « A practical application of fuzzy control for an air-conditioning system », *International Journal of Approximate Reasoning*, vol. 5, nº 3, p. 331‑348, mai 1991, doi: 10.1016/0888-613X(91)90016-F.

[203] G. Jahedi et M. M. Ardehali, « Genetic algorithm-based fuzzy-PID control methodologies for enhancement of energy efficiency of a dynamic energy system », *Energy Conversion and Management*, vol. 52, nº 1, p. 725‑732, janv. 2011, doi: 10.1016/j.enconman.2010.07.051.

[204] F. Calvino, M. La Gennusa, G. Rizzo, et G. Scaccianoce, « The control of indoor thermal comfort conditions: introducing a fuzzy adaptive controller », *Energy and Buildings*, vol. 36, nº 2, p. 97‑102, févr. 2004, doi: 10.1016/j.enbuild.2003.10.004.

[205] A. I. Dounis et D. E. Manolakis, « Design of a fuzzy system for living space thermal-comfort regulation », *Applied Energy*, vol. 69, nº 2, p. 119‑144, juin 2001, doi: 10.1016/S0306-2619(00)00065-9.
[206] A. B. Shepherd et W. J. Batty, « Fuzzy control strategies to provide cost and energy efficient high quality indoor environments in buildings with high occupant densities », *Building Services Engineering Research and Technology*, vol. 24, nº 1, p. 35‑45, févr. 2003, doi: 10.1191/0143624403bt059oa.
[207] C. P. Underwood, « Robust control of HVAC plant II: controller design », *Building Services Engineering Research and Technology*, vol. 21, nº 1, p. 63‑71, févr. 2000, doi: 10.1177/014362440002100109.
[208] S. A. K. Al-Assadi, R. V. Patel, M. Zaheer-uddin, M. S. Verma, et J. Breitinger, « Robust decentralized control of HVAC systems using -performance measures », *Journal of the Franklin Institute*, vol. 341, nº 7, p. 543‑567, nov. 2004, doi: 10.1016/j.jfranklin.2004.06.001.
[209] J. W. Moon et S. Y. Kim, « Artificial Neural Network for the Control of the Openings and Cooling Systems of the Double Skin Envelope Buildings », *AMR*, vol. 610‑613, p. 2859‑2865, déc. 2012, doi: 10.4028/www.scientific.net/AMR.610-613.2859.
[210] W. Gang et J. Wang, « Predictive ANN models of ground heat exchanger for the control of hybrid ground source heat pump systems », *Applied Energy*, vol. 112, p. 1146‑1153, déc. 2013, doi: 10.1016/j.apenergy.2012.12.031.
[211] P. M. Ferreira, S. M. Silva, et A. E. Ruano, « Model based predictive control of HVAC systems for human thermal comfort and energy consumption minimisation », *IFAC Proceedings Volumes*, vol. 45, nº 4, p. 236‑241, 2012, doi: 10.3182/20120403-3-DE-3010.00085.
[212] F. Boithias, M. El Mankibi, et P. Michel, « Genetic algorithms based optimization of artificial neural network architecture for buildings' indoor discomfort and energy consumption prediction », *Build. Simul.*, vol. 5, nº 2, p. 95‑106, juin 2012, doi: 10.1007/s12273-012-0059-6.
[213] « EBSCOhost | 77709075 | Neural Networks Approach for Energy Consumption in Air-Conditioned Administrative Building. » https://web.b.ebscohost.com/abstract?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=00012505&asa=Y&AN=77709075&h=NYFQnuG0BS6ctpciTHXBZAJbE%2b9nzFQNv02sJIxJGKWnVyZFWcLRYTXVU8OaMIDf2jVJ8TTHPJFIL18F85dwUg%3d%3d&crl=c&resultNs=AdminWebAuth&resultLocal=ErrCrlNotAuth&crlhashurl=login.aspx%3fdirect%3dtrue%26profile%3dehost%26scope%3dsite%26authtype%3dcrawler%26jrnl%3d00012505%26asa%3dY%26AN%3d77709075 (consulté le oct. 22, 2020).
[214] P. M. Ferreira, A. E. Ruano, S. Silva, et E. Z. E. Conceição, « Neural networks based predictive control for thermal comfort and energy savings in public buildings », *Energy and Buildings*, vol. 55, p. 238‑251, déc. 2012, doi: 10.1016/j.enbuild.2012.08.002.
[215] T. Logenthiran, D. Srinivasan, et D. Wong, « Multi-agent coordination for DER in MicroGrid », in *2008 IEEE International Conference on Sustainable Energy Technologies*, Singapore, Singapore, nov. 2008, p. 77‑82, doi: 10.1109/ICSET.2008.4746976.
[216] M. Pipattanasomporn, H. Feroze, et S. Rahman, « Multi-agent systems in a distributed smart grid: Design and implementation », in *2009 IEEE/PES Power Systems Conference and Exposition*, Seattle, WA, USA, mars 2009, p. 1‑8, doi: 10.1109/PSCE.2009.4840087.
[217] Faa-Jeng Lin, Li-Tao Teng, Jeng-Wen Lin, et Syuan-Yi Chen, « Recurrent Functional-Link-Based Fuzzy-Neural-Network-Controlled Induction-Generator System Using Improved Particle Swarm Optimization », *IEEE Trans. Ind. Electron.*, vol. 56, nº 5, p. 1557‑1577, mai 2009, doi: 10.1109/TIE.2008.2010105.

