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Ecole Nationale Polytechnique

République Algérienne Démocratique et Populaire
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
Laboratoire de Génie Mécanique et Développement-LGMD
Département de Génie Mécanique

Final studies project dissertation
For obtaining State Engineer Degree in Mechanical Engineering

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Hybridisation of the LGMD solar heating system: Feasibility study of a natural gas backup system

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Realized by:
GOUMRI Taki Eddine

Composition of the jury:

Chairman	Slimane DJELLAL	MCB	ENP
Supervisor	Arezki SMAILI	Professor	ENP
Co-supervisor	Mohammed Dhiya Eddine SARMOUK	Doctor	U.Sherbrooke
Examiner	Mohammed Amokrane MAHDI	MCB	ENP
Guest of honor	Abdelhamid BOUHELAL	Doctor	ENP

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Mémoire de projet de fin d’études
pour l’obtention du diplôme d’Ingénieur d’État en génie mécanique

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Hybridation de l'installation de chauffage solaire du LGMD: Étude de faisabilité d'un système d'appoint à gaz naturel

---

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ملخص

الهدف من هذا المشروع هو العمل على تطوير محاكاة عددية باستخدام برنامج Openstudio لدراسة مدى فاعلية نظام تسخين مهجن يعمل بالغاز الطبيعي والطاقة الشمسية ،المتواجد في مختبر الطاقات الخضراء والتطوير الميكانيكي بالمدرسة الوطنية متعددة التقنيات. تتمثل هذه الدراسة في إنشاء علاقة بين مؤشرات أداء النظام ، خاصة الكسر الشمسي (SF) ، ومعدل توفير الطاقة الأولية (PESR) ، والتكلفة المستوية للحرارة (LCOH) واعدادات التصميم حيث تم الحصول على التكوين الأمثل 39.2٪ و 32.2٪ و 9.56 DA / kWh لـ SF و PESR و LCOH على التوالي.

الكلمات المفتاحية: أنظمة الطاقة الشمسية الهجينة ، المستشعر الحراري ، المحاكاة الرقمية ، التحليل الحراري ، التحليل الاقتصادي, OpenStudio

Résumé

L’objectif ultime de ce projet est de mettre au point une approche de simulation numérique permettant d’étudier la faisabilité de l’hybridation de l’installation de chauffage solaire-gaz naturel du LGMD en utilisant le logiciel OpenStudio. L’approche consiste à établir la relation entre les paramètres pertinents de performance du système, principalement la fraction solaire (SF), le taux d’économie d’énergie primaire (PESR), le coût actualisé de la chaleur (LCOH) et les paramètres de design. Une configuration optimale a été obtenue pour le SF, PESR et LCOH ayant les valeurs respectivement : 39.2%, 32.2% et 9.56 DA/kWh.

Mots clés : Systèmes solaires hybrides, capteur thermique, Simulation numérique, Analyse thermique, Analyse économique, OpenStudio,

Abstract

The ultimate goal of this project is to develop a numerical simulation approach to study the feasibility of the hybridization of the LGMD solar-natural gas heating system using OpenStudio. The approach consists of establishing the relationship between the system’s pertinent performance parameters mainly the solar fraction (SF), primary energy savings ratio (PESR), levelized cost of heat (LCOH) and the design parameters. An optimal design was obtained for the SF, PESR and LCOH having the values 39.2%, 32.2% and 9.56 DA/kWh respectively.

Keywords: Hybrid solar systems, Thermal collector, Numerical simulation, Thermal analysis, Economic analysis, OpenStudio,

Acknowledgment:

"It is not possible to prepare a project report without the assistance & encouragement of other people. This one is certainly no exception."

At the very outset of this report, I would like to extend my sincere & heartfelt obligation towards all the personages who have helped me in this endeavour.

Without their active guidance, help, cooperation & encouragement, I would not have made headway in the project.

I am ineffably indebted to Pr. Arezki SMAILI and Dr. Mohammed Dhiya Eddine Sarmouk for their conscientious guidance and encouragement to accomplish this assignment.

I would like also to thank Dr. Slimane DJELLAL and Dr. Mohammed Amokrane MAHDI, for agreeing to be part of the jury, *without missing to thank Dr. Abdelhamid BOUHELAL for honouring us with his presence.*

Last but not least gratitude goes to all of my friends who directly or indirectly helped me to complete this project report.

Any omission in this brief acknowledgment does not mean a lack of gratitude.

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Nomenclature

Abbreviations:

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AS-SAHP	Air source solar assisted heat pump
AST	Apparent Solar Time
AVM	Available manager
COP	Coefficient of performance
DHW	Domestic hot water
DX-SAHP	Direct expansion solar assisted heat pump
GUI	Graphical user interface
HP	Heat pump
HS	Hybrid system
HSGHS	Hybrid solar gas heating system
HSHPS	Hybrid solar heat pump system
HVAC	Heating, Ventilation and Air-Conditioning
IWEC	International Weather for Energy Calculations
IX-SAHP	Indirect expansion solar assisted heat pump
LCOH	Levelized cost of heat
LGMD	Laboratory of Green and Mechanical Development
LST	Local Standard Time
NREL	National Renewable Energy Laboratory
OS	OpenStudio
PESR	Primary energy saving ratio
PV	Photovoltaic
SAHP	Solar assisted heat pump
SF	Solar fraction

Latin letters:

a1	1st order heat loss coefficient	[W/m².K]
a2	2nd order heat loss coefficient	[W/m².K²]
Ac	Collector area	[m²]
Cp	Massive Specific heat	[kJ.kg-1.K-1]
FR	Heat removal factor	[-]
I	Solar radiation	[W/m²]
$\dot{m}$	Mass flow rate	[kg.s-1]
UL	Heat loss coefficient	[W/m².K]

Greek letters:

θ	Incidence angle
δ	Declination
φ	Latitude
β	Slope of the collector

γ_s	Solar azimuth angle
γ_0	Surface azimuth angle
ω	Hour angle
θ_z	Solar zenith angle
η_b	Gas boiler's efficiency
η_c	Thermal collector's efficiency
η_h	Hydraulic efficiency
η_m	Mechanical efficiency
ρ	Volumetric mass
ρ_g	Ground reflectance

Subscript

Avg	Average
b	Beam
d	Diffuse
ext	Exterior
g	Ground

General introduction

Scope and Motivations

The constant growth of energy consumption in all its forms and the associated polluting effects, mainly caused by the combustion of fossil fuels, led scientists to search for an alternative source that provides clean and inexhaustible energy this is where we start shifting to the renewable energies. Among all the renewable sources, solar energy has attracted considerable attention as a promising alternative, especially for producing hot water and resolving the different buildings heat demand. However, the main issue with renewable energy sources is that their power production is variable and unreliable, which can be overcome by combining the supply source with an auxiliary one as a backup forming the so-called hybrid system. From this point forward, the complexity of the system multiplies and many problematics questions have raised in the figure of: which configuration is the most efficient to adopt? What is the most appropriate control strategy to implement?

Report goals

The aim of this project is to investigate the feasibility of hybridisation of a solar heating installation using natural gas as a backup. In this project, the Laboratory of Green and Mechanical Development (LGMD) installation developed by Sarmouk et al [10][21] has been considered as prototype to carry out the calculations and simulations. Mainly, the automatic operation that takes into account the back-up system has not yet been studied and implemented, which will thus be the heart of this project. To do this, the Openstudio (which is an open-source and cross platform product) is used to perform the simulations. In this work, to overcome the difficulty of modelling the dynamic behavior of the hybrid solar gas heating system (HSGHS), accurate predictions of the following pertinent parameters have been carried out; namely, solar fraction (SF), primary energy saving ratio (PESR), and levelized cost of heat (LCOH), using Openstudio. Because predicting such performance parameters would play prominent role in the design considerations before making any investigations, the proposed numerical simulation method could eventually serve not only for the optimization of the current HSGHS of the LGMD, but also for any given hybridisation task on heating installation.

Report structure

This report consists of three chapters:

The first chapter gives a brief bibliographical review on the hybrid solar systems, description, different procedures of hybridisation, advantages and inconvenients.

In the second chapter, we present our numerical simulation approach carried out on the Openstudio platform for the HSGHS. Mainly, an appropriate control strategy in real time and conditions is applied, the performance parameters of the systems can be predicted, and therefore the profitability of the hybridisation can be demonstrated.

In the third chapter, the validity of the proposed numerical simulation approach is described. Where we have used the BIN method to calculate the heat demand in the building, combined with Liu and Jordan's model to calculate the available solar radiation in the solar thermal collector. By the end of this chapter, we present an automated application with graphical user interface using Matlab Appdesigner.

1 Chapter 1 Bibliographical review on the hybrid solar heating systems

1.1 Introduction

Every day, our species consumes massive amounts of energy, especially with the increase in global population and the rise of industrialization in developing nations, this caused humanity's hunger for energy to reach unprecedented levels. However, the main source currently used is fossil fuels that generate important Greenhouse gases, this led scientists to search for an alternative source that provides clean and inexhaustible energy.

The search for more eco-friendly and renewable energy sources has grown in recent years as a result of rising energy costs, environmental degradation caused by traditional fossil-based fuels, and the knowledge that they are non-renewable.

From all the renewable energy sources the solar energy has been identified as the one with the greatest potential where the sun provides more than enough energy to meet the whole world's energy needs, and unlike fossil fuels, it will not run out anytime soon. As a renewable energy source, one of the limitations of solar power is our ability to turn it into electricity in an efficient, cost-effective, and stable way, where the idea to develop hybrid systems.

In this chapter, we present an overview of the present situation of energy sources then we will mainly focus on the solar energy, presenting different existing configurations of the hybrid solar systems.

1.2 The evolution of renewable energy

The evolution of renewable energy over the past decade has surpassed all expectations. Global installed capacity and production from all renewable technologies have increased substantially, and supporting policies have continued to spread to more countries in all regions of the world.

The global policy landscape has largely driven the expansion of renewable energy technologies by attracting investment and creating markets that have brought about economies of scale and supported technology advances as shown in figure 1-1.

A handful of countries particularly Germany and the US have led the way, developing innovative policies that have driven much of the change witnessed over the past decade, China is considered as the leading country in installed renewable energy capacity worldwide followed by the US and Brazil.

Today the use of renewable energy provides electricity, heating and cooling, and transportation and even though Gas and Oil remain to be the main sources of energy as shown in figure 1-2, recent developments suggest sustained growth in the market of solar and wind energies worldwide.

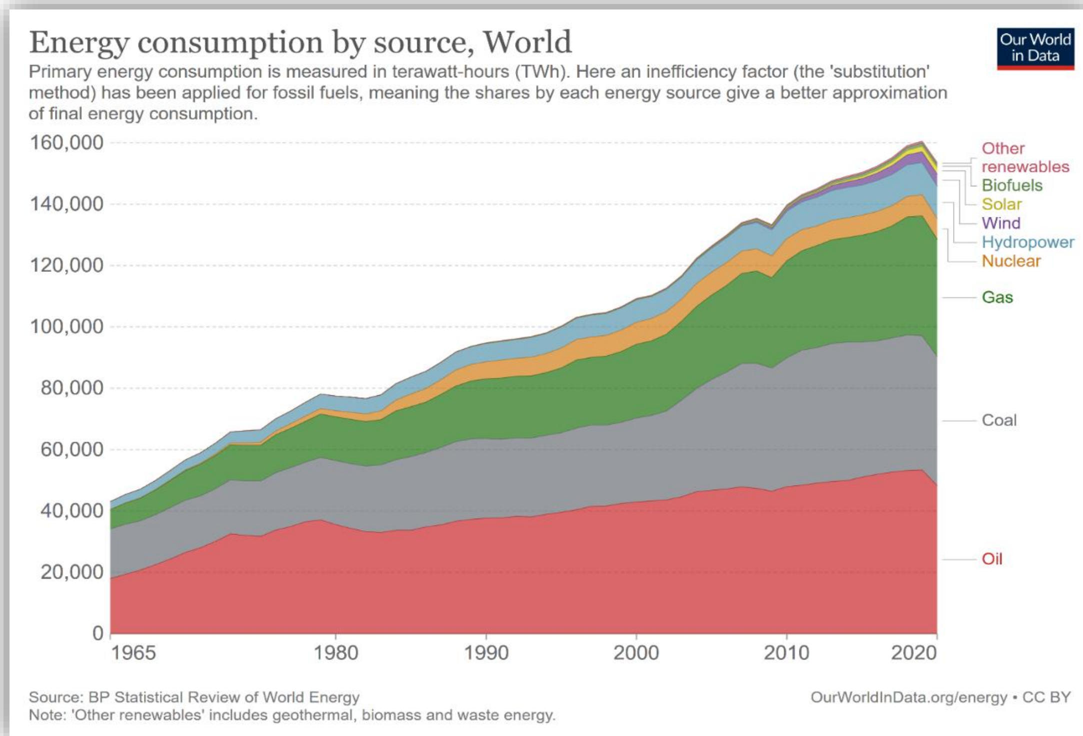


Figure 1-1 Evolution of energy consumption by source [1].

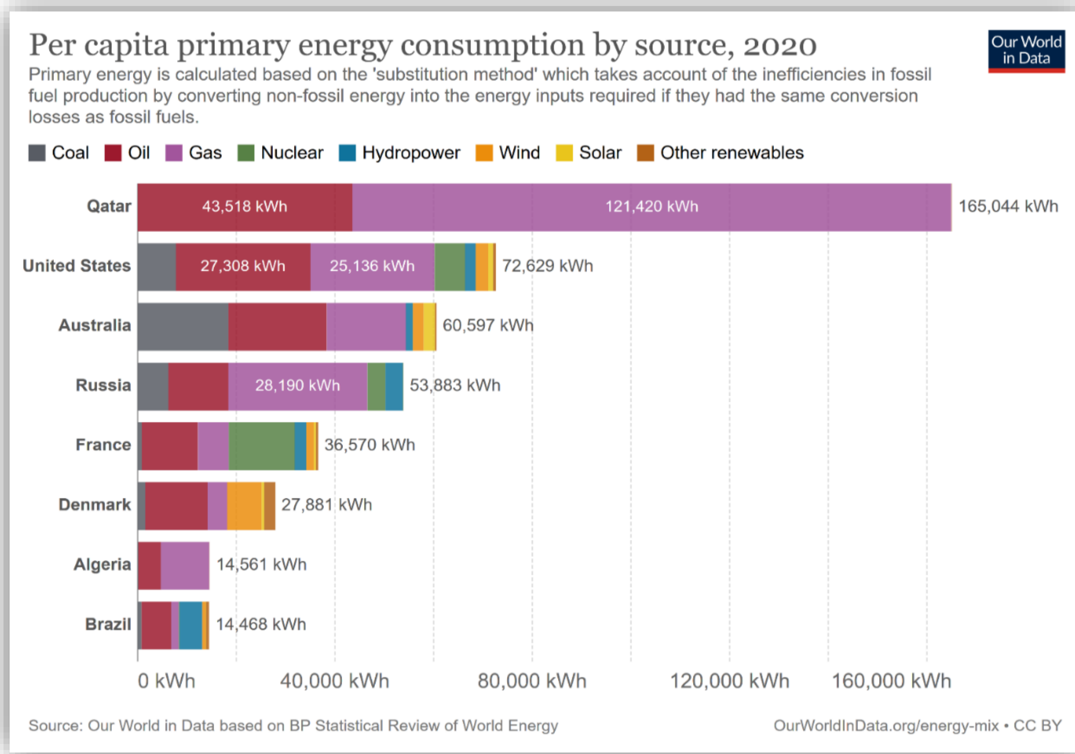


Figure 1-2 2020 Energy consumption by country [1].

1.3 Solar energy and its potential:

Solar energy has been identified as a significant competitor for reducing emissions released during the burning of conventional fuels and for lowering the national energy bill among the different possibilities evaluated [1].

At the upper atmosphere, the Earth gets 174 petawatts (PW) of solar radiation (insolation), about 30% of the energy is reflected back to space, with the remainder absorbed by clouds, seas, and landmasses. At the Earth's surface, solar light is predominantly in the visible and near-infrared bands, with a minor portion in the near ultraviolet. The majority of the world's population lives in places with daily insolation of 150–300 W/m^2, or 3.5–7.0 kWh/m^2 [2].

Solar radiation is absorbed by the Earth's land surface, oceans – which cover about 71% of the globe – and atmosphere. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapour condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anticyclones. Sunlight absorbed by the oceans and landmasses keeps the surface at an average temperature of 14 °C. By photosynthesis, green plants convert solar energy into chemically stored energy, which produces food, wood and the biomass from which fossil fuels are derived [2].

The total solar energy absorbed by Earth's atmosphere, oceans and landmasses is approximately 3850000 EJ per year. In 2002, this was more energy in one hour than the world used in one year. Photosynthesis captures approximately 3000 EJ per year in biomass [2].

Yearly solar fluxes & human consumption[1]	
Solar	3,850,000
Wind	2,250
Biomass potential	~200
Primary energy use	539
Electricity	~67

Table 1-1 Energy given in Exajoule (EJ) = 27 TWh Consumption as of year 2010 [2]

The potential solar energy that people could utilize differs from the quantity of solar energy existing at the planet's surface because geography, temporal variation, cloud cover, and the amount of land available to humans restrict the amount of solar energy that we can receive. In 2021, the Carbon Tracker Initiative calculated that the land area required to generate all of our energy from sunlight alone would be 450,000 km2, or roughly the same as the area of Sweden, Morocco, or California (0.3 percent of the Earth's total surface area) [2].

1.4 Hybrid systems:

The problem with the variable and non-guaranteed power produced by renewable energy sources can be solved by coupling the sources of supply and forming a so-called hybrid system (HS).

A hybrid renewable energy system (HRES) is an electrical system, comprising multiple energy sources, of which at least one is renewable. The hybrid system may include a storage device. From a more global point of view, the energy system of a given country can be considered as a hybrid system.

1.5 Hybrid solar heat pump system:

The heat pump has been the trend in several researches of hybrid systems, such as in Li et al. (2013), Tagliafico et al. (2012), Kim et al. (2013) and Zhao et al. (2014). The heat pump is more efficient when compared to other sources for heating, such as direct use of electricity (electric power) and combustion (gas boiler) . Although the heat pump is not a recent technology, its concept is still less widespread in some parts of the world (Staffell et al., 2012). And according to Hepbasli & Kalinci (2008), the greatest portion of electricity consumption goes to water heating, along with lighting and air conditioning.

The heat pump performance coefficient (COP) depends on the following factors (Jordan et al., 2016; Zhao et al., 2014, Safa et al., 2015, Akbulut et al., 2016): heat source temperature, condenser and water for consumption temperature, the used refrigerant fluid, as well as the different characteristics of the heat pump. Solar panels and heat pumps are very promising systems for heating air and water, and they can be combined to build hybrid systems that operate in **serial** or **parallel**.

The efficiency of the hybrid system can be improved by balancing of the solar panel and the COP of the heat pump. Most studies deal with direct expansion systems to produce of water at temperatures neighboring 45 ° C, for both air conditioning or water heating (Tagliafico et al., 2012). Recent studies by odrigo A. Jordan, Johnny T. Yamasaki, Vivaldo Silveira Júnior, et al present the assembly, in the field, of a prototype for water heating using solar collectors, with two configurations: distinct and parallel, for the supplementary heating. This prototype was tested using both configurations, obtaining data on the final water temperature and energy consumption of the supplementary heating, allowing a comparative study of the performance of each configuration. Which we will discuss later on.

1.6 Solar-assisted heat pump (SAHP):

SAHP is a machine that combines a heat pump with thermal solar panels to create a single integrated system to produce hot water, these two methods are usually utilized individually (or only in parallel). The solar thermal panel serves as a low-temperature heat source in this system, and the heat produced is used to feed the heat pump's evaporator. The purpose of this system is to get a high COP so that energy may be produced in a more efficient and cheaper way [3].

In conjunction with the heat pump, any form of solar thermal panels can be used (sheet and tubes, roll-bond, heat pipe, thermal plates) or hybrid (mono/polycrystalline, thin film).
A hybrid panel (PV/T) is desirable since it may cover a portion of the heat pump's electric energy demand, lowering power consumption and, as a result, the system's variable costs.

The presence or absence of an intermediary fluid that carries heat from the panel to the heat pump (intermediate heat exchanger) distinguishes the two conceivable configurations of this system: indirect expansion, direct expansion, and air source .

1.6.1 Indirect expansion (IX-SAHP):

This configuration uses mainly water as a heat transfer fluid, mixed with an antifreeze fluid (usually glycol) to avoid ice formation phenomena in the winter period.

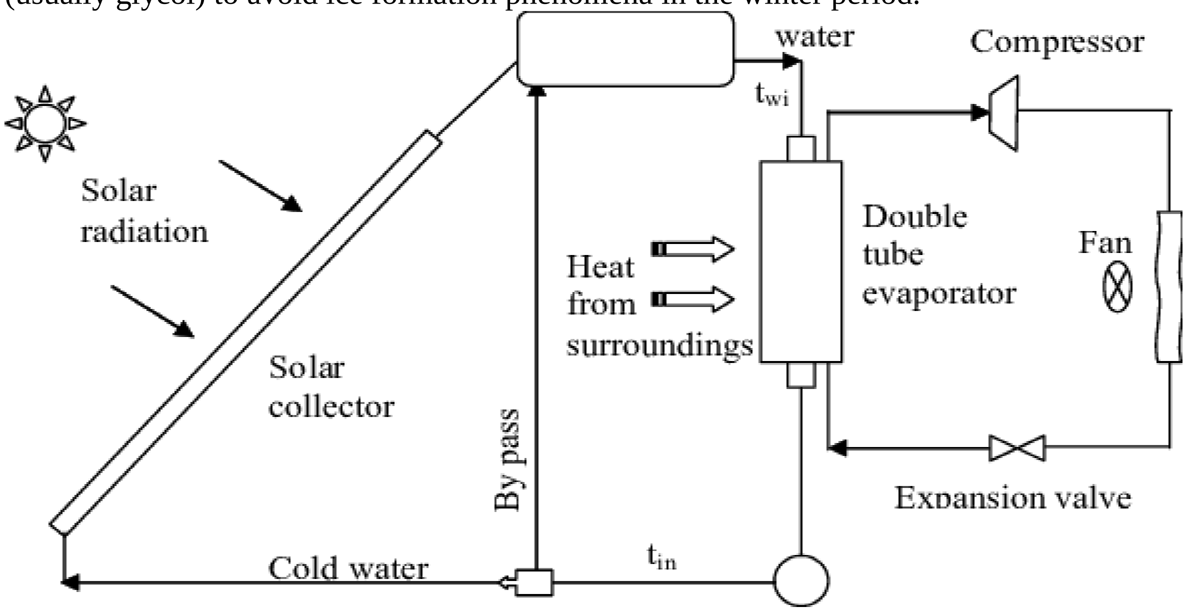


Figure 1-3 IX- SAHP [4]

1.6.2 Direct-expansion (DX-SAHP):

In this configuration the refrigerant fluid is placed directly inside the hydraulic circuit of the thermal panel, where the phase transition takes place. Even though this configuration is more complex from a technical point of view, it has several advantages:

- A better transfer of the heat produced by the thermal panel to the working fluid which involves a greater thermal efficiency of the evaporator, linked to the absence of an intermediate fluid;
- The presence of an evaporating fluid allows a uniform temperature distribution in the thermal panel with a consequent increase in the thermal efficiency (in normal operating conditions of the solar panel, the local thermal efficiency decreases from inlet to outlet of the fluid because the fluid temperature increases);
- Using hybrid solar panels, in addition to the advantage described in the previous point, the electrical efficiency of the panel increases (for similar considerations).

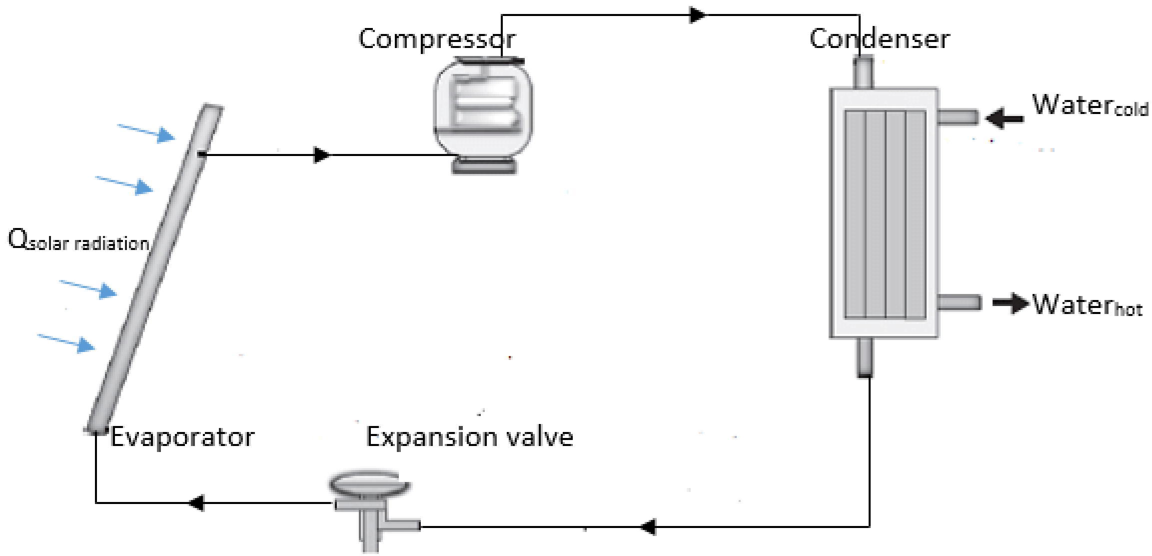


Figure 1-4 DX-SAHP [4]

1.6.3 Air source SAHP (AS-SAHP):

This configuration is mainly composed of a finned tube evaporator, a collector evaporator, a reciprocating compressor, a capillary and a water cooled condenser. Compared with the traditional DX-SAHP, a finned tube evaporator is connected in series with the collector evaporator in the AS-SAHP system. The finned tube evaporator is capable of recovering heat from the ambient effectively due to the heat transfer enhancement of fins:

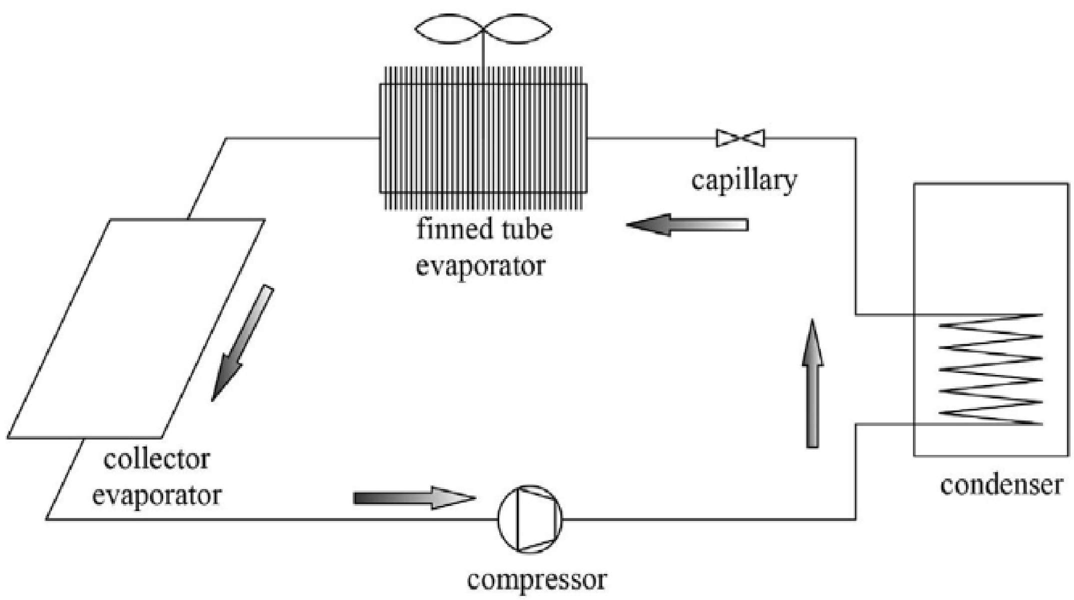


Figure 1-5 AS-SAHP [5]

1.6.4 Comparison IX-SAHP vs DX-SAHP vs ASHP:

An advance mathematical model developed by researchers: Jingyong Cai,Zhouhang Li,Jie Ji and Fan Zhou leads to the results shown in figure 1-6 (4):

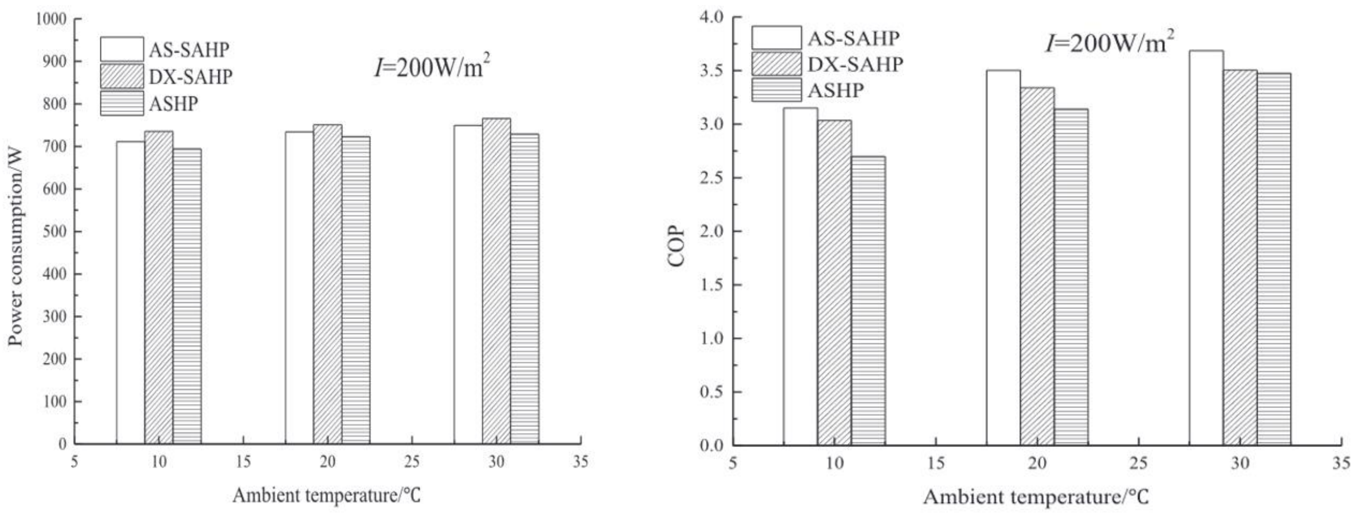


Figure 1-6 AS-SAHP vs DX-SAHP vs ASHP [5].

Comments and interpretation:

- The AS-SAHP system can operate effectively under various working conditions. The average COP increases from 2.78 to 3.31 with the ambient temperature rising from 5 C to 15 C, and rises from 2.71 to 3.22 with the solar irradiation increasing from 100 W/m2 to 300 W/m2. In addition, remarkable improvement of COP in the AS-SAHP system can be achieved with relatively low increment of power consumption by inputting solar irradiation at evaporating side of the system [4].
- The evaporating temperature of the AS-SAHP system remains between that of ASHP and DX-SAHP. Therefore, the heat loss to environment can be avoided and the performance of AS-SAHP system is improved. The system shows the best performance under a range of environmental conditions compared with conventional ASHP and DX-SAHP [4].

1.7 Hybrid Solar Gas Heating System (HSGHS)

1.7.1 Presentation:

Solar systems frequently use conventional gas boilers to meet the residual energy requirements.

As a result, the appropriate connectivity of both heat sources is critical. The important signal is final energy usage, which must be decreased while also taking into account the used quantity of the original energy.

1.7.2 Different configurations (variants):

Several authors analysed the integration of boilers in conventional heat supply systems [5]. Other studies investigate the optimization of solar thermal systems; a part of them also discusses the proper pellet boiler integration in the system [6].
A simulation study by [7] has been performed using TRNSYS, it discusses the different variants of solar thermal systems with gas or oil boilers as conventional heat generators.
Figure 1-7 shows the principles of the four basic configurations (variants) under discussion:

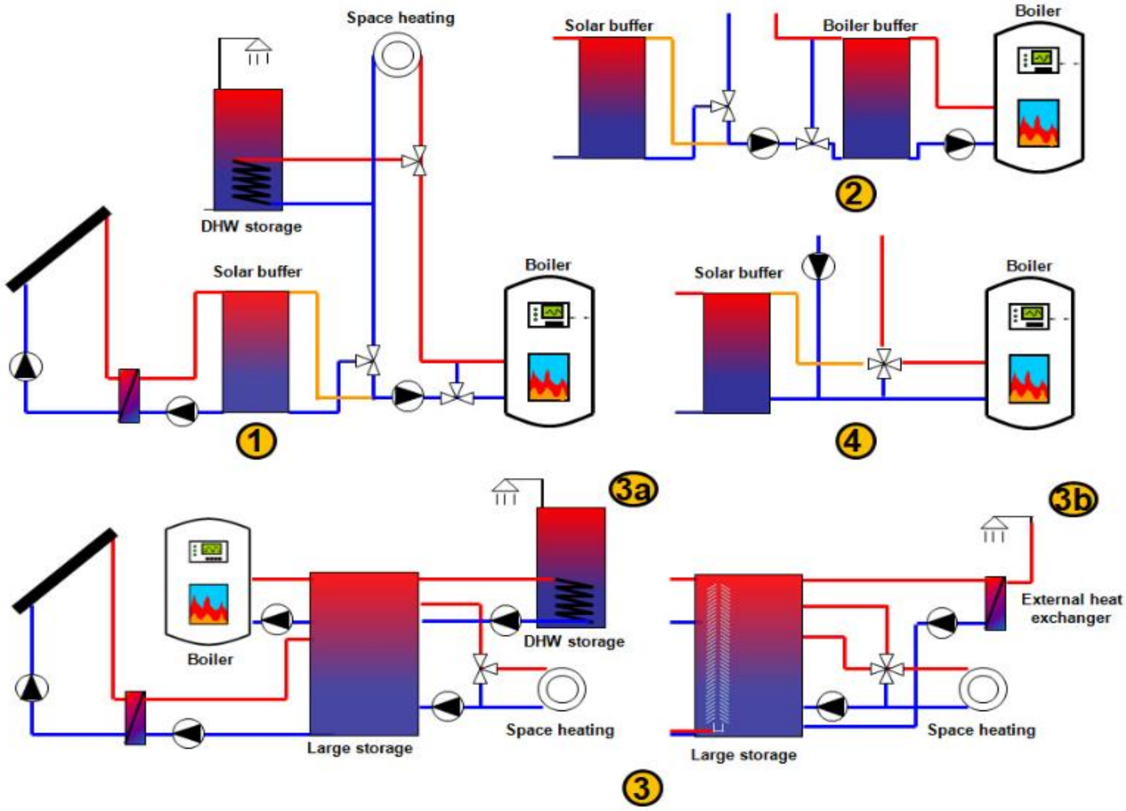


Figure 1-7 The four basics variants in HSGHS [8].

In variant 1, the solar heat is stored in a solar buffer storage, which is connected to the return of the heating system. The return may be pre-heated by the solar buffer storage and heated up to the desired set temperature by the boiler afterwards. If the buffer temperature is above the set temperature, the system operates without the boiler (bypass before boiler). The domestic hot water (DHW) is prepared and stored in a small DHW tank.

Variant 2 includes an additional boiler buffer storage, which is installed in parallel between the boiler and the heating network.

Variant 3 integrates the solar and boiler buffers in one (larger) storage tank, either a DHW tank (variant 3a) or an external heat exchanger (fresh water module, variant 3b) that is used for the domestic hot water preparation. An improvement of the stratification within the storage may lead to higher energy savings, especially in a larger storage tank. Such an improvement is realized in variant 3b using an ideal stratification device for the collector inlet on one hand and two outlets for the space heating circuit on the other hand, which enables a stratified discharging in combination with a four way valve.

In variant 4 the boiler and the solar buffer are connected in parallel. A four-way valve directs the return mass flow to both components, where the distribution depends on the return, storage and set temperatures. The motivation for this scheme is that the boiler can operate in its optimum condition, because it receives the lowest possible return temperature and not a pre-heated mass flow. This seems to be advantageous, as the inlet temperature affects the boiler efficiency, whereas the outlet temperature has only a marginal effect.

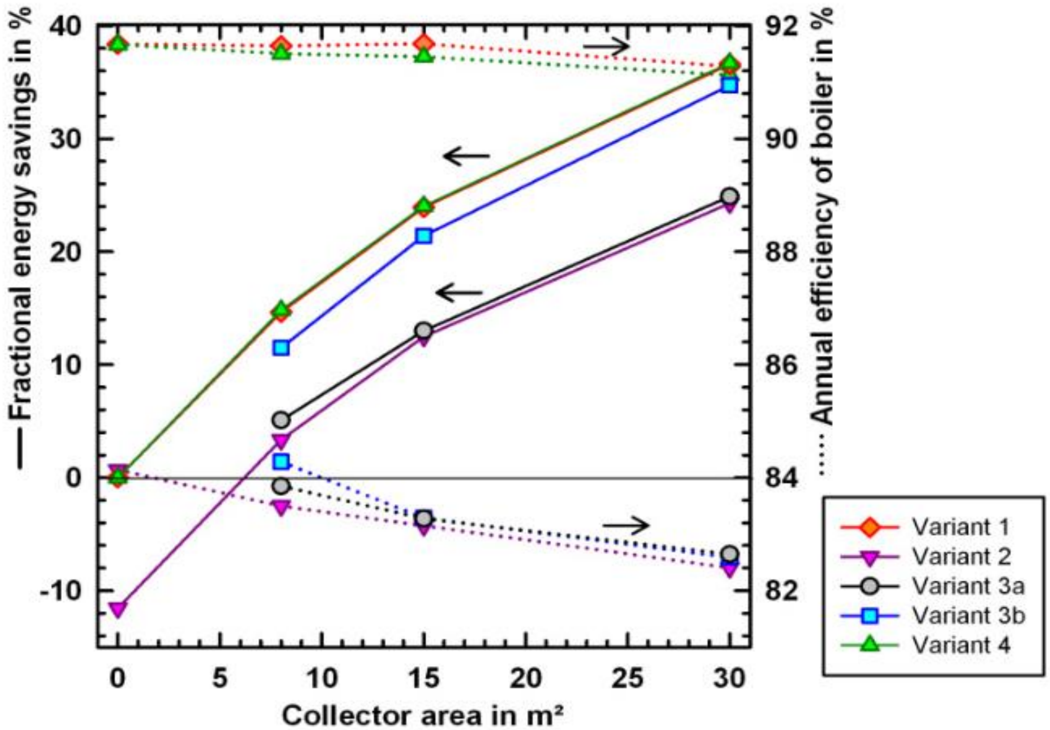


Figure 1-8 Fractional energy savings and annual boiler efficiencies of all variants [8]

1.7.3 Summary of the results:

In summary, the following conclusions can be taken from the study:

- The effects of a solar thermal system on the annual boiler efficiency are not important.
- When a solar subsystem and a boiler operate simultaneously, the solar warmed fluid raises the input temperature, lowering the boiler's efficiency. The effect on yearly boiler efficiency is minor if the time of simultaneous operation is short (as in variation 1).
  Furthermore, with greater intake temperatures, the solar collectors minimize the boiler's operation time for hot water preparation. As a result, the solar thermal system's total influence on yearly boiler efficiency can be positive.
- The number of boiler cycles has an impact on its efficiency at high temperatures. If the avg boiler operating time reduces, the ambient heat losses increase dramatically. The solar system and a modulation burner both lower the number of boiler cycles, resulting in longer avg operation times.

- The boiler buffer of variant 2 reduces the boiler cycle rate but leads to additional heat losses and a higher boiler inlet temperature. The latter may be mitigated if the buffer storage is only used for space heating (not simulated).
- The combination of the solar and the boiler buffer in one bivalent buffer tank (variant 3a) decreases the storage heat losses and thus increases the energy savings if compared to variant 2. The storage heat losses are reduced even more, if the hot water preparation is performed via an external heat exchanger instead of the hot water storage tank. This system (variant 3b, equipped with charging and discharging devices) has lower storage heat losses and reaches almost the same fractional energy savings as in variant 1. However, its hydraulic scheme is more complex.
- All variants with a boiler buffer unit (variant 2 and 3) have significant lower boiler efficiencies than variant 1 due to a higher boiler inlet temperature. Furthermore, the effects of the solar thermal system on the boiler efficiency are more pronounced. Since solar heat leads to higher temperatures in the boiler buffer, the Avg annual boiler inlet temperature is increased if compared to variants 1 and 4.
- The lowest boiler efficiency occurs in variants 2 and 3 with a collector area of 30 m².
- The most important indicator of solar thermal systems is the final energy savings. For a complete evaluation, the collector yield and boiler efficiency are insufficient. Variant 3b, which has the lowest boiler efficiency, saves nearly as much energy as variant 1, which has the highest boiler efficiency.

1.7.4 Comparison Heat pump vs Electric power vs Gas boiler:

Table 1-2 Heat pump vs Electric power vs Gas boiler

Auxiliary source	Heat pump	Electric power	Gas boiler
Efficiency (%)	$200 < COP < 600$	≈ 100	≈ 90
Cost	expensive(electricity)	expensive(electricity)	cheap(gas)
Safety	High	High	Medium
Environment friendly	Yes/No	Yes/No	No
Maintenance	Very easy	Very easy	Easy

1.8 Conclusion:

In this chapter, we discussed several features related to the hybrid solar systems and their different configurations and we concluded that for electric base auxiliary supply the air source heat-assisted heat pump is the best choice for most scenarios and for gas base auxiliary supply the variant 1 tends to be the most suitable configuration.

However, in order to make the final choice it is important to take the specific climate of your region different equipment's costs into considerations before making any further investigation.

2 Chapter 2 Numerical simulation using OpenStudio

2.1 Introduction:

In this chapter, we develop a simulation model for the HSGHS installation using Openstudio to provide realistic and accurate predictions of the system's performance. An optimization process is performed by understanding the relationship between the system's performance and the design parameters and according to it; we achieve the optimal design.

2.2 OpenStudio:

Open studio is a free open source product developed by the national renewable energy laboratory (NREL) and the US department of energy, openstudio's objective is to help building owners, architects, designers and engineers to design buildings and systems that are more energy efficient. (8)

2.3 Simulation workflow:

We can break down the Openstudio user interface into 15 tabs: site, schedules, constructions, loads, space types, geometry, facility, spaces, thermal zones, HVAC systems, output variables, simulation settings, measures, run simulation, results summary (see figure 2-1). In the next coming sections we demonstrate our simulation workflow step-by-step until reaching the final model by the end of the chapter.

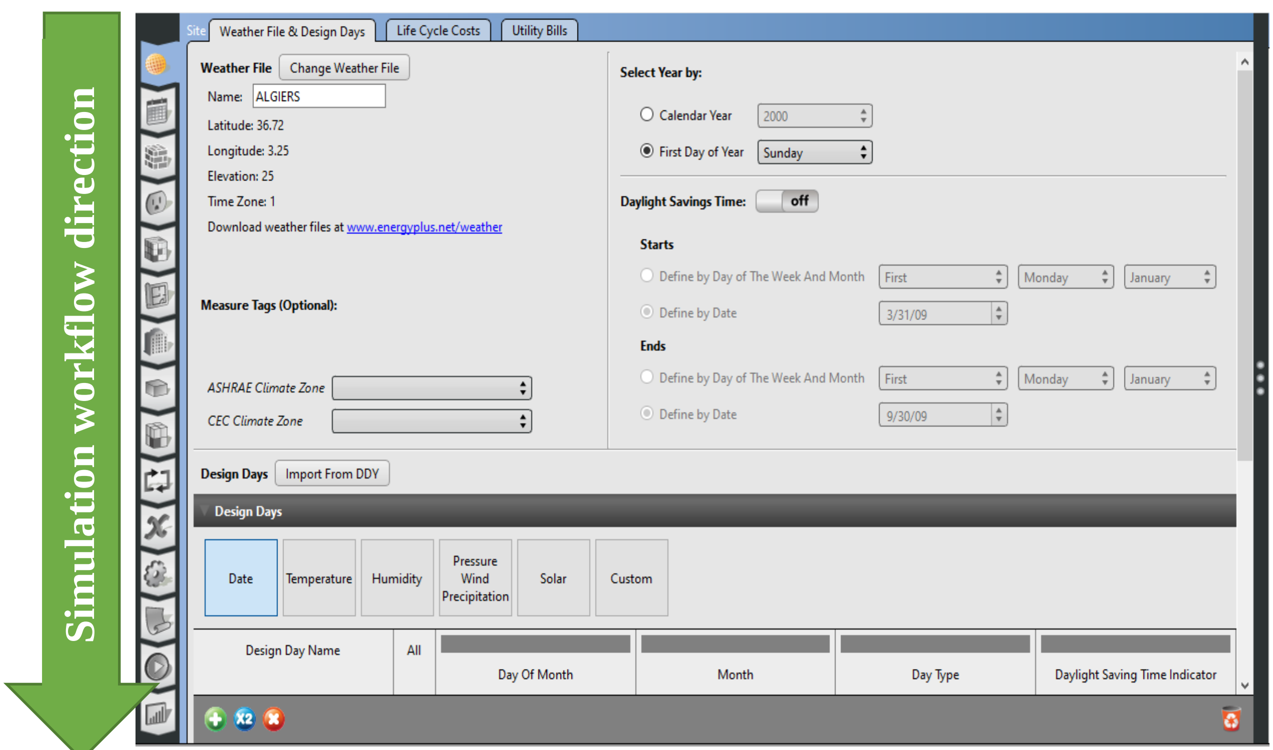


Figure 2-1 Simulation workflow chart

2.4 Weather files:

Source weather data for building energy simulation programs can be broken into two major classes: historical data and typical weather years. Historical data is just "real" data: usually measured (but sometimes modelled) data from a particular location for a given period of record. Typical years are ersatz years assembled to match the long-term data from a particular location using a particular statistical measure. Typical data may also be "real" data but may not be a contiguous year - the data may be comprised of months from multiple years [9].

In our simulation we work with the IWEC files weather data (International Weather for Energy Calculations)

The IWEC are the result of ASHRAE Research Project 1015 conducted by Numerical Logics and Bodycote Materials Testing Canada for ASHRAE Technical Committee 4.2 Weather Information. The IWEC data files are **'typical'** weather files suitable for use with building energy simulation programs for 227 locations outside the USA and Canada [9].

The files are derived from up to 18 years of DATSAV3 hourly weather data originally archived at the U S National Climatic Data Center. The weather data is supplemented by solar radiation estimated on an hourly basis from earth-sun geometry and hourly weather elements [9].