[218] Z. Wang, L. Wang, A. I. Dounis, et R. Yang, « Multi-agent control system with information fusion based comfort model for smart buildings », *Applied Energy*, vol. 99, p. 247‑254, nov. 2012, doi: 10.1016/j.apenergy.2012.05.020.

[219] R. Yang et L. Wang, « Multi-zone building energy management using intelligent control and optimization », *Sustainable Cities and Society*, vol. 6, p. 16‑21, févr. 2013, doi: 10.1016/j.scs.2012.07.001.

[220] G. E. Kelly et S. T. Bushby, « Are intelligent agents the key to optimizing building HVAC system performance? », *HVAC&R Research*, vol. 18, nº 4, p. 750‑759, août 2012, doi: 10.1080/10789669.2012.682693.

[221] Rui Yang et Lingfeng Wang, « Multi-agent based energy and comfort management in a building environment considering behaviors of occupants », in *2012 IEEE Power and Energy Society General Meeting*, San Diego, CA, juill. 2012, p. 1‑7, doi: 10.1109/PESGM.2012.6345671.

[222] A. Araújo et R. Silva, « Energy modeling of solar water heating systems with on-off control and thermally stratified storage using a fast computation algorithm », *Renewable Energy*, vol. 150, p. 891‑906, mai 2020, doi: 10.1016/j.renene.2020.01.026.

[223] H. P. Garg, *Solar Water Heating Systems: Proceedings of the Workshop on Solar Water Heating Systems New Delhi, India 6–10 May, 1985*. Springer Science & Business Media, 2012.

[224] M. Ko, « A Novel Design Method for Optimizing an Indirect Forced Circulation Solar Water Heating System Based on Life Cycle Cost Using a Genetic Algorithm », *Energies*, vol. 8, nº 10, p. 11592‑11617, oct. 2015, doi: 10.3390/en81011592.

[225] H. Huang *et al.*, « An experimental investigation on thermal stratification characteristics with PCMs in solar water tank », *Solar Energy*, vol. 177, p. 8‑21, janv. 2019, doi: 10.1016/j.solener.2018.11.004.

[226] M. Prauzek, P. Krömer, J. Rodway, et P. Musilek, « Differential evolution of fuzzy controller for environmentally-powered wireless collectors », *Applied Soft Computing*, vol. 48, p. 193‑206, nov. 2016, doi: 10.1016/j.asoc.2016.06.040.

[227] S. Panda, « Differential evolutionary algorithm for TCSC-based controller design », *Simulation Modelling Practice and Theory*, vol. 17, nº 10, p. 1618‑1634, nov. 2009, doi: 10.1016/j.simpat.2009.07.002.

[228] A. Courtois, C. Martin-Bonnefous, et M. Pillet, *Gestion de production*. Paris: Ed. d'Organisation, 2003.

[229] Y. Crama, « Eléments de GESTION DE LA PRODUCTION », p. 115.

[230] « Chapitre 6: Implantation d'atelier. - ppt video online télécharger ». https://slideplayer.fr/slide/10651814/ (consulté le oct. 23, 2020).

[231] « Droit du travail | BLOG OJRAWEB - Part 2 ». https://blog.ojraweb.com/tag/droit-du-travail/page/2/ (consulté le oct. 23, 2020).

[232] « Comment calculer la consommation d'un appareil électrique ? », *Energuide*. https://www.energuide.be/fr/questions-reponses/comment-calculer-la-consommation-dun-appareil-electrique/94/ (consulté le oct. 23, 2020).