The IWEC data are distributed in the EPW format (Energyplus format) making it available to implement in the Openstudio application for free at **http://www.energyplus.net/weather**

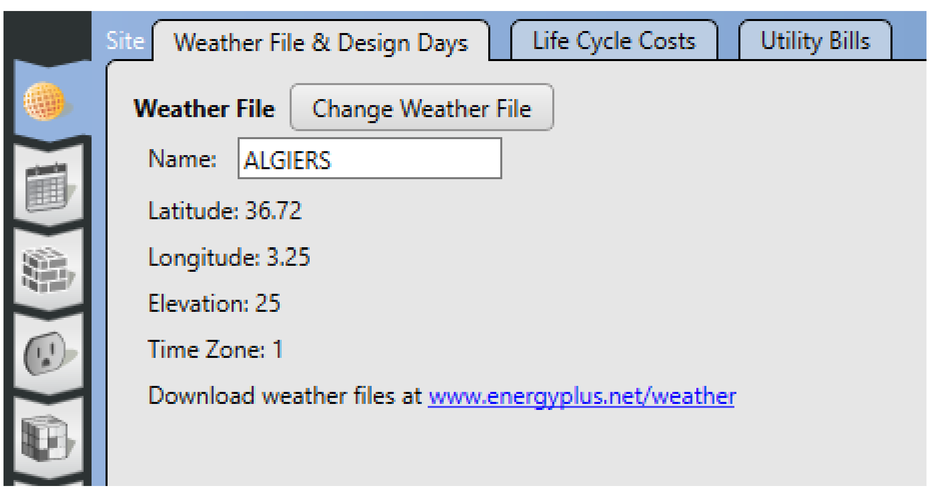


Figure 2-2 Open studio site tab

Figure 2-3 shows the meteorological data mainly the Global horizontal radiation (Wh/m^2) and the outdoor dry bulb temperature (°C) with a time step =1h with figure 2-4 zooming into 13th January.

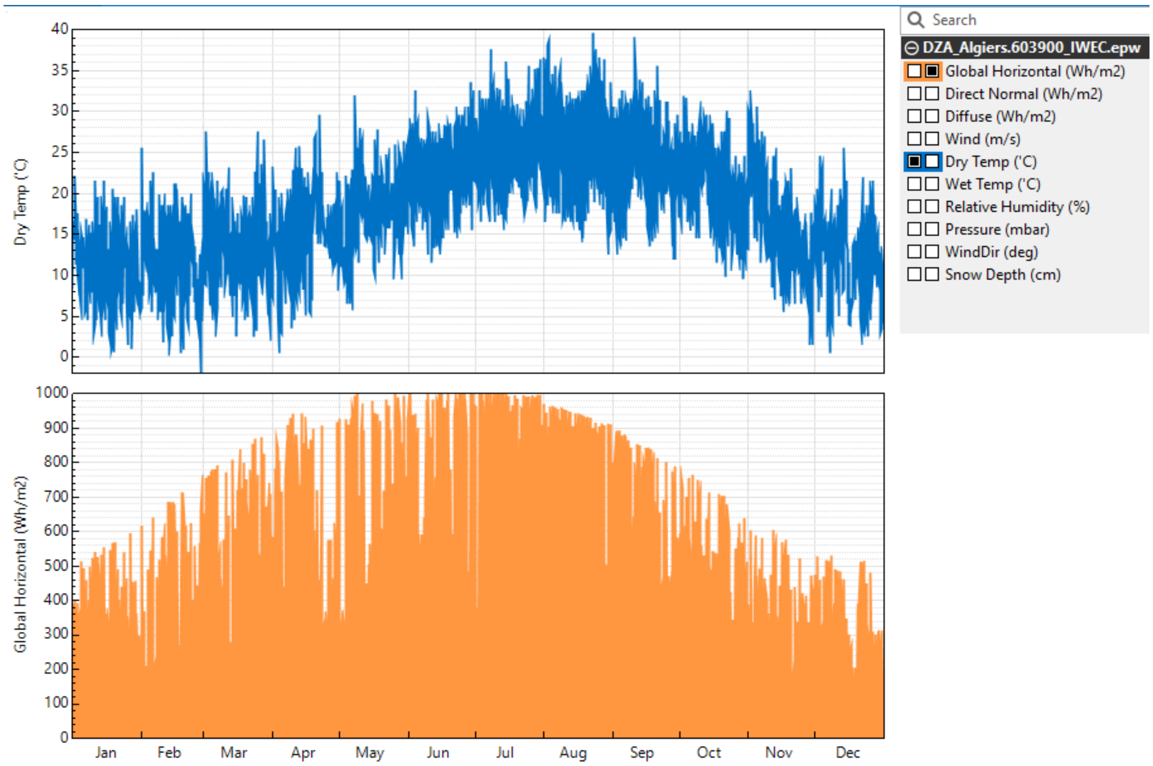


Figure 2-3 Annual Dry temperature (°C), Global horizontal (Wh/m^2) chart

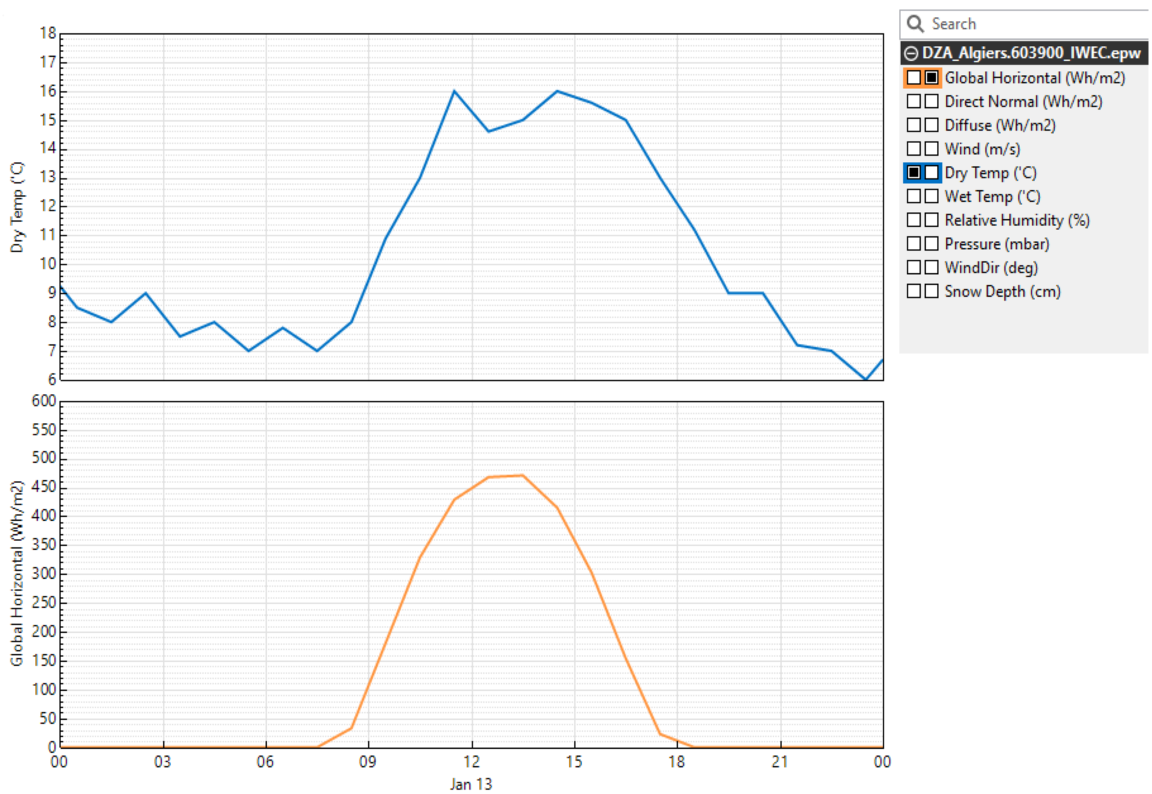


Figure 2-4 13th January Dry temperature (°C), Global horizontal (Wh/m^2) chart

2.5 Envelope Geometry and Building Spaces:

2.5.1 Geometry:

A hybrid solar gas heating system (HSGHS) was built in the "École Nationale Polytechnique" located in the city of El-harrach (36.72N; 3.15E), Algiers, Algeria. A Mediterranean city characterized by a relatively big amount of solar energy even in the winter period.

The system is intended to provide heat for an office at a setpoint temperature of 21°C. The office has an area of 50 m² (10m x 5m x 4m), and it is located on the ground floor of a two-story non-insulated building, as shown in Figure 2-8. The northern wall is the only wall exposed to outside weather conditions; its orientation disfavours the solar gain. Only the deemed office (shown in red) is equipped with a heating system in the building, thus, its internal walls are adjacent to none heated zones [10].

There is a number of ways to develop the envelope and the interior geometry for an OpenStudio model. The floor plan editor integrated within the OpenStudio application may be used to develop a two-dimensional floor plan for each building story. Third party Computer Aided Drafting (CAD) tools are capable of exporting geometry in Green Building. Extensible Markup Language (gbXML) format can also be used.

In this simulation, we used the OpenStudio Plug-In for Trimble SketchUp, which is highly recommended over the others mentioned earlier especially for detailed three dimensional building geometry. (See Figure 2-5 and 2-6)

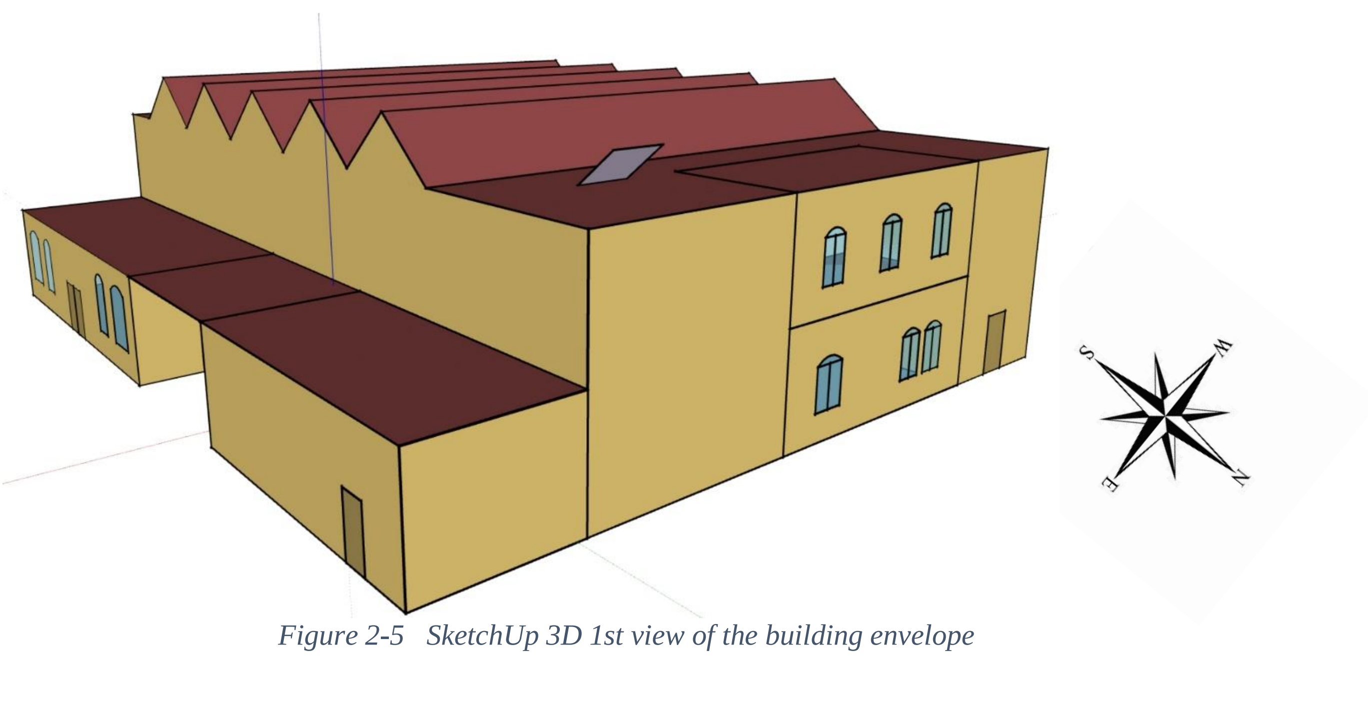


Figure 2-5 SketchUp 3D 1st view of the building envelope

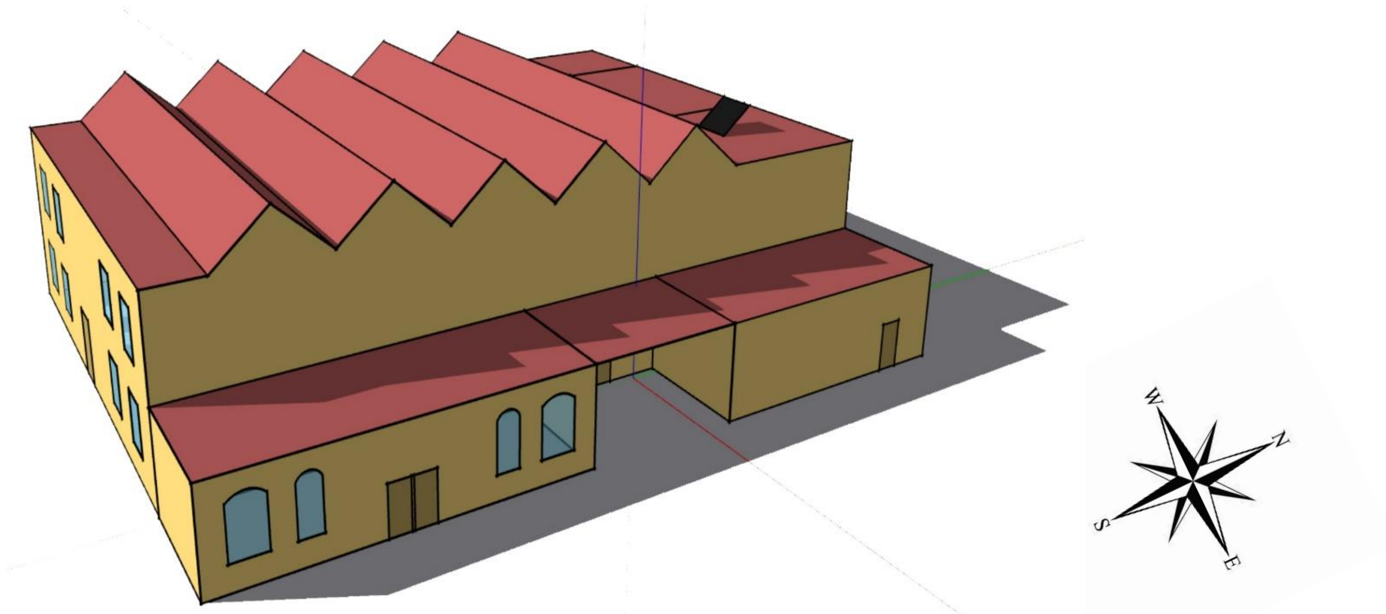


Figure 2-6 SketchUp 3D 2nd view of the building envelope

2.5.2 Assigning thermal zones:

The building was divided into four thermal zones, 1st floor Office, 2nd floor office, classroom, and corridor. The heat transfer between the thermal zones is considered through the common walls; moreover, each zone can be treated separately on Openstudio. Figure 2-7 shows the building geometry and the thermal zones partition on SketchUp.

In this study, we could have combined thermal zones 2, 3, 4 together to minimize the calculation runtime but in reality, their external boundary conditions are clearly different (sun and wind exposition). Therefore, the interior temperature distribution is different in each zone so the simplification proposition is not applied. (To know more about when to combine spaces into thermal zones see reference [11] "Rules of thumb for combining Spaces into thermal zones").

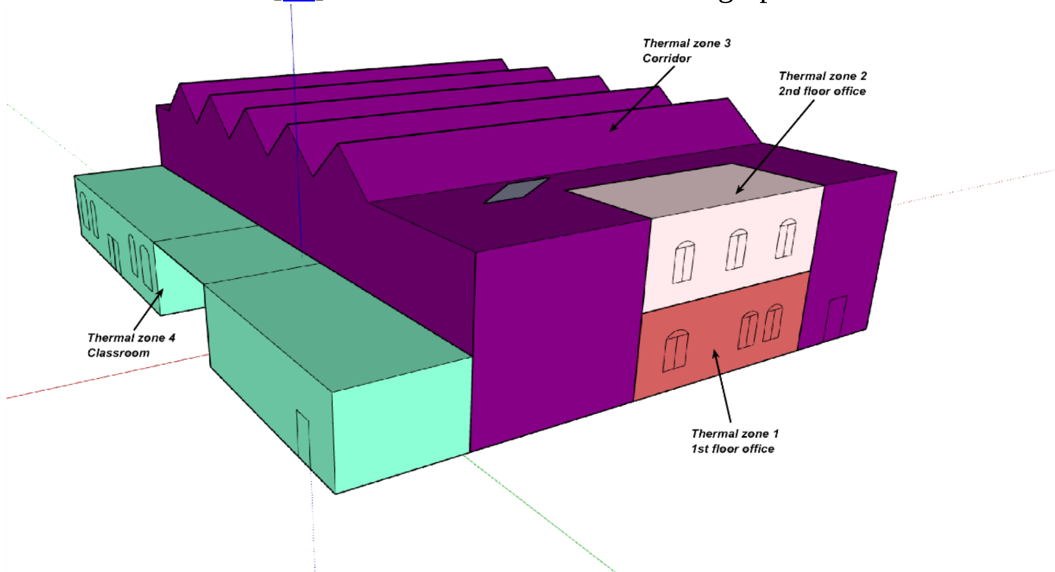


Figure 2-7 Thermal zones partition

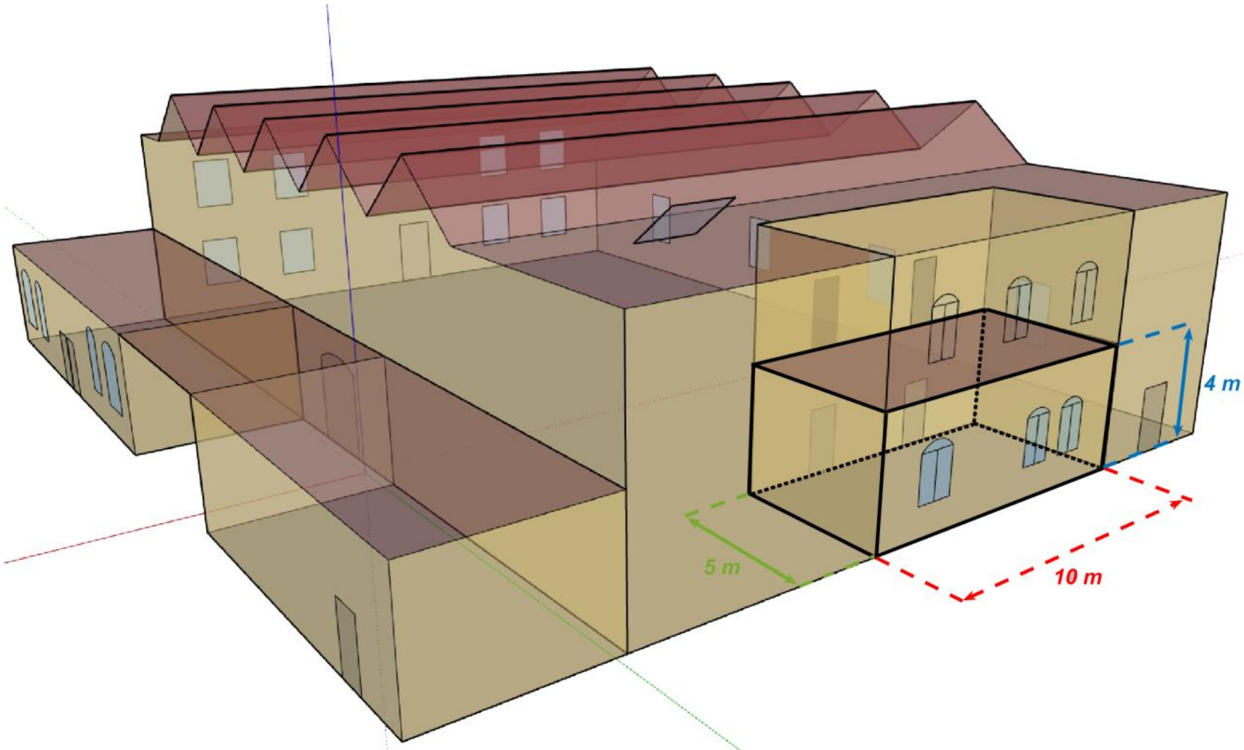


Figure 2-8 Heating space (thermal zone 1, 1st floor office) Highlighted

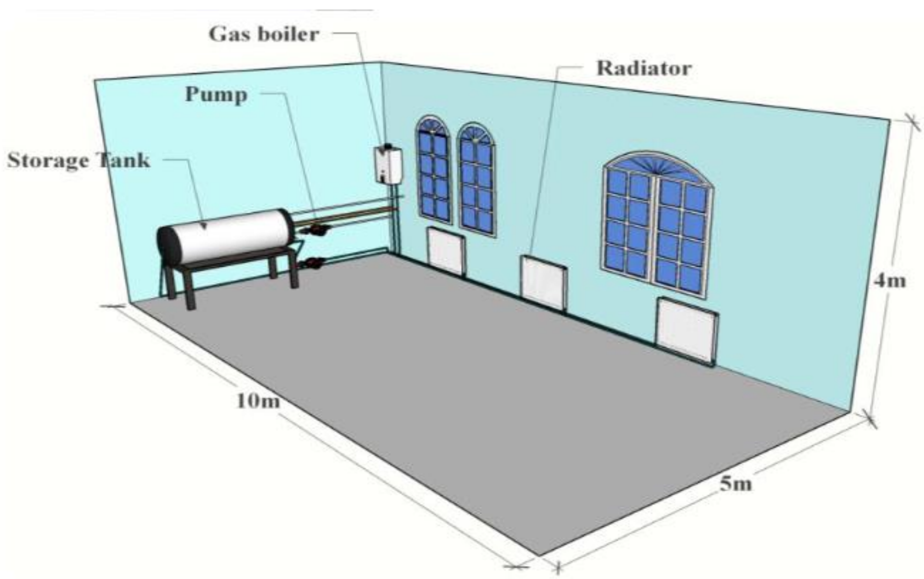


Figure 2-9 3D inside view of the HSGHS [10]

2.5.3 Assigning constructions:

A construction set is the collection of different construction part each is dedicated to a specified surface type (interior walls, exterior walls, window, ceiling, roof …).A Construction is composed of several layers of materials. Materials are ordered from the exterior layer to the interior layer And each layer of materials is defined by 8 characteristics (Roughness, thickness, conductivity Density, specific heat, thermal absorptance, solar absorptance, and visible absorptance) as shown in the figure 2-10:

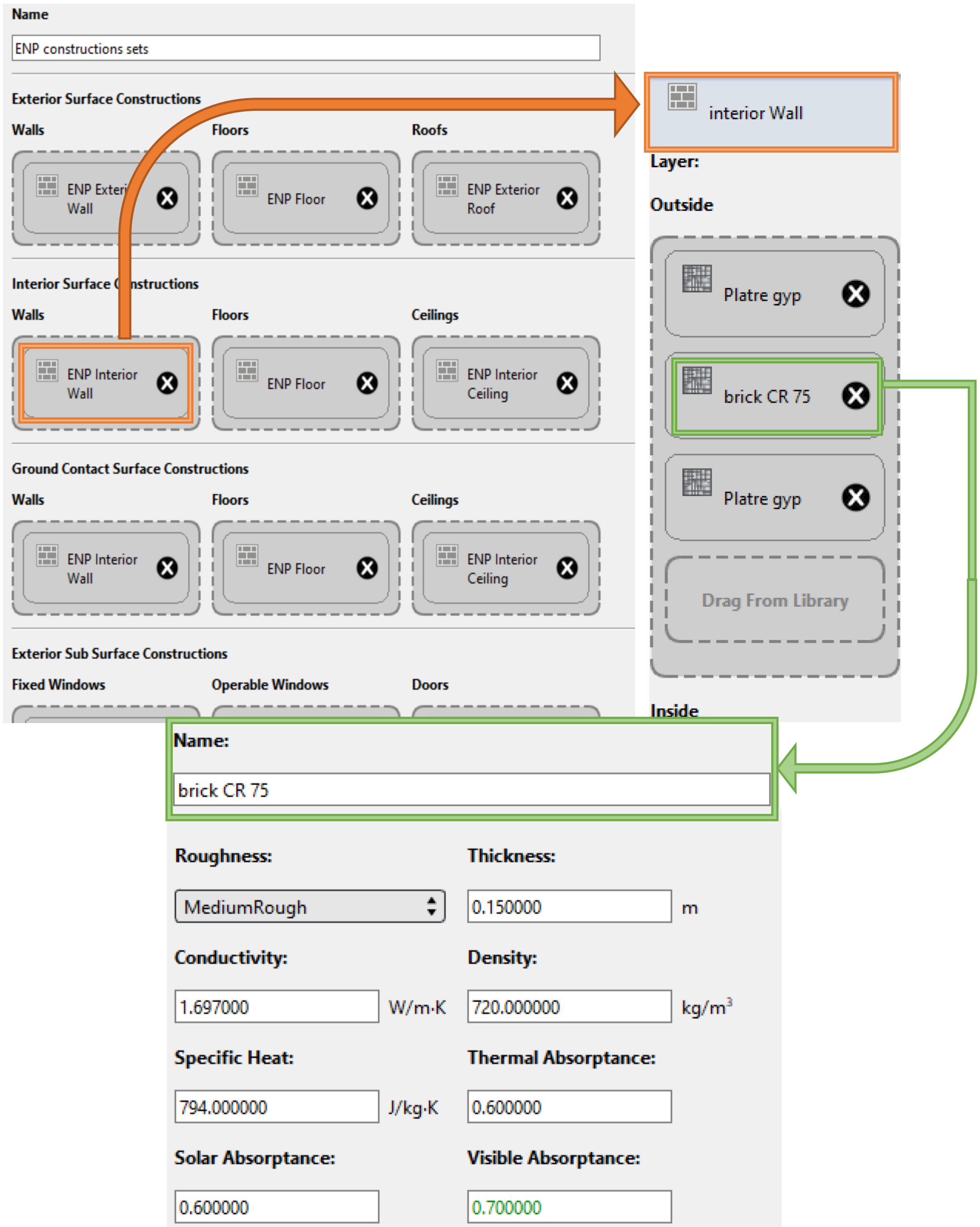


Figure 2-10 ENP constructions set, constructions, materials

2.6 Modelling the HSGHS:

2.6.1 System Description:

The system configuration is presented in the figure 2-11 is referred to as the Hybrid solar gas heating system (HSGHS). The system is comprised of the following major components:

- Solar collectors
- Hot water storage tank
- Gas boiler
- Serpentine heat exchanger
- Radiators
- Two hot water circulating pumps

2.6.2 Experimental unit presentation:

The experimental test unit described, see Figure 2-11, has been built from the very beginning to accommodate the experimental investigation of the HSGHS. The experimental testing apparatus consists of a closed-loop indirect solar system, represented schematically in Figure 2-13. The collectors are installed on a south oriented frame with 37° inclination angle, close to location latitude. This angle ensures a maximum energy collection over the entire year in Algiers. The solar collectors installed on the building's roof are depicted in Figure 2-12.

A 187 L storage tank allows the system to operate in a closed loop, thus collecting energy during the day. The inlet port from the collector is located at the top, the outlet ports towards the collectors and the radiators are located at the bottom and the inlet port from the radiator is located at the center. The storage tank was initially installed on a mono-bloc water heater; therefore, the disposition of the ports was limited and thus discourages the mixing inside the tank. The storage tank was modified to be able to achieve the hybridization by conceiving a serpentine heat exchanger and installing it at the tank's level. Water is circulated in the collector loop with a three-speed circulation pump (model Salmson NXL 13-25P) and in the distribution loop with a similar pump (model Grundfos UPS 25-60). The main components within the building are illustrated in Figure 2-11. Table 2-1, summarizes the main components of the system and their models [10].

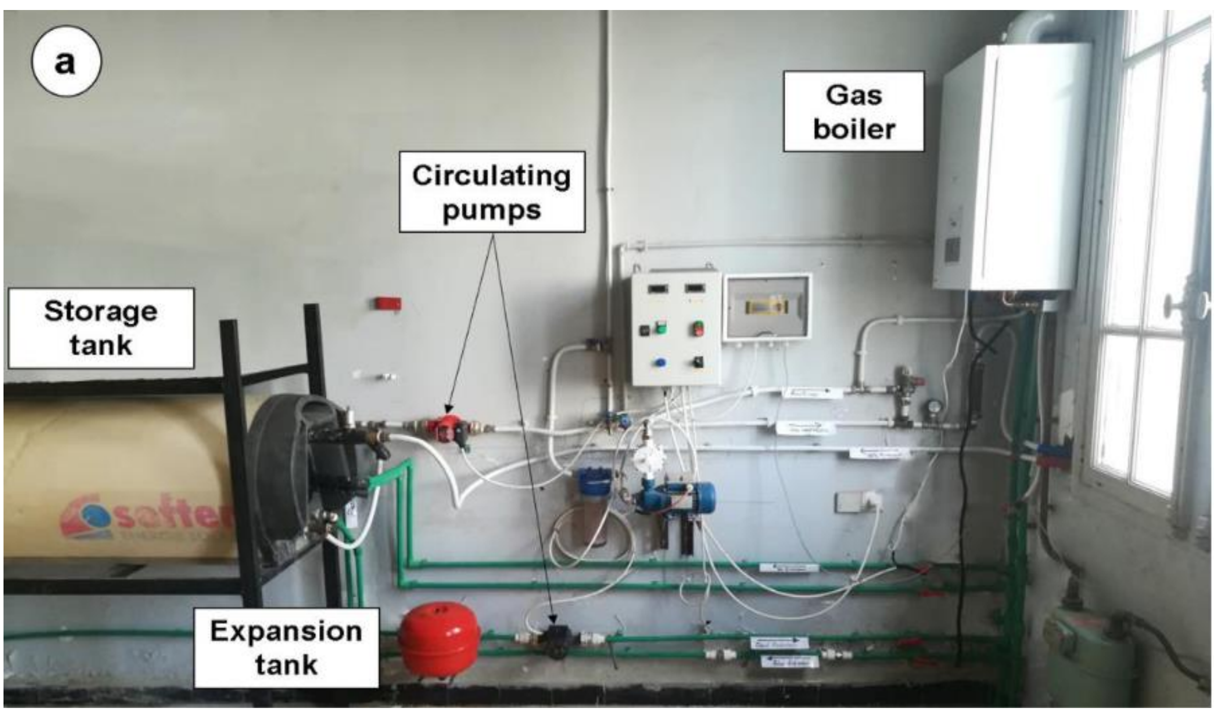


Figure 2-11 Experimental unit

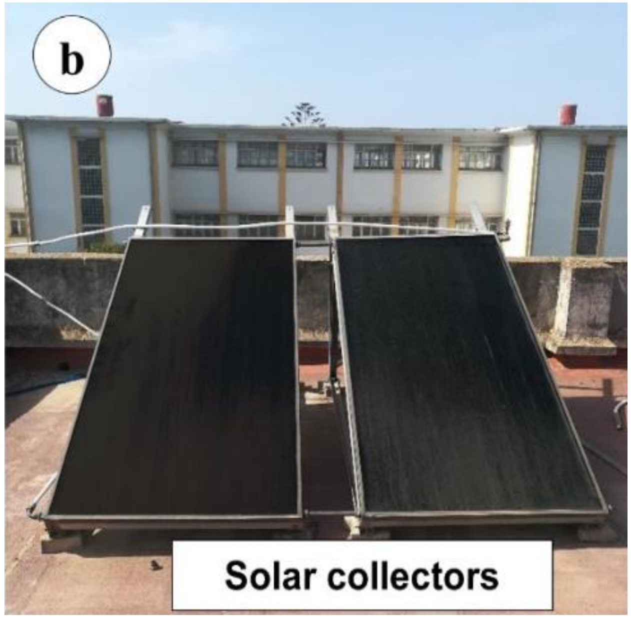


Figure 2-12 Solar collectors

Equipment	Make and Model	Size
Solar collectors	GIORDANO C8/11.SU	2 m²
Storage tank	GIORDANO KSH 200 SH	187 L
Gas boiler	Saunier Duval F25	24 kW
Circulation pump	Salmson NXL 13-25P	45 W
Circulation pump	Grundfos UPS 25-60	60 W

Table 2-1 HSGHS equipments [10]

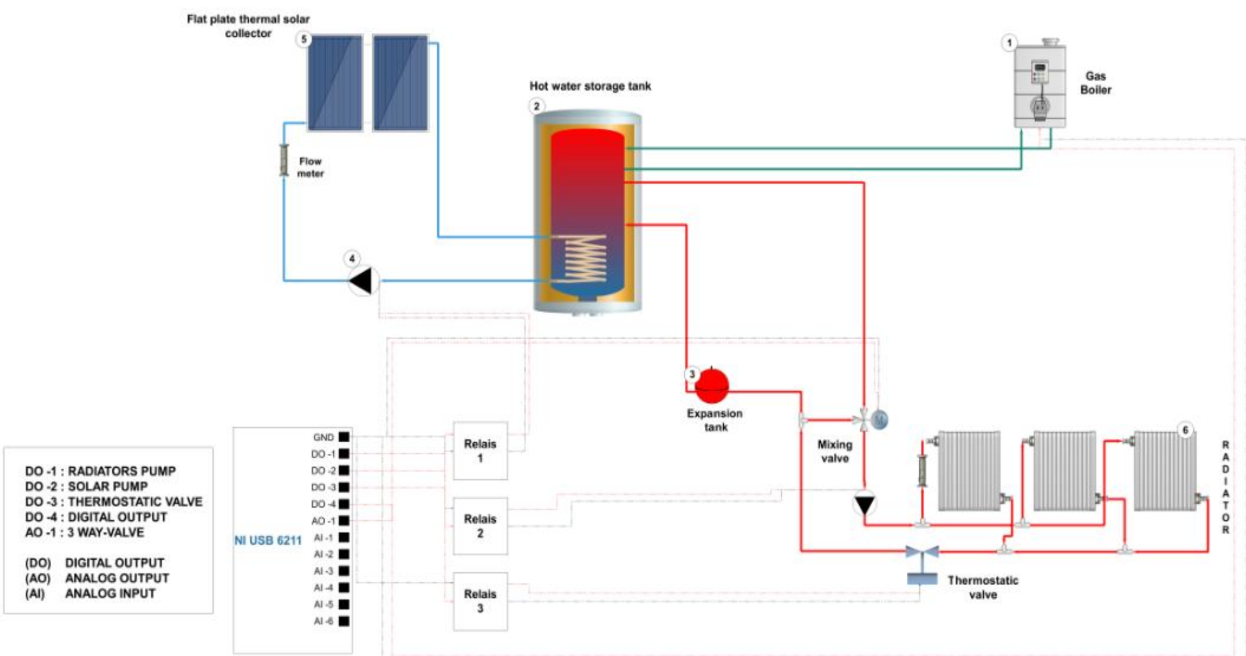


Figure 2-13 HSGHS scheme [10].

2.6.3 Openstudio Model of the HSGHS:

After ensuring the description of our system, the next step consists of working on to the HVAC system tab where we can add different heating cooling humidification dehumidification … systems associated to different thermal zones.

Figure 2-14 shows the final open model of our HSGHS formed by three circulating water loop (solar loop, boiler loop and distribution loop). The fourth loop is an air loop, which meant to describe the heat transfer between the radiators and the heating space. It worth to be highlighted that the air mass flow will not be imposed since the air is driven by the laws of **natural convection phenomena.**

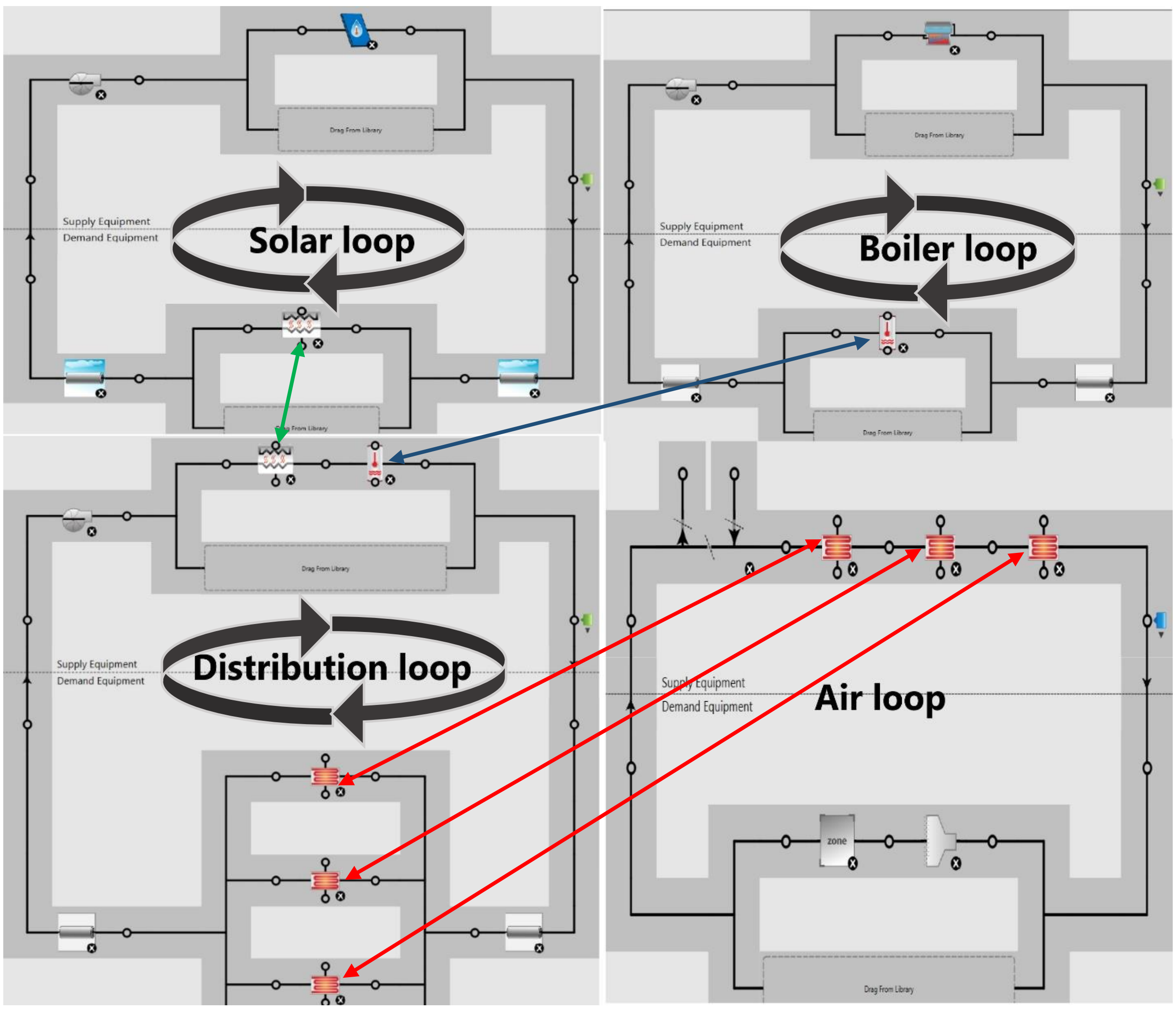
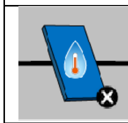
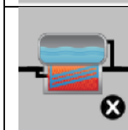
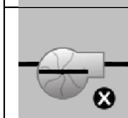
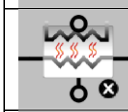
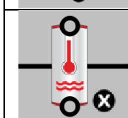
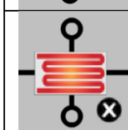
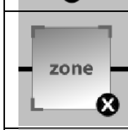
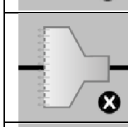
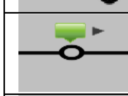
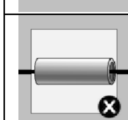
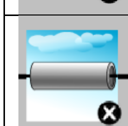
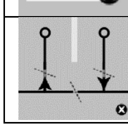


Figure 2-14 Openstudio model of the HSGHS

Table 2-2 Openstudio types of the different components

Icon	Component
	Solar Flat Plate collector
	Hot water boiler
	Constant speed pump
	Fluid-to-Fluid heat exchanger
	Water Heater
	Hot water Heating Coil (radiator)
	Thermal Zone
	Diffuser
	Temperature setpoint manager
	Indoor pipe
	Outdoor Pipe
	Outdoor Air Controller

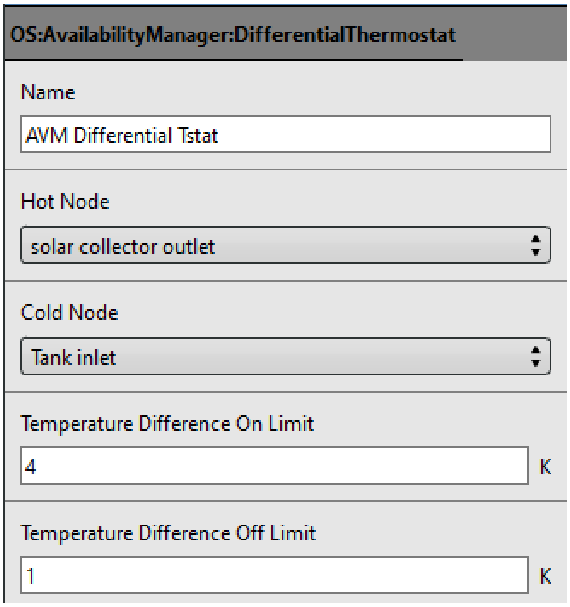
2.7 Control strategy:

In order to control the cycle on/off of each loop we use what is called the system Availability Managers (AVM). AVM are one of the high-level control tools in Openstudio, they are able to access data from any of the HVAC system nodes and use this data to set flags telling a central air system or plant loop to turn ON or OFF so they play the role of sensors and actuators combined [12].

2.7.1 The solar loop:

To ensure the good operation of the solar loop, a common control scheme is to use an AVM Differential Thermostat. It requires knowing the temperatures at the bottom of the tank T_{tank} and at the collector's outlet temperature $T_{c,o}$. When the temperature $T_{c,o}$, exceeds T_{tank} by a specific amount $\Delta \boldsymbol{T}_{\boldsymbol{ON\ limit}}$ the pump is turned on. Once the pump is ON, when the measured temperature difference falls below a specified amount $\Delta \boldsymbol{T}_{\boldsymbol{OFF\ limit}}$, the controller turns the pump OFF.

Figure 2-15 shows the AVM differential thermostat dialog box.



Algorithm of the AVM Differential thermostat:

$$\Delta T = T_{hot\ node} - T_{cold\ node}$$
$$if\ (\Delta T > \Delta T_{ON\ limit})$$
$$\{\ AVM_{status} = 1$$
$$else\ if\ \ (\Delta T < \Delta T_{OFF\ \ limit})$$
$$\{AVM_{status} = 0$$
$$else$$
$$AVM_{\text{Status}} \text{ remains in its previous state.}\}\}$$

Figure 2-15 AVM differential Thermostat dialog box

To avoid a high frequency of the ON/OFF cycle. The choice of ΔT_{ON} and ΔT_{OFF} is determined using the equation below. (11)

$$\Delta T_{OFF} \leq \frac{A_c F_R U_L}{\dot{m} C_P} \Delta T_{ON}$$

Where

A_c : is the collector area (m²).
F_R : is the heat removal factor.
U_L : is the overall heat loss coefficient (W/ (m².K))
$\dot{m}$: is the mass flow rate of the fluid (kg/s)
C_p : is the specific heat (kJ/(kg.K)).

2.7.2 The gas boiler loop:

The second control strategy is about the supply loop to the water tank, the gas boiler's pump operates until the air temperature reaches the Setpoint temperature 21°C. To avoid recurrent ON/OFF cycle, the controller works in a dead band of 1°C (hysteresis effect) so the space temperature will eventually oscillate in the range of [20.5 – 21.5] °C. Figure 2-16 shows the operation scheme of the gas boiler's pump.

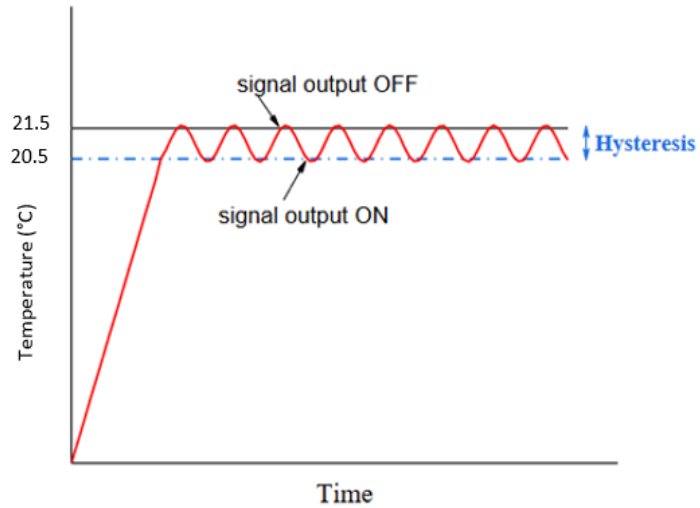


Figure 2-16 Operation scheme of the gas boiler's pump

2.8 Selecting outputs variables:

Before running the simulation, it is important to configure the simulation by setting some detailed time series data as it is very critical when studying the dynamics function of the system. The most pertinent variables in our case are the system nodes temperature, zone temperature, site outdoor air-dry bulb temperature, solar collector heat gain, boiler heat rate and mass flow rate in different loop.

In addition, we change the logging rate for each variable from Hourly to Timestep (Δt =6 min) to capture data more frequently as shown in Figure 2-17.