[233] « Site web officiel de l'ONEE - Branche Electricité ». http://www.one.org.ma/FR/pages/interne.asp?esp=1&id1=2&id2=125&id3=128&t2=1&t3=1 (consulté le oct. 23, 2020).

[234] « Les chauffe-eau à gaz causent 60 décès chaque année - La Vie éco ». https://www.lavieeco.com/economie/les-chauffe-eau-a-gaz-causent-60-deces-chaque-annee-1908/ (consulté le oct. 23, 2020).

[235] « Les chauffe-eau toujours aussi meurtriers | Aujourd'hui le Maroc ». https://aujourdhui.ma/societe/les-chauffe-eau-toujours-aussi-meurtriers-105917 (consulté le oct. 23, 2020).
[236] « Calculer son Besoin en Fonds de roulement (BFR) », *Dynamique-Mag.com*, oct. 04, 2010. https://www.dynamique-mag.com/article/calculer-son-besoin-en-fonds-de-roulement-bfr.2659 (consulté le oct. 23, 2020).
[237] L. F. P. Tous, « Comment calculer un coût de revient ? », *La finance pour tous*. https://www.lafinancepourtous.com/pratique/vie-pro/creer-son-entreprise/comment-calculer-un-cout-de-revient/ (consulté le oct. 23, 2020).
[238] « Comment déterminer un prix de vente ? | LBdD », *Le Blog du Dirigeant*. https://www.leblogdudirigeant.com/fiche-pratique-gestion-commerciale-determiner-prix-de-vente/ (consulté le oct. 23, 2020).
[239] « Le chiffre d'affaires : définition et calcul du CA ». https://www.l-expert-comptable.com/fiches-pratiques/le-chiffre-d-affaires-definition-et-calcul-du-ca.html (consulté le oct. 23, 2020).
[240] T. Clermont, « Comment estimer les dotations aux amortissements prévisionnelles dans un business plan ? », *Compta-Facile*, janv. 20, 2016. https://www.compta-facile.com/estimation-dotations-aux-amortissements-previsionnelles-business-plan/ (consulté le oct. 23, 2020).
[241] « Le seuil de rentabilité : définition, calcul et utilité ». http://www.compta-facile.com/calcul-du-seuil-de-rentabilite/ (consulté le oct. 23, 2020).
[242] A. B. Ali, « Mise en place d'un Système de Management de la Qualité selon la norme ISO9001 version 2015 », p. 66.
[243] « ISO 9000:2015(fr), Systèmes de management de la qualité — Principes essentiels et vocabulaire ». https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v2:fr (consulté le oct. 23, 2020).
[244] P. Longin et H. Denet, *Construisez votre qualité-2e éd.: Toutes les clés pour une démarche qualité gagnante*. Dunod, 2008.
[245] « Risque », *Wikipédia*. sept. 08, 2020, Consulté le: oct. 23, 2020. [En ligne]. Disponible sur: https://fr.wikipedia.org/w/index.php?title=Risque&oldid=174544990.
[246] « Gestion des risques », *Wikipédia*. sept. 09, 2020, Consulté le: oct. 23, 2020. [En ligne]. Disponible sur: https://fr.wikipedia.org/w/index.php?title=Gestion_des_risques&oldid=174561804.
[247] « Memoire Online - Le management de risque dans les projets de déploiement des réseaux de téléphonie mobile - Edgard NDASSIMBA », *Memoire Online*. https://www.memoireonline.com/01/17/9498/m_Le-management-de-risque-dans-les-projets-de-deploiement-des-reseaux-de-telephonie-mobile8.html (consulté le oct. 23, 2020).
[248] J. K. Kim, R. Sharman, H. R. Rao, et S. Upadhyaya, « Efficiency of critical incident management systems: Instrument development and validation », *Decision Support Systems*, vol. 44, n° 1, p. 235‑250, nov. 2007, doi: 10.1016/j.dss.2007.04.002.
[249] D. Duret et M. Pillet, *Qualité en production: de l'ISO 9000 à Six Sigma*. Editions Eyrolles, 2011.
[250] *Appliquer la maîtrise statistique des processus msp/spc - Maurice... - Librairie Eyrolles*. .
[251] « Gage R&R », *Wikipédia*. oct. 15, 2019, Consulté le: oct. 23, 2020. [En ligne]. Disponible sur: https://fr.wikipedia.org/w/index.php?title=Gage_R%26R&oldid=163565967.