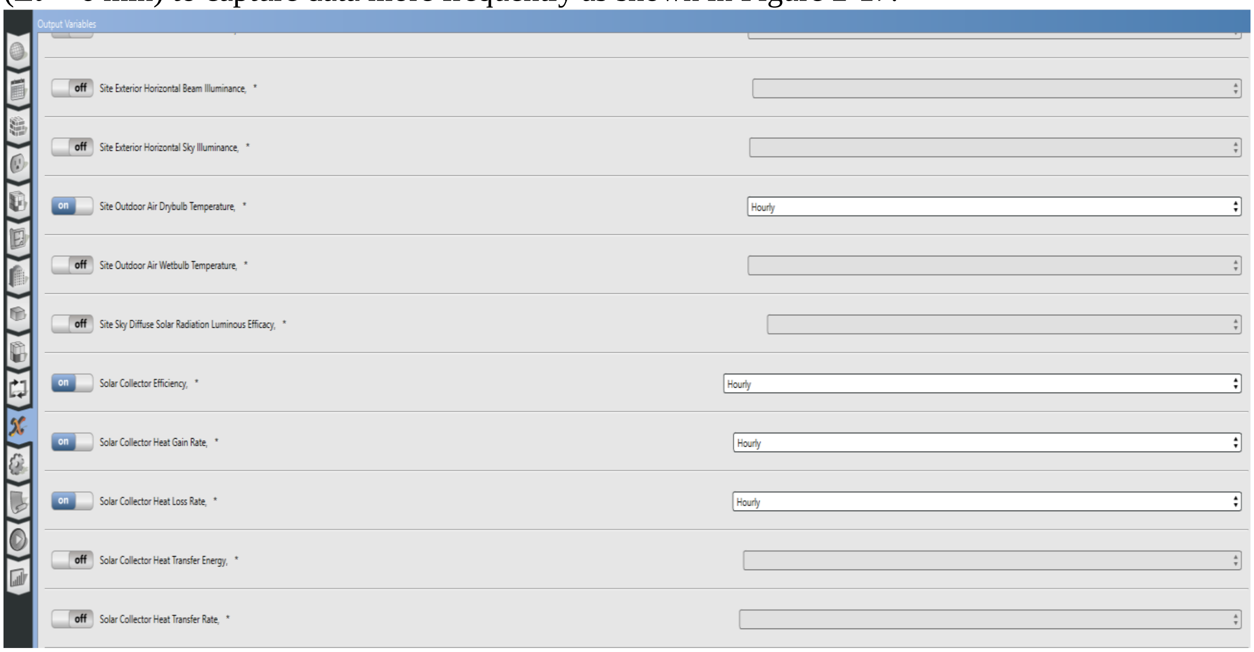


Figure 2-17 Openstudio output variables tab

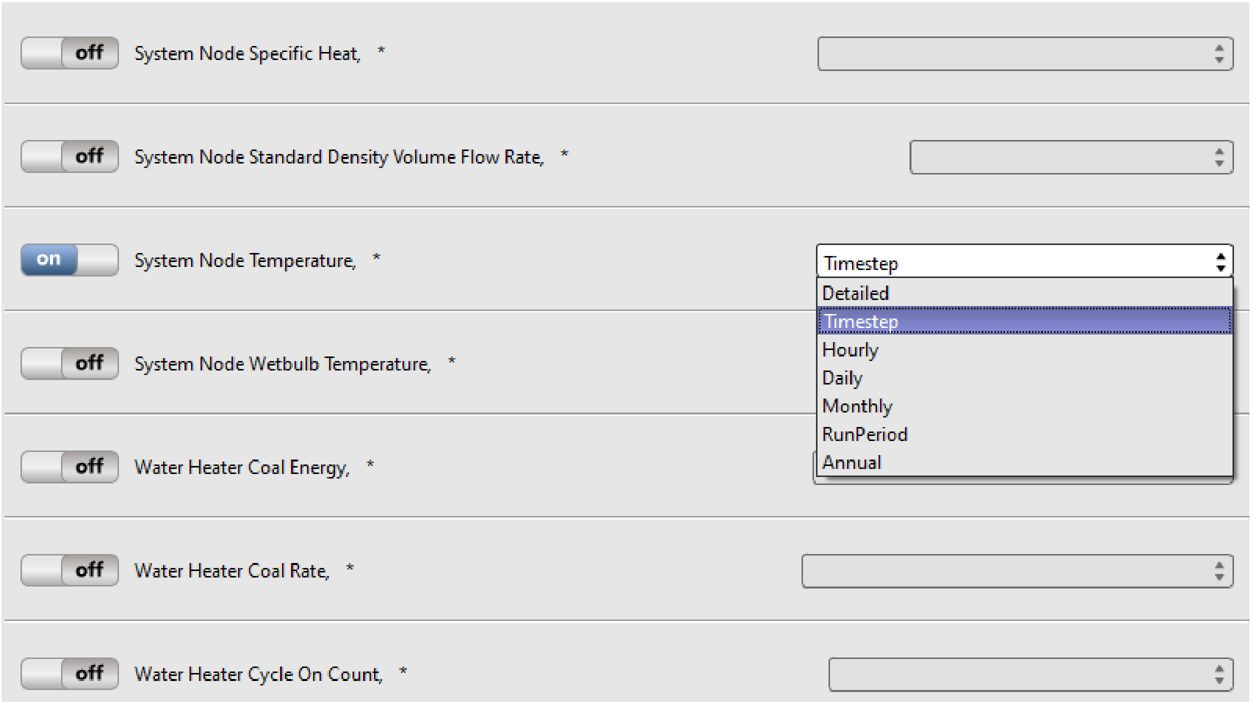


Figure 2-18 Openstudio system node temperature, timestep

2.9 Simulation results:

To illustrate the dynamics functioning of the system we show two winter days 31 January (see figure 2-19) and 15 January (see figure 2-20) with different meteorological conditions. For each we plot the important systems variables as a timestep series function namely:

- Outdoor temperature.
- Thermal zone temperature (zone 1 (the 1st floor office which is the space heated zone and unexposed to sun) and zone 3 (the corridor which is not heated and sun exposed). The choice is justified since it is interesting to show their temperature evolution along the day in conjunction with the outdoor temperature.
- Temperature in critical nodes (T outlet boiler, T water tank, T inlet radiator, T outlet radiator, T outlet collector).
- Mass flow rate in different loops ($\dot{m}$ Gas loop, $\dot{m}$ radiator loop and $\dot{m}$ solar loop), in order to check for each loop when it is on and when it is off, making it easy to follow the relationship between the excitation variables (T outdoor) and the response variables (zone temperature, nodes temperatures, masse flow rate of different loops available manager status...).

Comments and interpretation:

31 January: clearly a cold and cloudy day (outdoor temperature <9°C during the entire day) so the solar collector does not take any action since its outlet temperature never exceeds the inlet temperature of the radiator so **the available manager differential status is always OFF**. Therefore, all the heat demand is covered by the gas boiler, which operates in three cycles (from 8:00 to 10:30, from 12:15 to 13:30 and from 15:00 to 16:00). Each time the space temperature reaches 21.5°C, the gas boiler loop is turned off, and turned on when it is below 20.5°C

15 January: a sunny day where the gas boiler was needed only in the morning (from 8:00 to 10:00) and then the solar collector takes the charge from 11:00 to 16:00. Where the solar collector's outlet temperature exceeds the inlet temperature of the radiator, so **the available manager differential status is ON** and it was able to maintain the water tank temperature at 45°C. The collector heat gain exceeds the 1000 W between 12:00 and 14:00, this result demonstrates the global interest in such hybrid system.

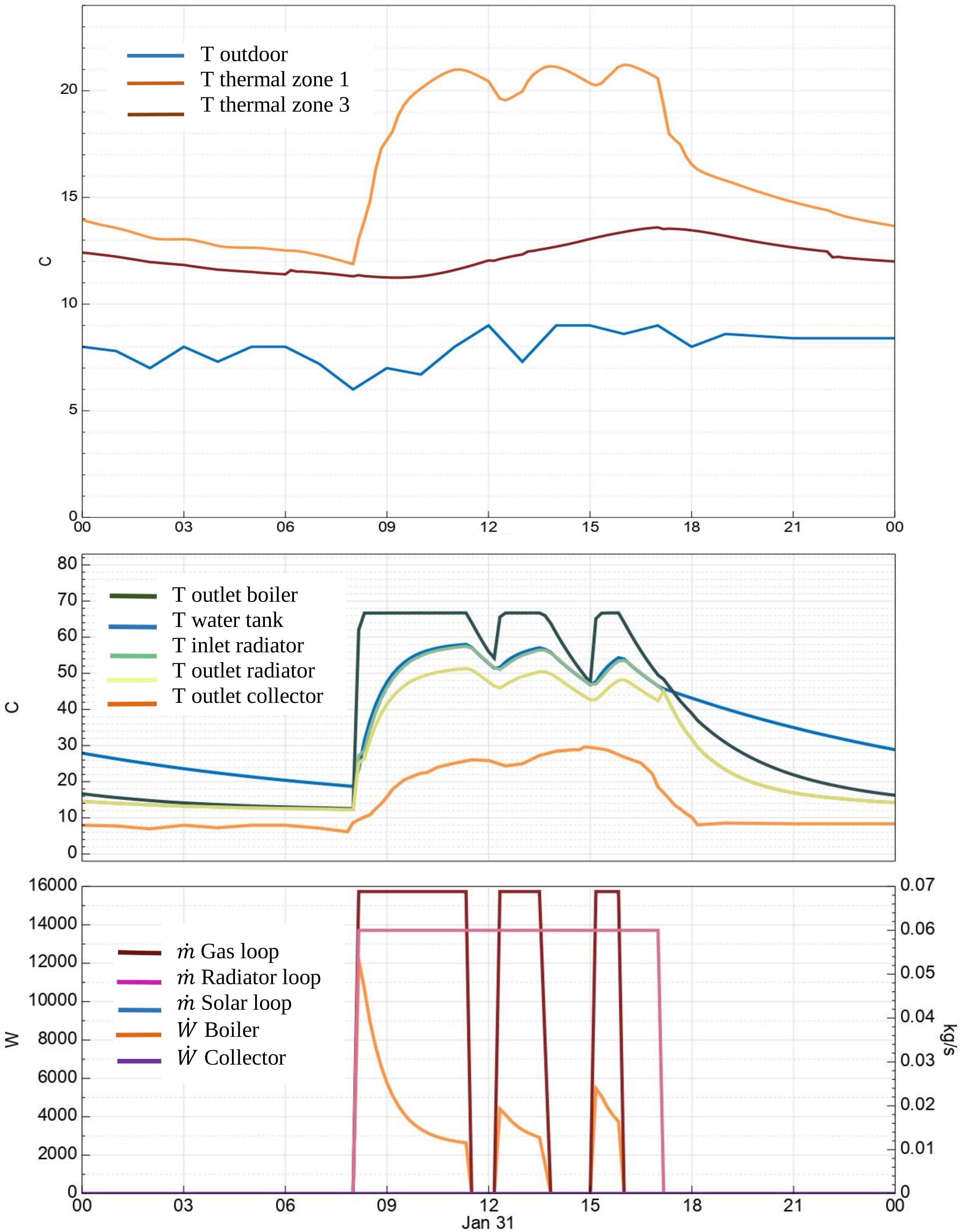


Figure 2-19 31 Jan

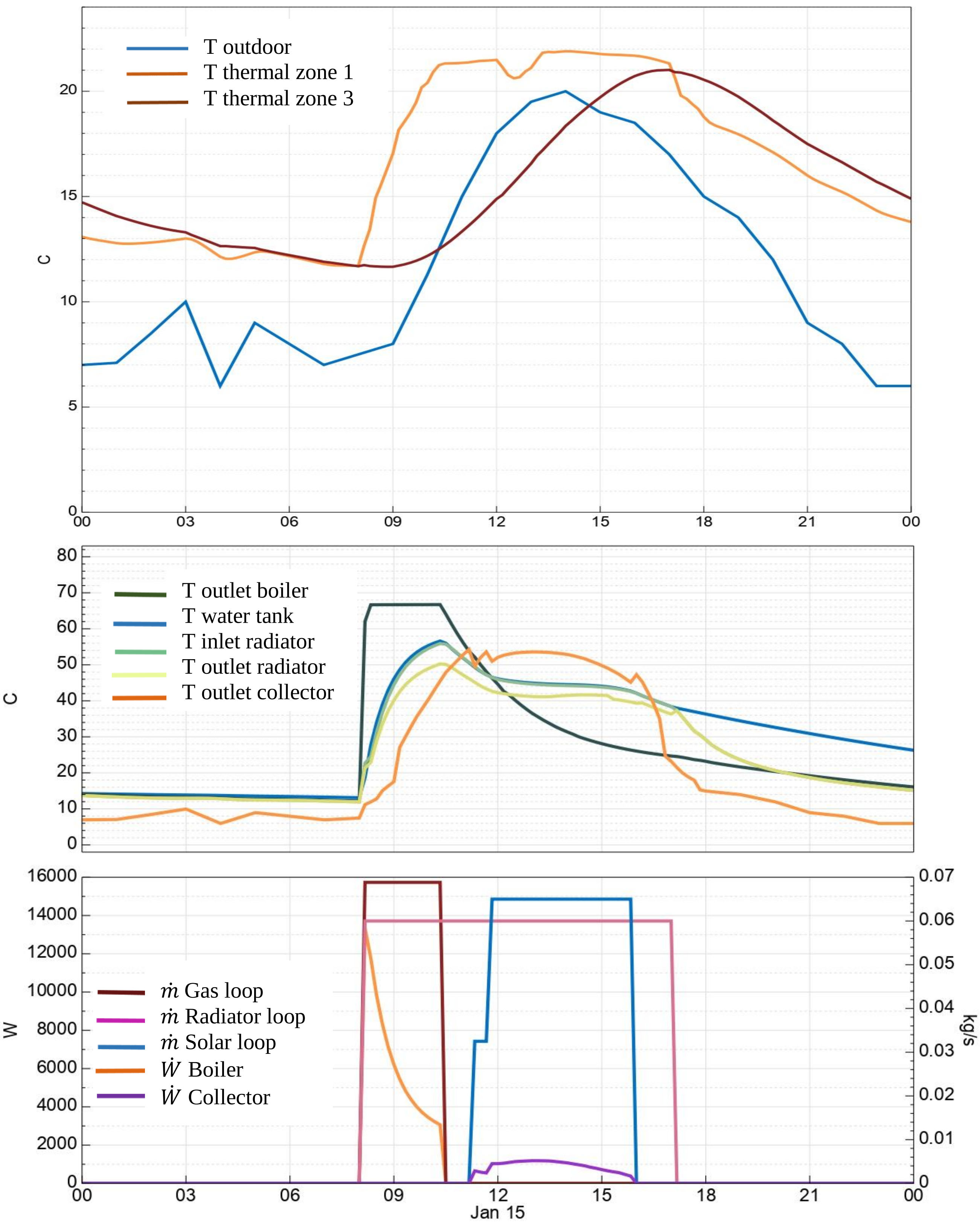


Figure 2-20 15 Jan

2.9.1 Heat exchanger design:

In order to design the heat exchanger properly we have to study the variation of the annual energy consumption with respect to the overall heat transfer coefficient of the heat exchanger.

The optimum design is the one that minimizes the annual energy consumption. To do that, we gradually change the overall heat transfer coefficient (UA) in the settings of the heat exchanger in a range of [0 100] (W/K) (see figure 2-21) and we note the corresponded annual consumption in each time we run the simulation results chart is shown in the figure 2-22:

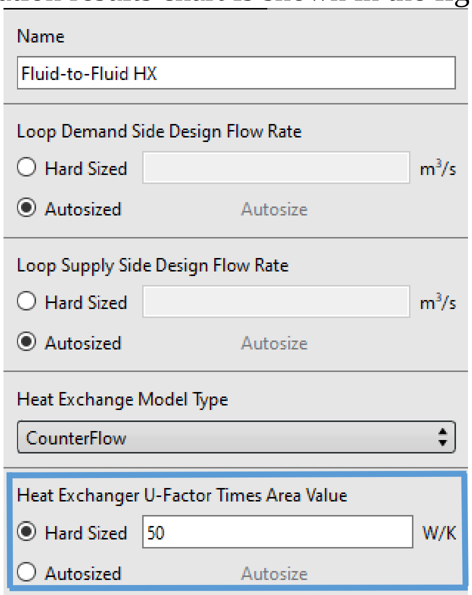


Figure 2-21 Defining the UA value for the heat exchanger

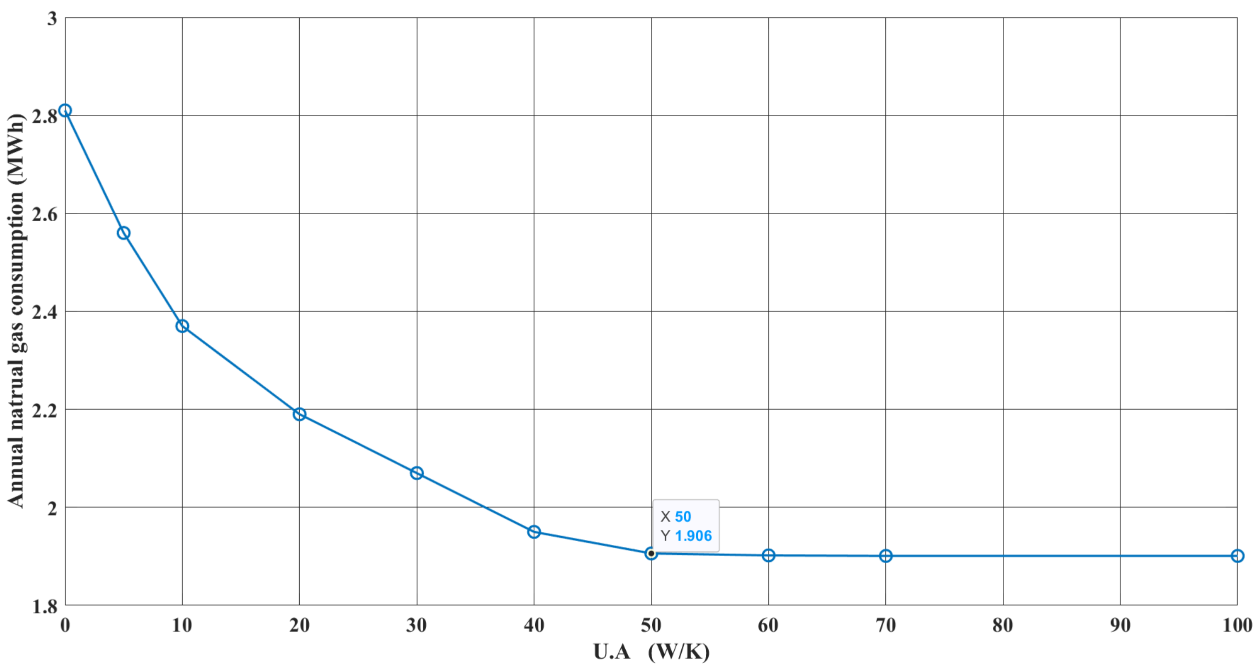


Figure 2-22 Variation of the annual energy consumption with respect to the overall heat transfer coefficient

Comments and interpretation:

- The chart shows that increasing the UA values (favouring the heat transfer between the solar collector and the storage tank) decreases the annual gas consumption exponentially from 2.81MWh when UA=0 (same as if we were in the monosource gas mode) to reach a lower limit equals to 1.905 MWh when U tends to infinity.
- One important result is that increasing the UA values above the 50 W/K does not allow us to save more energy

Therefore, the optimal heat exchanger design for this study needs to achieve a UA value in the range of [40 50] W/K, ensuring the maximum solar contribution without oversizing the heat exchanger (because that will generate much more pressure drop).

2.9.2 Monthly energy consumption:

Hybrid mode:

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Energy consumption (MWh)	0.44	0.32	0.22	0.1	0.07	0.01	0.0	0.01	0.02	0.08	0.21	0.42	1.906

Table 2-3 Monthly energy consumption in the hybrid mode

Gas mode:

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Energy consumption (MWh)	0.52	0.45	0.37	0.26	0.16	0.04	0.0	0.02	0.05	0.12	0.34	0.47	2.81

Table 2-4 Monthly energy consumption in the gas mode

2.9.3 Annual energy saving ratio (PESR):

$$PESR = 1 - \frac{Q_{hybrid} + Q_{parasitic,hybrid}}{Q_{gas} + Q_{parasitic,gas}}$$

Where:

Q_{gas} : is the amount of natural gas energy that would be needed to meet the heating load working with gas only.

Q_{hybrid} : is the amount of natural gas that would be needed to meet the load in the hybrid mode.

$Q_{parasitic}$: is the energy associated with running the other components of the system that use energy (e.g. pumps and controllers), and in each mode, we quantify the corresponded $Q_{parasitic}$

$Q_{hybrid} + Q_{parasitic,hybrid}$: is the total energy consumption in the hybrid mode.

$Q_{hybrid} + Q_{parasitic,hybrid}$: is the total energy consumption in the gas mode.

$$PESR = 1 - \frac{Q_{hybrid}}{Q_{gas}}$$
$$PESR = 32.2\%$$

2.9.4 Annual load:

$$Q_{load} = Q_{gas}.\eta_b$$

Where:
$\eta_b = 0.927$ (Efficiency of the gas boiler).

$$Q_{load} = 2.605\ MWh$$

2.9.5 Annual solar fraction (SF):

The thermal performance of solar hybrid systems is typically described in terms of the solar fraction (SF), which is defined as the percentage of the heating load that can be met by solar energy on an annual, monthly or daily basis. The equation for SF is shown below,

$$SF_{annual} = \frac{Q_{solar}}{Q_{load}}$$

$$Q_{solar} = \int q_{solar}\, dt = 1.02\ MWh$$

q_{solar}: Solar useful heat gain (W) (drawn as a time vector from the openstudio results file)
$\int q_{solar}\, dt$: is calculated using “trapz” command in Matlab

$$SF_{annual} = 39.2\ \%$$

2.9.6 Pumps sizing:

Table 2-5 Pumps sizing results table

	Pumps		
	Solar	Radiator	Gas boiler
Pressure drop ΔP (KPa)	254	330	271
Theoretical height H_{th} (m)	25.9	33.6	27.6
mass flow rate ($kg.s^{-1}$)	0.065	0.06	0.07
Power shaft W_p (W)	21.7	26	19.7
Annual Functioning time (h)	273	972	316
Annual electrical energy use (KWh)	5.92	25.27	6.23
Total electricity consumption (KWh)	37.42		

Used equations:

Pressure drop ΔP: drawn from open studio output results

$$H_{th} = \frac{\Delta P}{\rho.g}$$

Where:
$\rho = 1000\ kg/m^3$
$g = 9.81\ m.s^{-2}$

$$W_p = \frac{\Delta P.\dot{V}}{\eta_h.\eta_m}$$

Where:
$\dot{V}$: Volume flow rate ($m^3.s^{-1}$)
η_h: Hydraulic efficiency (80%)
η_h: Mechanical efficiency (95%)

The annual Functioning time also was drawn directly from Openstudio results.

2.9.7 Unmet heating hours:

Unmet load hours are any hours of operation when conditioned spaces are outside the throttling range for heating or cooling controls. That is, they are the hours in a year that the HVAC system serving a space cannot maintain space setpoint. If unmet load hours for multiple spaces coincide (occur in the same hour), they are counted as only one unmet load hour for the building.
ASHRAE Standard 90.1-2007 imposes limits on unmet load hours in the design process as follows:
"Unmet load hours for the proposed design or baseline building designs shall not exceed 300 (of the 8760 hours simulated), and unmet load hours for the proposed design shall not exceed the number of unmet load hours for the baseline building design by more than 50. If unmet load hours in the proposed design exceed the unmet load hours in the baseline building by more than 50, simulated capacities in the baseline building shall be decreased incrementally and the building resimulated until the unmet load hours are within 50 of the unmet load hours of the proposed design. If unmet load hours for the proposed design or baseline building design exceed 300, simulated capacities shall be increased incrementally and the building with unmet loads resimulated until unmet load hours are reduced to 300 or less. Alternatively, unmet load hours exceeding these limits may be accepted at the discretion of the rating authority provided that sufficient justification is given indicating that the accuracy of the simulation is not significantly compromised by these unmet loads" [13].

In our case, the unmet load hours will simplify to what is known as the unmet heating hours since we our installations is a heating systems in another word the unmet load hours is the more general term that is used we have heating and cooling.
Therefore, the annual corresponded unmet heating hours of our installation will be defined as the cumulative time where the space temperature is below 20.5°C that gives us 29 hours of unmet heating from 972 hours of heating in total. That gives us a ratio of 3% which is below the limit imposed by "ASHRAE standard 90.1-2007" (300/8760≈ 3.4%), so we will not have any conformity issues.

2.9.8 Levelized cost of heat:

When it comes to the economic aspect of the HSGHS, Levelized Cost of Heat (LCOH) is wildly used as an economic indicator. LCOH is derived from the levelized cost of energy, it is used to assess the costs of heat production over the lifetime of a solar thermal system and to compare different technological solutions. The LCOH can be estimated using the following formula [10].

$$LCOH = \frac{I_0 - S_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}}$$

$$C_t = O + M$$

Where
I_0 : Initial investment in DA.
S_0 : Subsidies and incentives in DA,
E_t : Final energy demand per year in kWh,
T : Period of analysis in years.
r : Discount rate (%)
C_t : The total yearly operation and maintenance costs in DA.
O : Represents the operation costs corresponding to the power consumption of the pumps, which depends on electricity price and of consumption of natural gas for the boiler gas and its price.
M : Represents the maintenance costs and is usually $0.01I_0 < M < 0.02I_0$ [10].

Numerical application:
The initial investment appears in the solar collector and the gas boiler other equipment are insignificants

- Solar collector type GIORDANO C8/11.SU cost around 55000 DA/m^2

Gas boiler type Saunier Duval F25 24 kW cost around 100000 DA
Therefore, for the hybrid installation we will have $I_0 = 55000 \times 4 + 100000 = 320000\ DA$
However, for the mono source installation we will have $I_0 = 100000\ DA$

- No Subsidies so $S_0 = 0$
- The final energy demand is calculated previously: $E_t = Q_{load} = 2605\ kW$
- The expected period of analysis is about 20 years with a suggested discount rate of 2%.
- The total yearly operation costs for hybrid mode is $C_t = 932\ DA$ and 1262 DA for gas mode
- The maintenance costs are generally estimated as 1% to 2% of the initial investment

By applying the formula, we get:
For the hybrid mode $LCOH = 9.56\ DA/kWh$ and 4.52 DA/kWh for the gas mode
Comment:
The numbers tell us that over the period of analysis the hybrid solar installation is unable to justify itself in term of economical aspect but there is obviously more aspects to consider namely the environmental aspect. In addition, when we consider the development in the industry of renewable energy, such components will be within reach and less expensive in the coming few years.

2.9.9 Comparison between the hybrid mode and gas mode:

Table 2-6 summarizes the comparison between conventional systems that operate with gas only and the HSGHS. The natural gas consumption decreases by 32.2%, reducing the energy bill by 330 DA per year. In addition, the operation time of the gas boiler is remarkably reduced from 378 h to 316h.

Table 2-6 Comparison table hybrid vs mono source gas

	Hybrid mode	**Gas mode**
Annual Natural gas consumption (kWh)	1905	2810
Annual Natural gas cost (DA)	732	1080
Annual electricity consumption (kWh)	37.42	34.2
Annual electricity cost (DA)	200	182
Annual cost (DA)	932	1262
Gas boiler functioning time (h)	316	378
LCOH (DA/kWh)	9.56	4.52

2.10 Uncertainty in building thermal performance modelling

Although we did take into consideration several practical aspects namely the control strategy, heat losses and pressure drop in pipes, exact building design and construction using Open studio plug in for sketchUp, there are still several factors that contribute to the uncertainty of the building simulation models which we could not control. For instance, the simulation software itself, software user's knowledge or simulation skills may be sources of uncertainty. In addition, the input parameters such as weather data and thermo-physical properties, since these parameters are always expressed under a certain part of uncertainties, this could be correlated to the lack of detailed information related to the occupant behaviour, equipment scenario, sub-metering instruments, and the complete as-built drawings, which could help in developing a detailed and accurate model. The stochastic nature of occupant behaviour often leads to the largest source of uncertainty in the building simulation, in addition to its large influence on energy consumption. Moreover, incomplete and fragmented weather data used for the creation of real weather files could lead to some uncertainties in the collected data and thus in the simulation results [10] p39.

2.11 Conclusion

In this chapter, we succeeded in simulating the dynamic behaviour of the solar gas hybrid heating system using Openstudio. Starting from 3D modelling of the building using sketchup, setting the associated materials of construction, assigning thermal zones, modelling the HSGHS by importing different components from the HVAC, implementing a convenient control strategy using the available managers (playing the role of sensors and actuators). Finally, tracking the simulation results in real time (masse flow rate, temperature in different nodes) gives us the impression as if we are in experimental tests at zero cost and that is the power of simulation.

In the end of the chapter, we compared the hybrid mode and the gas mode in terms of overall performance, where we demonstrate that with the hybrid system the annual gas consumption decreases by 0.904 MWh (that is 32.2%), reducing the energy bill by 330 DA per year.
The operating time of the gas boiler is also reduced (which eventually increases its lifetime). Surely that is not enough compensation for the initial investigations from an economical point of view but with the continuous development in the industry of renewable energy, such components will be within reach.

3 Chapter 3 Analytical validation

3.1 Introduction

In this chapter, we develop a numerical based model to predict the performance of the HSGHS (Qconsumption, SF and PESR). Where we have used the BIN method to calculate the heat demand in the building, combined with Liu and Jordan's model to calculate the available solar radiation in the solar thermal collector, This model will eventually validate the previously established openstudio model. By the end of this chapter, we present an automated application with graphical user interface using Matlab app designer.

3.2 Evaluation of the annual energy consumption using the Bin method:

3.2.1 Presentation of the method:

The "bin method" is the "hand" calculation procedure for heating or cooling load, where monthly weather data is sorted into discrete groups (bins) of weather conditions. Each bin contains the number of average hours of occurrence in a month or year of a particular range of weather conditions.

The bin method is recommended because this method has the ability to perform instantaneous heating and cooling energy calculations at many different outdoor dry bulb temperature conditions (bin). This approach takes into account infiltration latent load, and is based on hourly weather data rather than daily averages, which makes it more accurate compared to the degree-day method [22].

Energy consumption is calculated for each bin of outdoor temperature, and multiplied by the number of hours of occurrence of the corresponded bin.
The equation for the calculation is shown below:

$$Q_{Bin} = N_{Bin} U_{tot} (T_{eq} - T_{ext\,,Bin})$$

Where, N_{Bin} is the number of hours for a given temperature range (Bin), in which the average outdoor temperature is $T_{ext,Bin}$.
T_{eq} is given by:

$$T_{eq} = T_i - \frac{Q_i}{U_{tot}}$$

T_{eq} : representing the outdoor temperature to which the heat losses of given space are entirely compensated by the internal heat source q_i.
From ASHRAE Energy standards, $\boldsymbol{T_i}$ **= 21 °C**, is recommended to ensure the **thermal comfort** of the space.
The resulting annual energy consumption Q is given by:

$$Q = \sum Q_{Bin}$$

3.2.2 Estimation of the overall heat exchange coefficient:

The building has an ancient construction (1925), the internal walls of the building consist of three layers, inner and outer layers 20 mm of gypsum plaster separated by hollow brick masonry with a thickness of 150 mm having a U-value of 1.715 W/m².K. The external wall is made of 500 mm reinforced concrete, the outer layer made of cement mortar 20 mm and the inner layer 20 mm of gypsum plaster. Its U-value is 1.924 W/m².K. The windows of the office are single glazing windows with a U-value of 5.69 W/m².K. From the building specifications, we can observe that the building envelope has week insulation and thus important heat losses [10] p53.

Table 3-1 summarizes the building envelope specifications:

Table 3-1 Building specifications

Surfaces type	Structure	U value $(W/m^2.K)$	R value $(K.m^2/W)$
Internal walls	20 mm gypsum plaster (inner) + 150 mm hollow brick masonry + 20 mm gypsum plaster (outer)	1.715	0.5831
External wall	20 mm gypsum plaster + 500 mm reinforced concrete + 20 mm cement mortar	1.924	0.5198
Ground	750mm concrete	0.75	1.3333
Ceiling	25 mm + 250 mm concrete slab C600	0.759	1.3175
Window	Single glazing 6 mm	5.69	0.1757

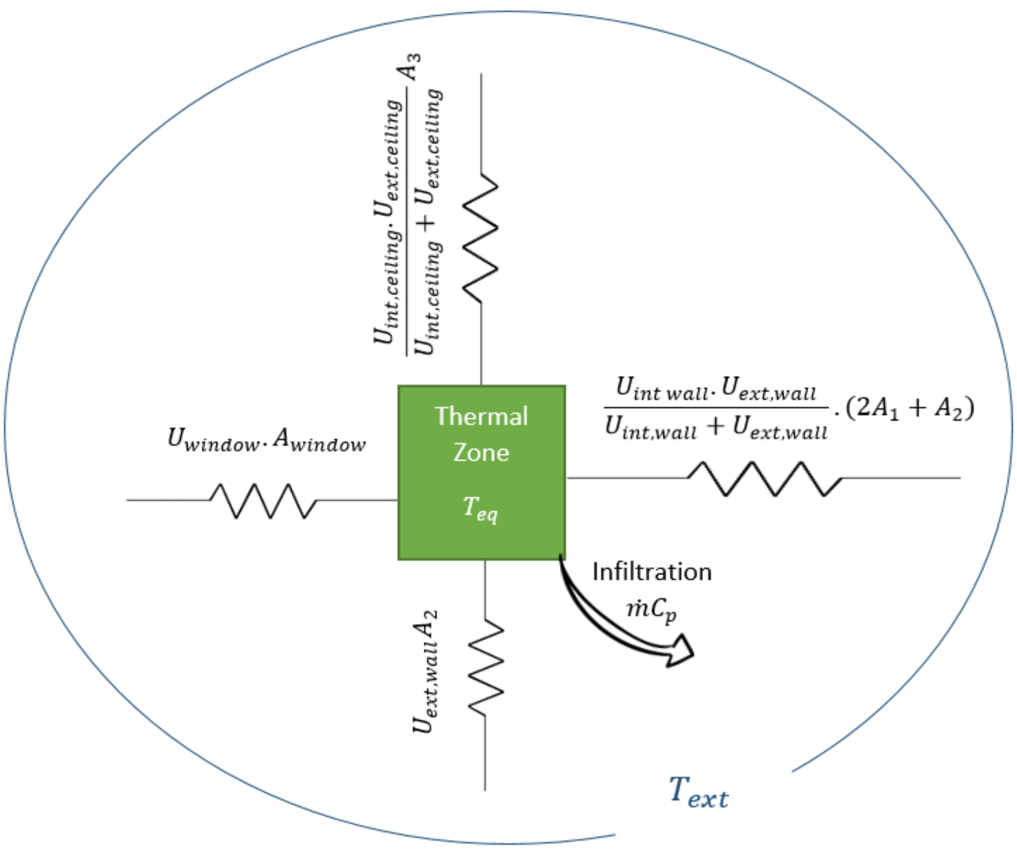


Figure 3-1 Thermal resistance representation of the building

$$U_{tot} = \sum_i U_i A_i + \dot{m}c_p$$

$$\boldsymbol{U_{tot} = 274.4\ W/K}$$

Table 3-2 T Bin table

Interval (°C)	Mean T (°C)	N Bin (h)	N Bin (h) From 8: 00 until 17: 00
0-1	0.5	5	1
1-2	1.5	15	5
2-3	2.5	23	5
3-4	3.5	51	14
4-5	4.5	65	17
5-6	5.5	100	30
6-7	6.5	127	24
7-8	7.5	206	51
8-9	8.5	227	52
9-10	9.5	309	78
10-11	10.5	307	88
11-12	11.5	329	81
12-13	12.5	348	95
13-14	13.5	355	109
14-15	14.5	405	136
15-16	15.5	409	111
16-17	16.5	393	130
17-18	17.5	425	169
18-19	18.5	399	163
19-20	19.5	407	179
20-21	20.5	410	159
21-22	21.5	389	149
22-23	22.5	339	141
23-24	23.5	324	155
24-25	24.5	245	112
25-26	25.5	247	129
26-27	26.5	193	95
27-28	27.5	172	93
28-29	28.5	159	79
29-30	29.5	159	85
30-31	30.5	128	73
31-32	31.5	98	54
32-33	32.5	65	44
33-34	33.5	31	19
34-35	34.5	17	10
35-36	35.5	11	7
36-37	36.5	10	5

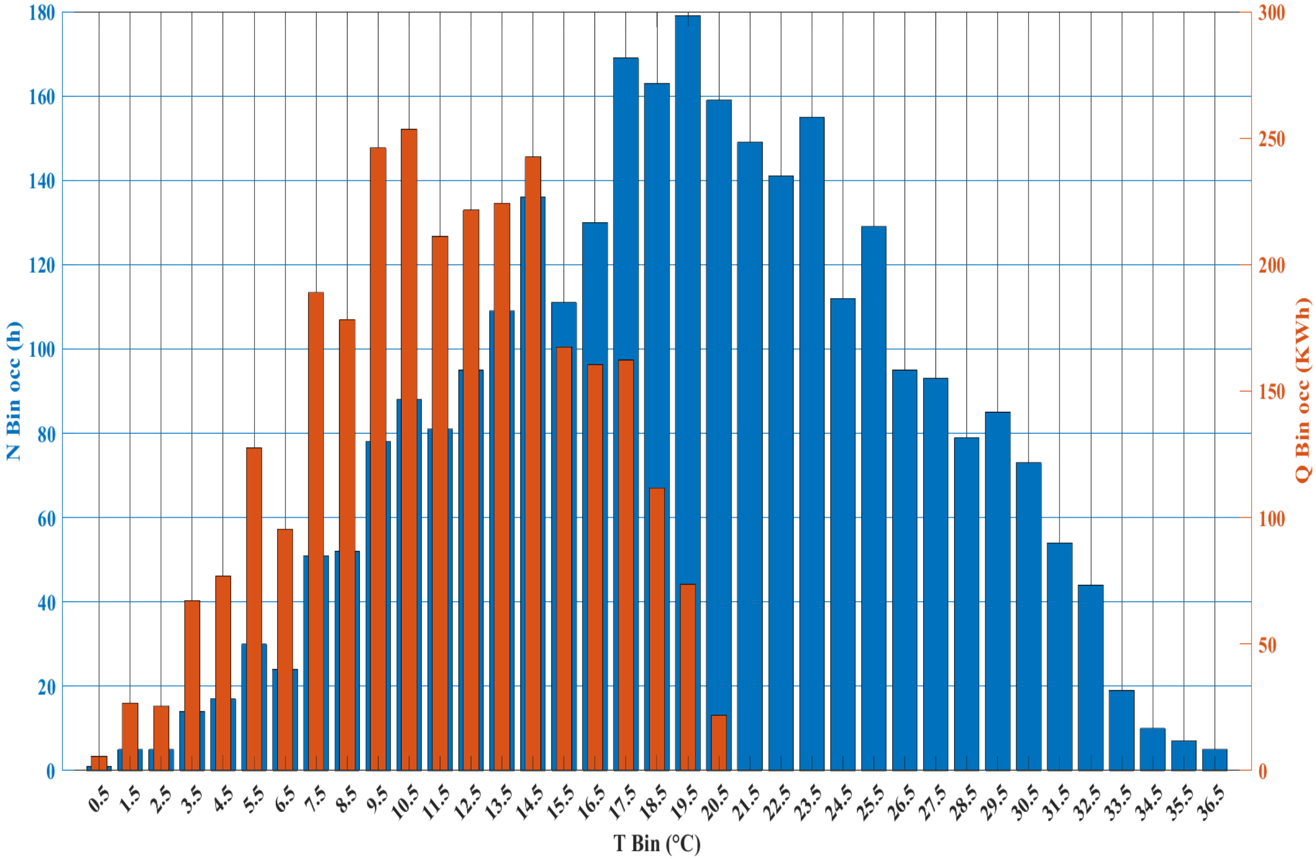


Figure 3-2 Bin Chart

$$Q_{load} = \frac{5}{7} \sum N_{Bin,occ} U_{tot} \left(T_{eq} - T_{ext,Bin}\right)$$

We multiplied it with 5/7 to exclude the weekend days from calculation.

The sum will be computed only where $T_{ext,Bin} < T_{eq}$ (winter period), we do not need heating while $T_{ext,Bin} > T_{eq}$.

In our case we take $T_{eq} \approx T_i = 21\ °C$ since we do not have a huge density of occupancy so the internal heating source will be neglected ($q_i \approx 0$)

The annual demand will be:

$$\boldsymbol{Q_{load} = 2.064\ MWh}$$

3.2.3 Alternative method:

We should note that we could have calculated the Q consumption in any period by integration (without rearranging the temperature's values in BINs) as follow:

$$Q_{load} = \int_{t_i}^{t_f} U_{tot} \left(T_{eq} - T_{ext}(t)\right) dt$$

$$Q_{load} = \frac{5}{7} U_{tot} \sum_{i=1}^{365} \int_{8:00}^{17:00} \left(T_{eq} - T_{ext}(t)\right) dt$$

And since T_{ext} is defined by discrete values, therefore a numerical integration is necessary

In this case, we compute the given integral with the trapezoidal integration by using the command "trapz" in Matlab:

$$\boldsymbol{Q_{load} = 1.947\ MWh}$$

Comment:

The two method gives practically the same result with a relative error of $\pm 5\%$ but it is definitely the alternative method that gives more precise results since working with the bin method is equivalent to computing the integral using the rectangle method which is less accurate than trapezoidal or Simpson integration.

3.3 Computation of the solar radiation flux through the solar collector:

3.3.1 The incidence angle (θ):

The incident angle θ is given by:

cosθ = sinδ sinϕ cosβ- sinδ cosϕ sinβ cosγo+ cosδ cosϕ cosβ cosω+ cosδ sinϕ sinβ cosγocosω+ cosδ sinβ sinγo sinω

Where:

θ : Incidence angle
δ : Declination
φ : Latitude
β : Slope of the collector
γ_s : Solar azimuth angle
γ_0 : Surface azimuth angle
ω : Hour angle
θ_z : Solar zenith angle

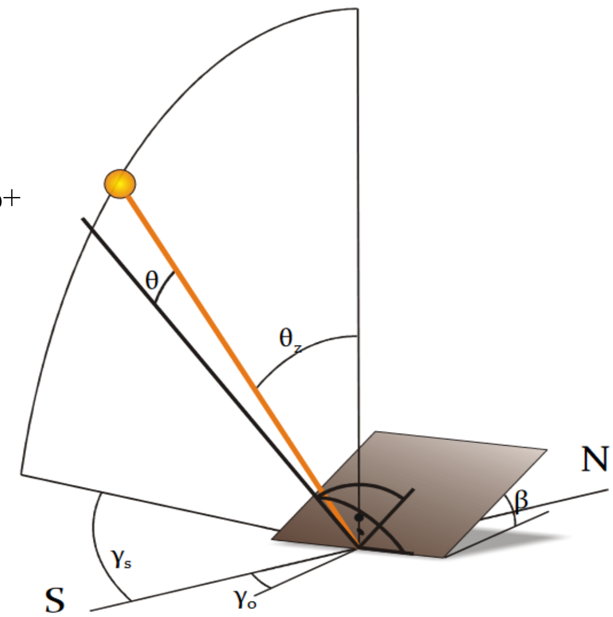


Figure 3-3 Solar angles

In our case the collector surface is facing towards south with a tilt angle equal to the latitude ($\gamma_0 = 0$ and $\beta = \emptyset$)

Therefore, the incident angle will be:

$$\cos(\theta) = \cos(\delta).\cos(\omega)$$
$$\delta = 23.45° \sin\left(360° \frac{284 + n}{365}\right)$$
$$\omega = 15°(AST - 12)$$

n : Day number.

AST: Apparent Solar Time.

Conversion from the local standard time (LST) to the apparent solar time to (AST):
In order to convert from standard time to the apparent solar time two corrections are needed [15]:
1) Correction for difference in longitude between observer's meridian and the meridian at which local standard time is based.
2) Correction from the equation of time which accounts for perturbations in the earth's rate of rotation.

The equation used to calculate solar time is below:

$$AST = LST + 4(L - L_{st}) + E \quad \text{(hour)}$$

LST : The local standard time
L : The longitude of the location in question.
L_{st} : The standard meridian for the local time zone.
$L = 3.25°$, $L_{st} = 15°$ $(GMT + 1)$ For Algiers.
E : The equation of time in hour.
Which can be determined from the equations below (16):

$$E = \frac{720}{\pi}\big(0.000075 + 0.001868\cos(B) - 0.032077\sin(B) - 0.014615\cos(2B) - 0.04089\, sin\,(2B)\big) \qquad (hour)$$

3.3.2 Available solar radiation on tilted surface:

Using the radiation data collected from CAMS Copernicus Atmosphere Monitoring Service, the available solar radiation on the collectors can be estimated, first by calculating the solar irradiance, denoted it, on the tilted surface, the collectors' array, and then multiplying it by the surface.

The solar irradiance can be calculated using Liu and Jordan model because the model takes into account the measurements of the solar irradiance (diffuse and global radiations received on horizontal plane). In addition, the model takes into consideration not only the clarity of the sky but also the isotropy of the sky [10].

$$G_t = G_b R_b + G_{d,h}\left(\frac{1 + \cos(\beta)}{2}\right) + \rho_g G_h\left(\frac{1 - \cos(\beta)}{2}\right)$$

Where G_b, $G_{d,h}$ and G_h are respectively the global direct normal, horizontal diffuse and total horizontal radiation, ρg is the ground reflectance, β is the slope of the collectors and R_b is the ratio of the beam radiation it depends on the incidence angle θ and the zenith angle θ_z which varies for each day and location.

$$R_b = \frac{\cos(\theta)}{\cos(\theta_z)}$$

Figure 3-4 present the variation of the available solar radiation on tilted surface for some selected days:

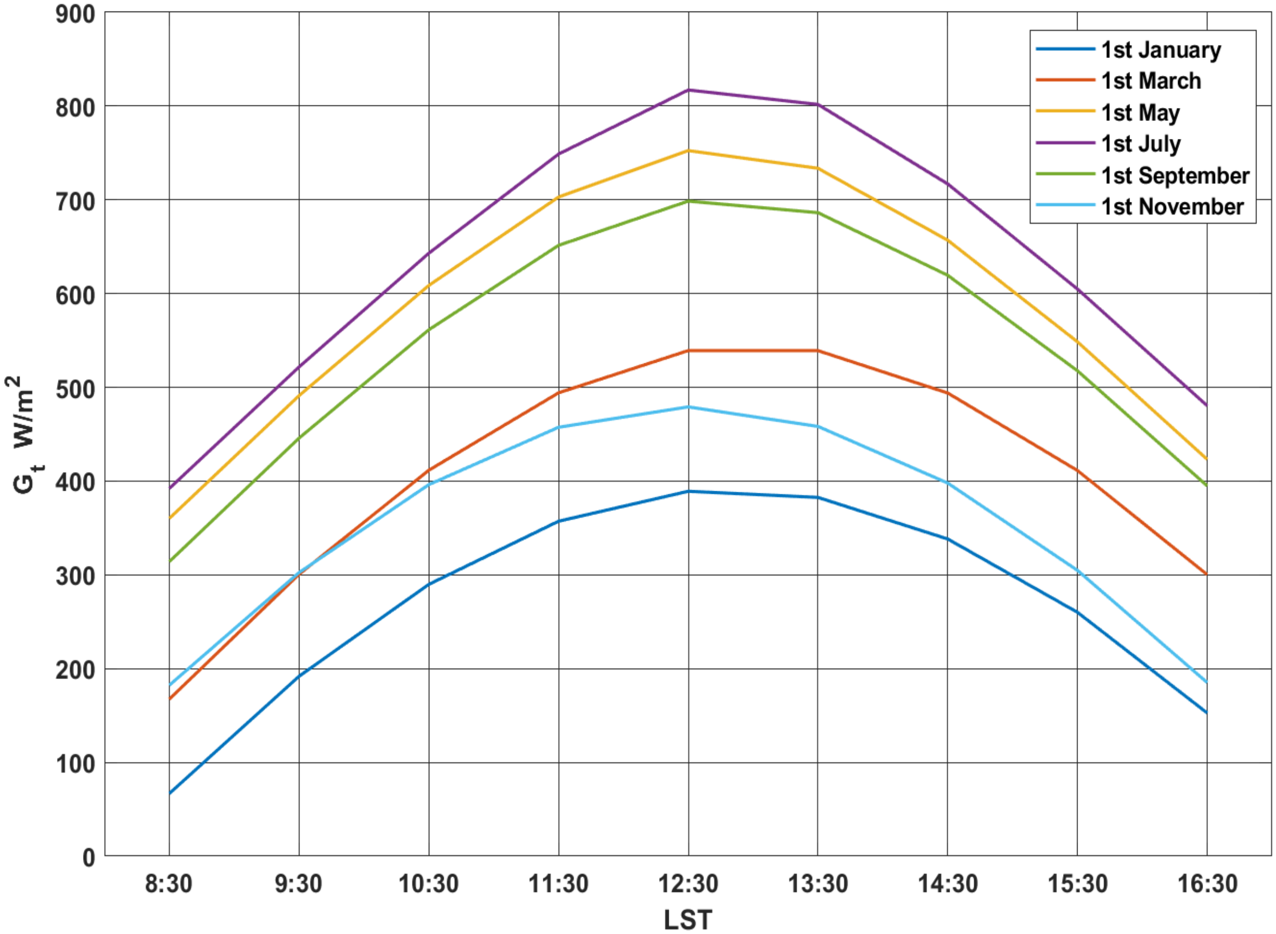


Figure 3-4 Available solar radiation for selected days

3.4 Thermal balance of the solar hybrid system:

$$Q_{\text{consumption}} = \frac{Q_{\text{load}} - Q_{solar}}{\eta_b}$$

η_b : Efficiency of the gas boiler

$$Q_{\text{solar}} = \eta_c \, G_t A_c$$

Where the efficiency of our thermal collector is given by:

$$\eta_c = \eta_0 - \frac{a_1}{G_t}(T_a - T_\infty) - \frac{a_2}{G_t}(T_a - T_\infty)^2$$

Where;

η_0 : The optical efficiency.

a_1 , a_2 : Respectively the 1st and 2nd order heat loss coefficient of efficiency.

G_t : The total available radiation calculated previously.

Solar collector's specifications and thermal characteristics are shown in the table below:

Table 3-3 Solar collector's characteristics

Collector Model	C8/11.SU
Gross area (m²)	2.1
Aperture area (m²)	2.0
Absorber area (m²)	1.97
Max service pressure (bars)	6
Gross dimensions l x w x h (mm) :	2002 x 1050 x 75
ntercept efficiency η0 (dimensionless)	0.73
1st order heat loss coefficient a1 (W/m².K)	4.003
2nd order heat loss coefficient a2 (W/m².K²)	0.015
Conventional stagnation temperature Tstg (°C)	126

Supposing that the absorber temperature is at $T_a = 40°C$ so we can calculate the solar heat gain as follow:

$$Q_{solar}(t) = \left(0.73 \times G_t(t) - 4.003\left(T_a - T_\infty(t)\right) - 0.015.\left(T_a - T_\infty(t)\right)^2\right) \times 3.94 \quad (W)$$

3.5 Simulation results:

Dynamic simulation of the system's variables with a time step $\Delta t = 1\ hour$ is implemented using Matlab and the complete sheet of results is exported to an EXCEL file.

See figure 3-5 present the simulations results (q demand, q solar, q consumption, SF) for selected days (1st January, 15th January, 31th January, 5 February).

Note that decreasing the simulation time step will not increase the precision since the meteorological data are available with a time step $\Delta t = 1\ hour$

3.6 Results analysis:

In order to analyse the system's performance let us take a close look at some typical days with different meteorological conditions see figure 3-5:

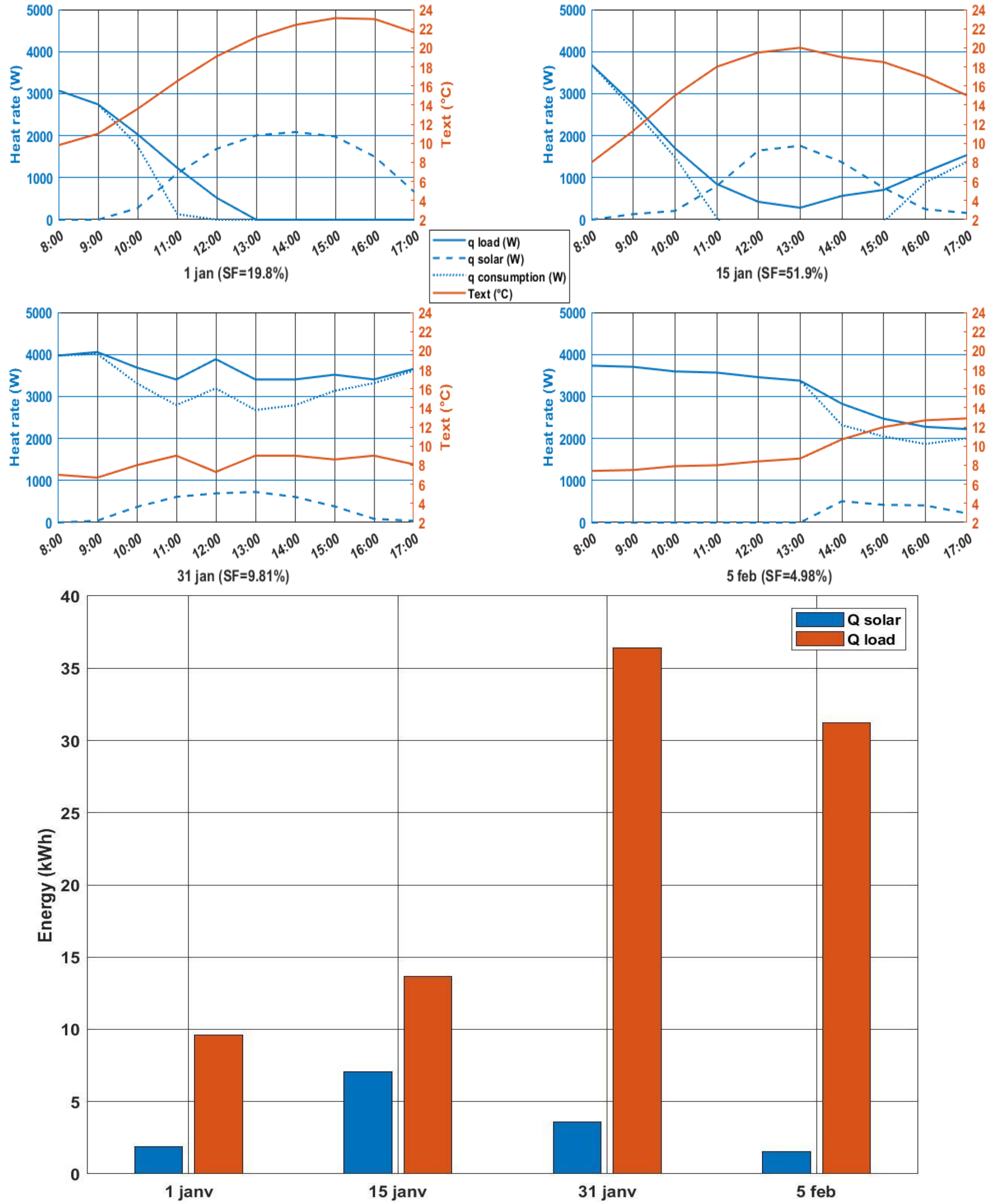


Figure 3-5 Simulation results for selected days

1st January: we did not get so much energy from the solar collector SF=19.5% since all the heat demand was in the period from 8:00 to 11:00 while the solar collector is still not warm yet after that the outdoor temperature exceed 21°C so there was no need for heating.
15th January: a perfect day for the solar collector, where there is a good solar exposure while the outdoor temperature is low. Therefore, we did get a solar fraction of 51.9%.
31st January: good sunshine and medium heat demand that gives us a solar fraction of 9.81%
5th February: cloudy day combined with very low outdoor temperature ~10°C, the solar collector was not used (SF=5%).

Variation of the solar fraction with respect to the tilt angle:

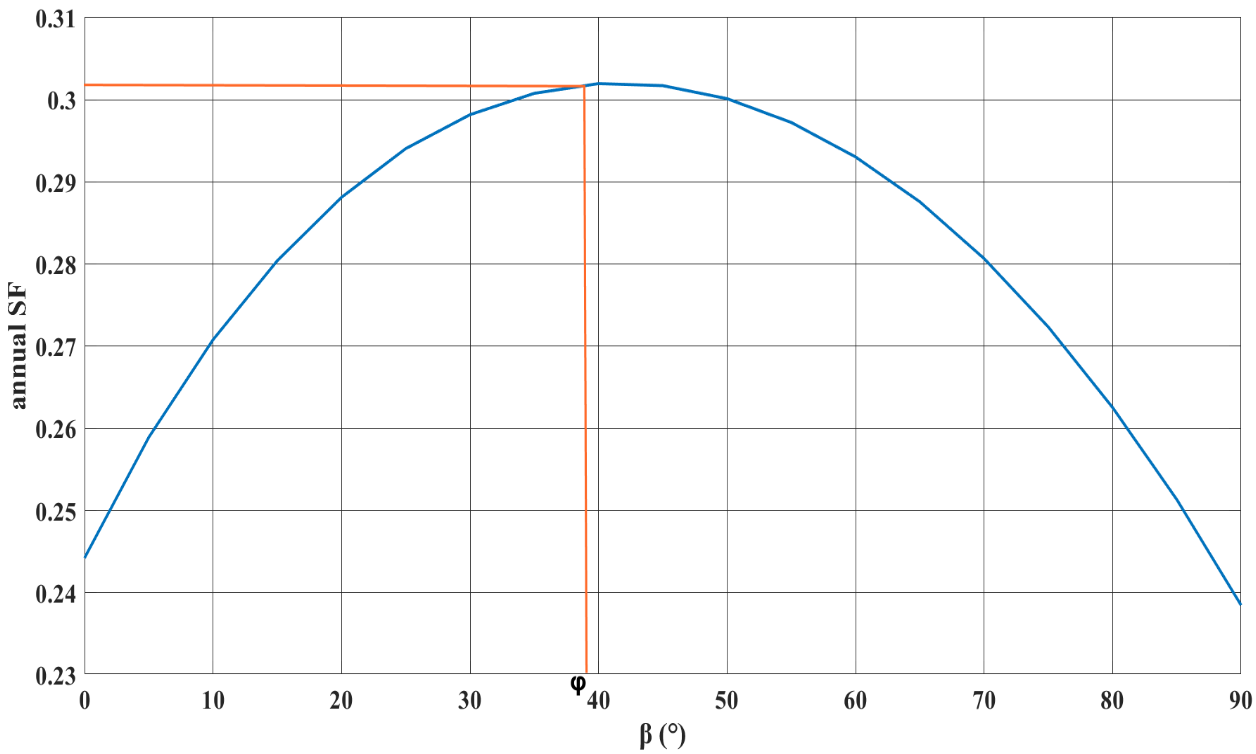


Figure 3-6 Variation of the solar fraction with respect to the tilt angle

Comment:

It is not surprising that the maximum annual solar fraction is accomplished when the tilted angle β equals to the latitude angle, the aim of this step of the calculations was to validate our model by arriving to this result.

3.7 Presenting the graphical user interface (GUI):

Now that the needed calculations are established, the next step consists automating our work into a graphical user interface, for that matter we used the “Appdesigner” in Matlab to design and customize the app. The source code is available in the appendix.

3.7.1 GUI different tabs:

Site tab: here we import the appropriate weather file(in TMY3 format), once you enter the weather file, the site name, latitude, longitude, time zone, and the elevation will be automatically detected.

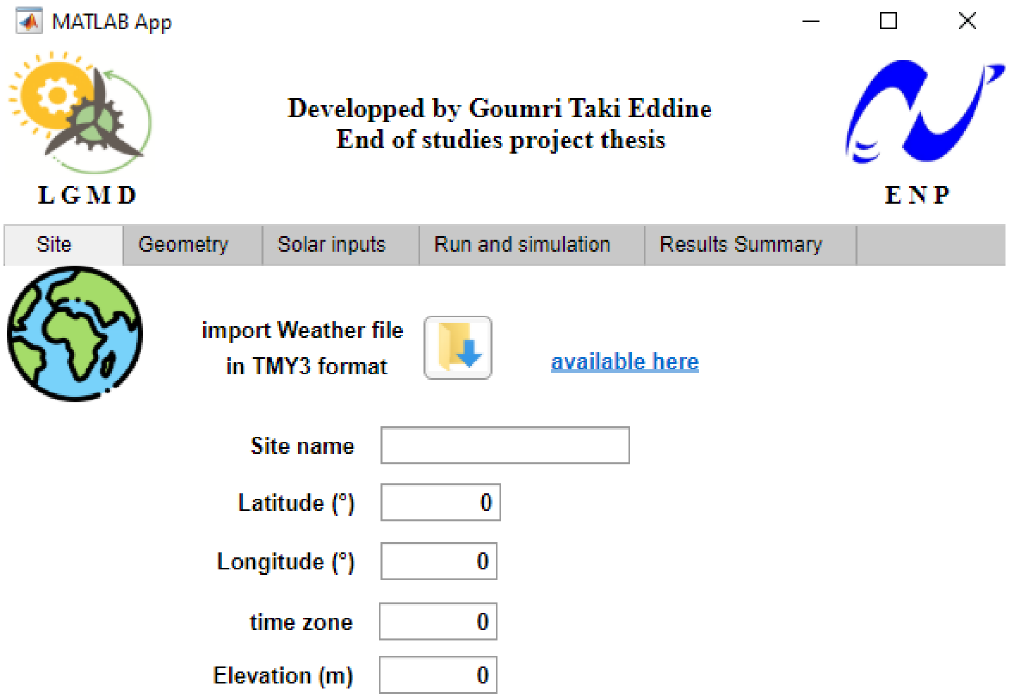


Figure 3-7 GUI Site table

Geometry tab: here we introduce the thermal resistance of the different constructions of the building (walls, roof, Ground, Windows) and their surfaces. As well as the infiltration mass flow, rate (amount of outdoor air interring the heating space due to the infiltration).

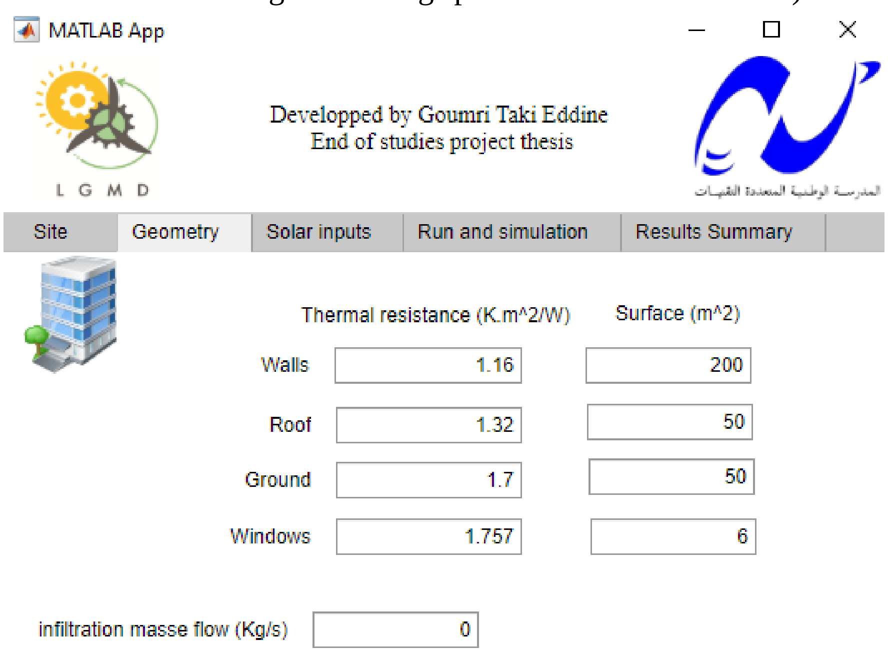


Figure 3-8 GUI Geometry tab

Solar inputs tab: it concerns different parameters of the solar thermal collector: tilted angle (β), orientation with respect to south direction (γ_0) and the 3 coefficient of efficiency : (a_0 , a_1 , a_2)

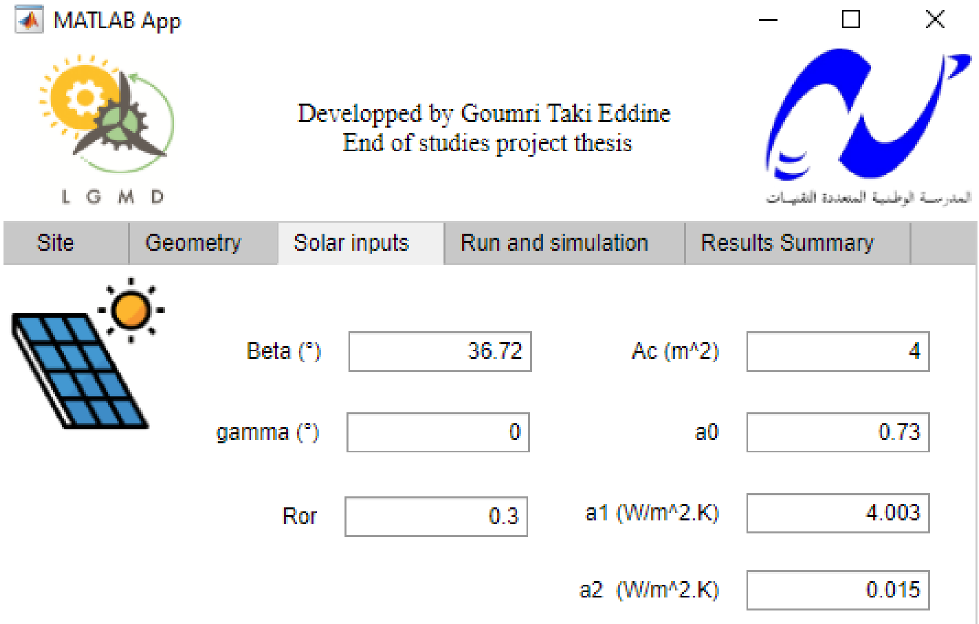


Figure 3-9 GUI Solar tab

Run and simulation tab: we must specify the start and the end date of the desired simulation and the format of the output file (.csv, .xlsx, and .txt), and then hit the run bottom and wait for the "simulation completed successfully" message to appear. After the end of the simulation, you can check your output file to see the full results. If you accidently forget to insert the weather file or the output file, an error message appears reminding you to do so.

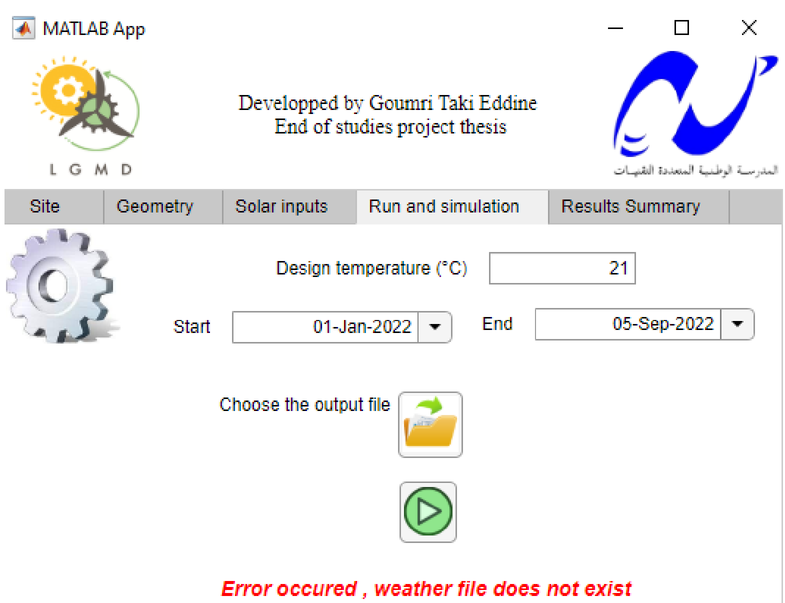


Figure 3-10 GUI Run and simulation tab, error message

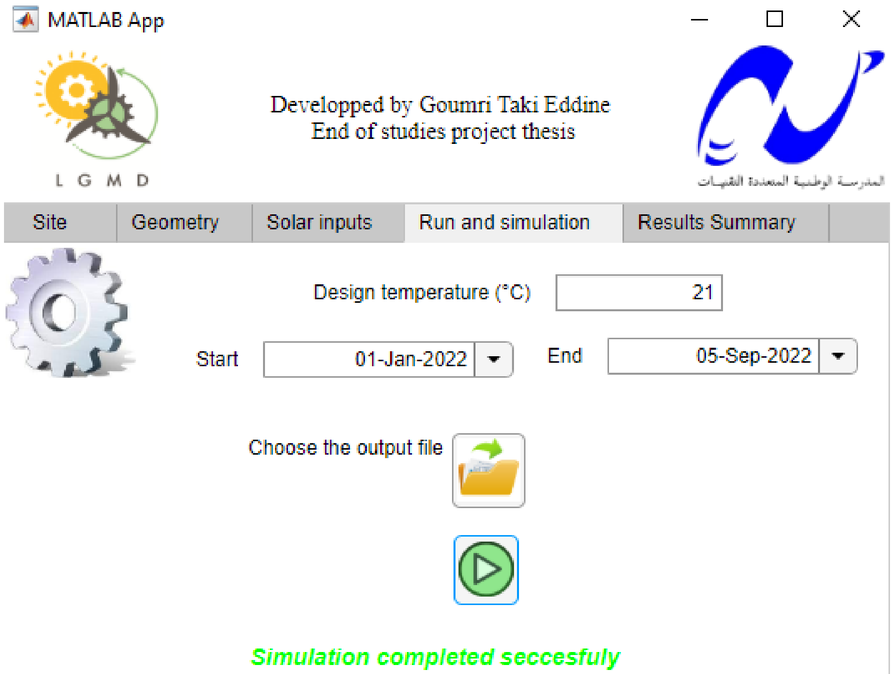


Figure 3-11 GUI Run and simulation, simulation completed successfully message

Results summary: gives you the overall heat transfer coefficient of the building and the solar fraction in percentage, if you are interested in the instant parameters you will find an hourly step simulation results in the indicated output file.

	A	B	C	D	E	F	G	H	I	J	K
1	01-Jan	LST	8:30 AM	9:30 AM	10:30 AM	11:30 AM	12:30 PM	1:30 PM	2:30 PM	3:30 PM	4:30 PM
2		AST	7:40 AM	8:40 AM	9:40 AM	10:40 AM	11:40 AM	12:40 PM	1:40 PM	2:40 PM	3:40 PM
3		Text (°C)	10.9	10.8	12.6	14.3	16.1	16.2	16.3	16.4	15.8
4		Q demand (Wh)	2456	2480	2042	1629	1191	1167	1143	1118	1264
5		teta °	67	54	41	30	24	25	33	45	58
6		Gt (W/m^2)	67	192	290	357	389	383	338	260	153
7		Q solar (Wh)	0	41	363	592	719	702	575	348	23
8		Q consumption (Wh)	2456	2438	1680	1037	472	465	568	770	1241
9	02-Jan	LST	8:30 AM	9:30 AM	10:30 AM	11:30 AM	12:30 PM	1:30 PM	2:30 PM	3:30 PM	4:30 PM
10		AST	7:39 AM	8:39 AM	9:39 AM	10:39 AM	11:39 AM	12:39 PM	1:39 PM	2:39 PM	3:39 PM
11		Text (°C)	16	17.5	19	19.8	20.6	20.2	19.7	19.3	18
12		Q demand (Wh)	1216	851	486	292	97	194	316	413	729
13		teta °	67	54	41	30	23	25	33	45	58
14		Gt (W/m^2)	66	192	290	358	390	384	340	262	154
15		Q solar (Wh)	0	169	484	697	805	780	642	407	69
16		Q consumption (Wh)	1216	682	2	0	0	0	0	7	660
17	03-Jan	LST	8:30 AM	9:30 AM	10:30 AM	11:30 AM	12:30 PM	1:30 PM	2:30 PM	3:30 PM	4:30 PM
18		AST	7:39 AM	8:39 AM	9:39 AM	10:39 AM	11:39 AM	12:39 PM	1:39 PM	2:39 PM	3:39 PM
19		Text (°C)	13	12.8	13.8	14.9	15.9	16	16	16	14.5
20		Q demand (Wh)	1945	1994	1750	1483	1240	1216	1216	1216	1580
21		teta °	67	54	41	30	23	25	33	45	58

results file

Figure 3-12 Excel output file

3.7.2 The app implementation:

For Matlab users:

- **To share:** you can simply package the source file into a Matlab app using the package app tool in the apps tab (only available for Matlab version 2016 or higher).
- **To install:** go to the install app in the app tabs and run the installation

For non-Matlab users:

- **To share:** you have to convert it into an executable application (.exe extension) this is can be done using the Matlab compiler available in the app tab.
- **To install:** execute the setup file (.exe file for windows users) and run the installation.[20]

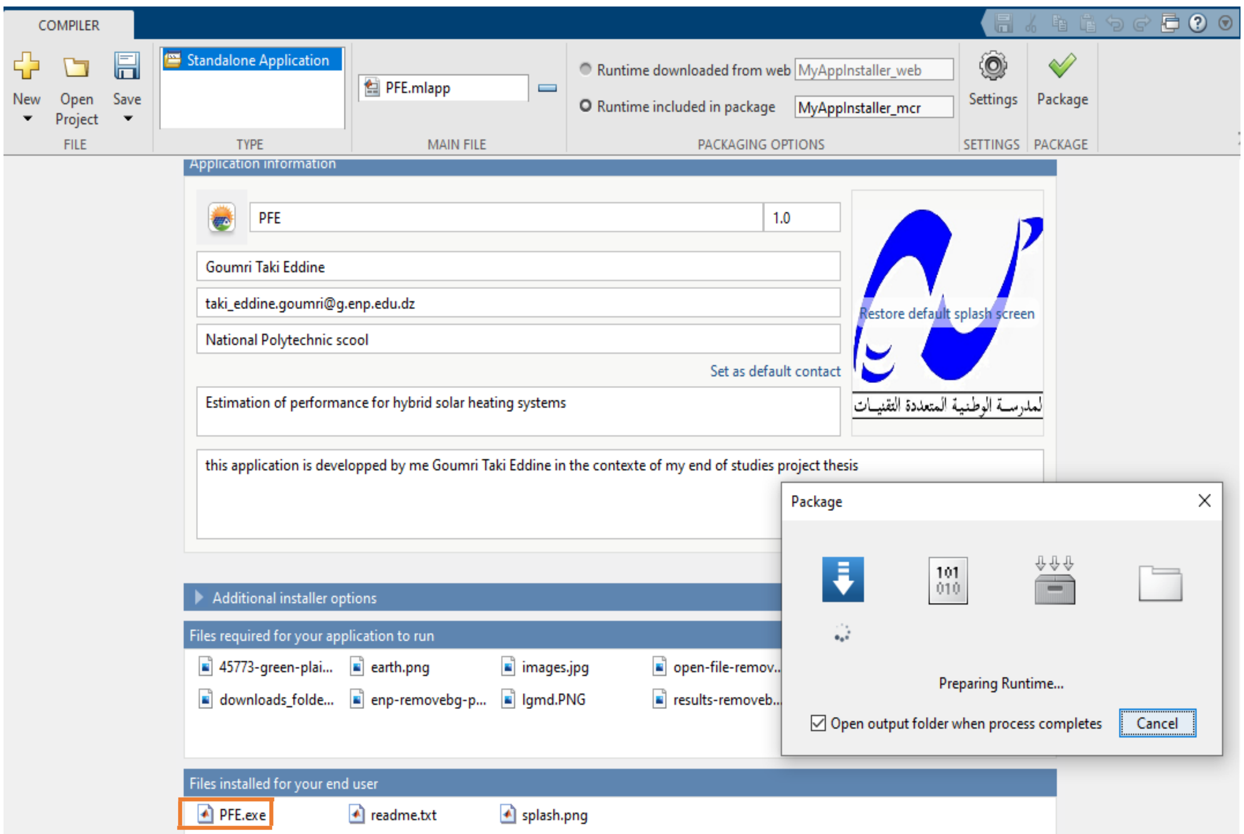


Figure 3-13 GUI compiler

3.8 Assumptions and approximations:

Approximations models are useful because our minds are a small part of the world itself. When we represent a piece of the world in our minds, we discard many aspects we make a model in order that the model fit in our limited minds. An approximate model is all that we can understand. Making useful models means discarding less important information so that our minds may grasp the important features that remain [17].

In this section, we summarize the used approximations in this chapter (other than the uncertainty of the meteorological data, which was discussed in chapter 2):

- The convection resistance of the walls has been neglected, so their external (internal) face temperature is considered equal to the external (internal) air temperature respectively.
- The modelling of the walls has been done in steady state so the stored energy term $\rho C_p \frac{dT}{dt}$ in the energy balance has been neglected. In the transitory state, the building is modelled as RC circuit. However, in this study we have modelled the building by just an overall thermal resistance since we assumed that we are in the steady state.
- The heat losses in pipes and the water tank have been neglected.
- No control strategy is implemented, we simply assumed that all the received heat from the thermal collector is subtracted from the necessary gas boiler heat.

3.9 Comparison Openstudio model vs Matlab model:

Table 3-4 Openstudio model vs Matlab model

	Openstudio model	Matlab model
Qload (MWh)	2.60	1.95
Qconsumption hybrid mode (MWh)	1.91	1.54
Qconsumption gas mode (MWh)	2.81	2.10
SF (%)	39.2	30.0
PESR (%)	32.2	26.7

3.10 Conclusion

Overall, the developed Matlab model gives us reasonable results and a brief and good estimation for the HSGHS system's performance with a marginal error of 25% in pertinent parameters (PESR, SF and LCOH) compared to Openstudio model developed in chapter 2. Due to the introduced approximations and assumptions discussed earlier, the Matlab model is judged to be less reliable than the Openstudio model nevertheless our developed Matlab app is totally customizable, with the right dedicated work and persistence it will go all the way up and contest the more advanced softwares such as Openstudio and Trnsys.

General conclusion:

In the context of energy transition from fossil-based toward zero-carbon by the second half of this century many challenges rise especially when dealing with hybrid systems.

Our objective in this report was to study the feasibility of the hybridization of the LGMD with a natural gas backup system. Firstly, we discussed several features of the hybrid solar systems based on an arts standpoint, which helped us to get familiar with these technologies. Then we presented systematically the working flow to reach the final Openstudio model. Starting from modelling the building envelope using sketchup to assigning materials and construction to defining thermal zones to modelling the HSGHS to properly implementing the control strategy using available managers within Openstudio. Reaching our final model, we were able to track the dynamic functioning of the installation in real time demonstrating the feasibility of the natural gas backup. Then we integrated those instantaneous parameters over the year, delivering 32.2%, 39.2% and 9.56 DA/kWh for solar fraction (SF), primary energy saving ratio (PESR), and levelized cost of heat (LCOH) respectively.

Then, a validation process is accomplished using the BIN method to calculate the heat demand in the building, combined with Liu and Jordan model to calculate the available solar radiation in the solar thermal collector.

The proposed numerical simulation approach will eventually serve not only for the optimization of the current hybrid solar installation of the LGMD at ENP, but also for future spreading related works. Predicting the performance parameters given the working conditions that are critical and important to consider before making any investigations.

Finally, the following tasks can be suggested to be tackled as future works:

- Experimental development of the LGMD hybrid solar-gas system will be carried out conveniently based on this numerical simulation approach. Mainly, the feasibility of automatic operation of hybridisation process (automatic switching between solar and gas sources) will be assessed experimentally.
- For the validation model, it can be proposed to go further and model the building in transient state, thus taking into account the density and thermal capacity of the walls in order to increase the accuracy of the model.
- For the GUI the source code in the appendix could easily be modified or add to it new functionalities to describe properly any given physical configuration.

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22. Course notes "Thermique apliquée chapiter 3" Prof. Arezki SMAILI, Mechanical Engineering Department, National Polytechnic School.

Appendix

Matlab app source code:

```
classdef PFE < matlab.apps.AppBase

% Properties that correspond to app components
properties (Access = public)
UIFigure matlab.ui.Figure
ENPLabel matlab.ui.control.Label
LGMDLabel matlab.ui.control.Label
Image7 matlab.ui.control.Image
Label matlab.ui.control.Label
Image6 matlab.ui.control.Image
TabGroup matlab.ui.container.TabGroup
SiteTab matlab.ui.container.Tab
Hyperlink matlab.ui.control.Hyperlink
SitenameEditField matlab.ui.control.EditField
SitenameEditFieldLabel matlab.ui.control.Label
inTMY3formatLabel matlab.ui.control.Label
timezoneEditField matlab.ui.control.NumericEditField
timezoneEditFieldLabel matlab.ui.control.Label
ElevationmEditField matlab.ui.control.NumericEditField
ElevationmEditFieldLabel matlab.ui.control.Label
Button_2 matlab.ui.control.Button
importWeatherfileLabel matlab.ui.control.Label
Image5 matlab.ui.control.Image
LongitudeEditField matlab.ui.control.NumericEditField
LongitudeLabel matlab.ui.control.Label
LatitudeEditField matlab.ui.control.NumericEditField
LatitudeEditFieldLabel matlab.ui.control.Label
GeometryTab matlab.ui.container.Tab
EditField4 matlab.ui.control.NumericEditField
EditField3 matlab.ui.control.NumericEditField
EditField2 matlab.ui.control.NumericEditField
EditField1 matlab.ui.control.NumericEditField
Surfacem2Label matlab.ui.control.Label
ThermalresistanceKm2WLabel matlab.ui.control.Label
infiltrationmasseflowKgsEditField matlab.ui.control.NumericEditField
infiltrationmasseflowKgsEditFieldLabel matlab.ui.control.Label
WindowsEditField matlab.ui.control.NumericEditField
WindowsEditFieldLabel matlab.ui.control.Label
GroundEditField matlab.ui.control.NumericEditField
GroundEditFieldLabel matlab.ui.control.Label
RoofEditField matlab.ui.control.NumericEditField
RoofEditFieldLabel matlab.ui.control.Label
```

```
WallsEditField matlab.ui.control.NumericEditField
WallsEditFieldLabel matlab.ui.control.Label
Image matlab.ui.control.Image
SolarinputsTab matlab.ui.container.Tab
Image2 matlab.ui.control.Image
a2Wm2KEditField matlab.ui.control.NumericEditField
a2Wm2KEditFieldLabel matlab.ui.control.Label
a1Wm2KEditField matlab.ui.control.NumericEditField
a1Wm2KLabel matlab.ui.control.Label
a0EditField matlab.ui.control.NumericEditField
a0EditFieldLabel matlab.ui.control.Label
Acm2EditField matlab.ui.control.NumericEditField
Acm2EditFieldLabel matlab.ui.control.Label
gammaEditField matlab.ui.control.NumericEditField
gammaLabel matlab.ui.control.Label
Ro_gEditField matlab.ui.control.NumericEditField
Ro_gEditFieldLabel matlab.ui.control.Label
BetaEditField matlab.ui.control.NumericEditField
BetaLabel matlab.ui.control.Label
RunandsimulationTab matlab.ui.container.Tab
EndDatePicker matlab.ui.control.DatePicker
EndDatePickerLabel matlab.ui.control.Label
DesigntemperatureCEditField matlab.ui.control.NumericEditField
DesigntemperatureCEditFieldLabel matlab.ui.control.Label
StartDatePicker matlab.ui.control.DatePicker
StartDatePickerLabel matlab.ui.control.Label
Label_2 matlab.ui.control.Label
Button_4 matlab.ui.control.Button
ChoosetheoutputfileLabel matlab.ui.control.Label
Button_3 matlab.ui.control.Button
Image3 matlab.ui.control.Image
ResultsSummaryTab matlab.ui.container.Tab
Label_3 matlab.ui.control.Label
WKLabel matlab.ui.control.Label
OverallheattransfercoefficientEditField matlab.ui.control.NumericEditField
OverallheattransfercoefficientEditFieldLabel matlab.ui.control.Label
Image4 matlab.ui.control.Image
SFEditField matlab.ui.control.NumericEditField
SFEditFieldLabel matlab.ui.control.Label
end

properties (Access = private)
Property % Description
input="taki";
output="taki";
```

```
end


% Callbacks that handle component events
methods (Access = private)

% Button pushed function: Button_2
function Button_2Pushed(app, event)
[file,path,index]=uigetfile;
app.input=[path file];
TMY=pvl_readtmy3(app.input);
app.SitenameEditField.Value=cell2mat(TMY.StationName);
app.LatitudeEditField.Value=TMY.SiteLatitude;
app.LongitudeEditField.Value=TMY.SiteLongitude;
app.timezoneEditField.Value=TMY.SiteTimeZone;
app.ElevationmEditField.Value=TMY.SiteElevation;
end

% Button pushed function: Button_3
function Button_3Pushed(app, event)
format shortG
%% data :
Ta=40;
beta=app.BetaEditField.Value;
fi=app.LatitudeEditField.Value;
L=app.LongitudeEditField.Value;
Ror=app.Ro_gEditField.Value;
gamma0=app.gammaEditField.Value;

Ac=app.Acm2EditField.Value;
a0=app.a0EditField.Value;
a1=app.a1Wm2KEditField.Value;
a2=app.a2Wm2KEditField.Value;
Consumption=0;
Demand=0;
%% Text
if (app.input=="taki")
app.Label_2.FontColor='r';
app.Label_2.Text='Error occured , weather file does not exist';

end
if (app.output=="taki")
app.Label_2.FontColor='r';
app.Label_2.Text='Error occured , output file does not exist';

end
```

```
if (app.output~="taki")

TMY=pvl_readtmy3(app.input);


for i=1:8760

temp(i)=mod(i,24);
if (temp(i)==0)
temp(i)=24;
end
end
M=[temp;TMY.DryBulb';TMY.DHI';TMY.DNI']';
N=8760;
k=1;
for i=1:N
if (temp(i)<18 && 7<temp(i))
Text(k)=M(i,2);
Gdh(k)=M(i,3);
Gb(k)=M(i,4);
k=k+1;
end
end
Text=reshape(Text,[10 365]);
Gdh=reshape(Gdh,[10 365]);
Gb=reshape(Gb,[10 365]);
Text=Text';
%% calculs
Mois=[31 28 31 30 31 30 31 31 30 31 30 31];
deb=datevec(app.StartDatePicker.Value);
fin=datevec(app.EndDatePicker.Value);
deb=sum(Mois(1:deb(2)-1))+deb(3);
fin=sum(Mois(1:fin(2)-1))+fin(3);


%%
for n=deb:fin
Gsc0=1366;
Gsc=Gsc0*(1+0.0334*cosd(360*n/365));
delta=23.45*sind(360*(284+n)/365);

% beta=fi;
temp=[8 9 10 11 12 13 14 15 16 17];
Lst=15;
```

```
x=360*(n-1)/365;
E = 180*4/pi* (0.000075 +0.001868*cosd(x)-0.032077*sind(x)-0.014615*cosd(2*x)-
0.0409*sind(2*x));

AST=temp+E/60-1/15*(Lst-L);
w=15*(AST-12);

R=1230; A=1.61; B=3.1; C=0.47; %normal conditions
sin_alphas=(sind(fi)*sind(delta)+cosd(fi)*cosd(delta)*cosd(w));
alphas=asin(sin_alphas);
cos_teta=sind(delta)*sind(fi)*cosd(beta)- sind(delta)*cosd(fi)*sind(beta)*cosd(gamma0)+
cosd(delta)*cosd(fi)*cosd(beta)*cosd(w)+
cosd(delta)*sind(fi)*sind(beta)*cosd(gamma0)*cosd(w)+
cosd(delta)*sind(beta)*sind(gamma0)*sind(w);
Gbh=Gb(:,n)'.*sin_alphas;
Gdt=Gdh(:,n)'*(1+cosd(beta))/2;
Grt=(Gdh(:,n)'+Gbh)*Ror*(1-cosd(beta))/2;
Gt=Gbh.*cos_teta./sin_alphas+Gdt+Grt; %% a revoir
cp=1005;
Utot=(app.EditField1.Value/app.WallsEditField.Value)+(app.EditField2.Value/app.RoofEditFiel
d.Value)+(app.EditField3.Value/app.GroundEditField.Value)+(app.EditField4.Value/app.Windo
wsEditField.Value)+app.infiltrationmasseflowKgsEditField.Value*cp;
Teq=app.DesigntemperatureCEditField.Value;

Qdemand=Utot*(Teq-Text(n,:));


Qsolar=(a0*Gt-a1*(Ta-Text(n,:))-a2*(Ta-Text(n,:)).^2)*Ac;
for i=1:10
if (Qdemand(i)<0)
Qdemand(i)=0;
end
end
for i=1:10
if (Qsolar(i)<0)
Qsolar(i)=0;
end
end
Qconsumption=(Qdemand-Qsolar);

for i=1:10
if (Qconsumption(i)<0)
Qconsumption(i)=0;
end
end
if (mod(n,7)~=6 && mod(n,7)~=0)
```

```
Consumption=Consumption+sum(Qconsumption);
Demand=Demand+sum(Qdemand);
end
var=["LST";"AST";"Text (°C)";"Q demand (Wh)";"teta °";"Gt (W/m^2)";"Q solar (Wh)";"Q
consumption (Wh)"];
nn=n-deb+1;
tab(8*nn-7:8*nn,2)=var';
tab(8*nn-7,3:12)=datestr(temp/24);
tab(8*nn-6,3:12)=datestr(AST/24);
tab(8*nn-5,3:12)=round(Text(n,:),1);
tab(8*nn-4,3:12)=round(Qdemand);
tab(8*nn-3,3:12)=round(acosd(cos_teta));
tab(8*nn-2,3:12)=round(Gt);
tab(8*nn-1,3:12)=round(Qsolar);
tab(8*nn,3:12)=round(Qconsumption);
if (n>59)
nnn=n+1;
else
nnn=n;
end
DATE=datestr(nnn);
DATE(7:11)=[];
tab(8*nn-7,1)={DATE};
end

writematrix(tab,app.output)
SCR=(Demand-Consumption)/Demand;
app.SFEditField.Value=SCR*100;
app.Label_2.FontColor='g';
app.Label_2.Text='Simulation completed seccesfuly';

app.OverallheattransfercoefficientEditField.Value=Utot;
end
end

% Callback function
function Button_4ValueChanged(app, event)

end

% Button pushed function: Button_4
function Button_4Pushed(app, event)
[file,path,index]=uigetfile;
app.output=[path file];
end
end
```

```
% Component initialization
methods (Access = private)

% Create UIFigure and components
function createComponents(app)

% Create UIFigure and hide until all components are created
app.UIFigure = uifigure('Visible', 'off');
app.UIFigure.Color = [1 1 1];
app.UIFigure.Position = [100 100 584 447];
app.UIFigure.Name = 'MATLAB App';

% Create TabGroup
app.TabGroup = uitabgroup(app.UIFigure);
app.TabGroup.Position = [1 1 584 345];

% Create SiteTab
app.SiteTab = uitab(app.TabGroup);
app.SiteTab.Title = ' Site ';
app.SiteTab.BackgroundColor = [1 1 1];

% Create LatitudeEditFieldLabel
app.LatitudeEditFieldLabel = uilabel(app.SiteTab);
app.LatitudeEditFieldLabel.HorizontalAlignment = 'right';
app.LatitudeEditFieldLabel.FontSize = 13;
app.LatitudeEditFieldLabel.FontWeight = 'bold';
app.LatitudeEditFieldLabel.Position = [131 173 74 22];
app.LatitudeEditFieldLabel.Text = 'Latitude (°)';

% Create LatitudeEditField
app.LatitudeEditField = uieditfield(app.SiteTab, 'numeric');
app.LatitudeEditField.FontSize = 13;
app.LatitudeEditField.FontWeight = 'bold';
app.LatitudeEditField.Position = [220 173 70 22];

% Create LongitudeLabel
app.LongitudeLabel = uilabel(app.SiteTab);
app.LongitudeLabel.HorizontalAlignment = 'right';
app.LongitudeLabel.FontSize = 13;
app.LongitudeLabel.FontWeight = 'bold';
app.LongitudeLabel.Position = [119 139 86 22];
app.LongitudeLabel.Text = 'Longitude (°)';

% Create LongitudeEditField
app.LongitudeEditField = uieditfield(app.SiteTab, 'numeric');
```

```
app.LongitudeEditField.FontSize = 13;
app.LongitudeEditField.FontWeight = 'bold';
app.LongitudeEditField.Position = [220 139 68 22];

% Create Image5
app.Image5 = uiimage(app.SiteTab);
app.Image5.Position = [1 242 82 79];
app.Image5.ImageSource = 'earth.png';

% Create importWeatherfileLabel
app.importWeatherfileLabel = uilabel(app.SiteTab);
app.importWeatherfileLabel.FontSize = 13;
app.importWeatherfileLabel.FontWeight = 'bold';
app.importWeatherfileLabel.Position = [116 273 130 22];
app.importWeatherfileLabel.Text = 'import Weather file ';

% Create Button_2
app.Button_2 = uibutton(app.SiteTab, 'push');
app.Button_2.ButtonPushedFcn = createCallbackFcn(app, @Button_2Pushed, true);
app.Button_2.Icon = 'downloads_folder.png';
app.Button_2.Tooltip = {'insert'; ''};
app.Button_2.Position = [245 255 40 37];
app.Button_2.Text = '';

% Create ElevationmEditFieldLabel
app.ElevationmEditFieldLabel = uilabel(app.SiteTab);
app.ElevationmEditFieldLabel.HorizontalAlignment = 'right';
app.ElevationmEditFieldLabel.FontSize = 13;
app.ElevationmEditFieldLabel.FontWeight = 'bold';
app.ElevationmEditFieldLabel.Position = [117 73 87 22];
app.ElevationmEditFieldLabel.Text = 'Elevation (m)';

% Create ElevationmEditField
app.ElevationmEditField = uieditfield(app.SiteTab, 'numeric');
app.ElevationmEditField.FontSize = 13;
app.ElevationmEditField.FontWeight = 'bold';
app.ElevationmEditField.Position = [219 73 69 22];

% Create timezoneEditFieldLabel
app.timezoneEditFieldLabel = uilabel(app.SiteTab);
app.timezoneEditFieldLabel.HorizontalAlignment = 'right';
app.timezoneEditFieldLabel.FontSize = 13;
app.timezoneEditFieldLabel.FontWeight = 'bold';
app.timezoneEditFieldLabel.Position = [139 104 65 22];
app.timezoneEditFieldLabel.Text = 'time zone';
```

```
% Create timezoneEditField
app.timezoneEditField = uieditfield(app.SiteTab, 'numeric');
app.timezoneEditField.FontSize = 13;
app.timezoneEditField.FontWeight = 'bold';
app.timezoneEditField.Position = [219 104 69 22];

% Create inTMY3formatLabel
app.inTMY3formatLabel = uilabel(app.SiteTab);
app.inTMY3formatLabel.FontSize = 13;
app.inTMY3formatLabel.FontWeight = 'bold';
app.inTMY3formatLabel.Position = [130 252 99 22];
app.inTMY3formatLabel.Text = 'in TMY3 format';

% Create SitenameEditFieldLabel
app.SitenameEditFieldLabel = uilabel(app.SiteTab);
app.SitenameEditFieldLabel.HorizontalAlignment = 'right';
app.SitenameEditFieldLabel.FontSize = 13;
app.SitenameEditFieldLabel.FontWeight = 'bold';
app.SitenameEditFieldLabel.Position = [138 206 67 22];
app.SitenameEditFieldLabel.Text = 'Site name';

% Create SitenameEditField
app.SitenameEditField = uieditfield(app.SiteTab, 'text');
app.SitenameEditField.FontSize = 13;
app.SitenameEditField.FontWeight = 'bold';
app.SitenameEditField.Position = [220 206 145 22];

% Create Hyperlink
app.Hyperlink = uihyperlink(app.SiteTab);
app.Hyperlink.URL = 'https://nsrdb.nrel.gov/data-sets/tmy';
app.Hyperlink.FontSize = 13;
app.Hyperlink.Position = [319 255 91 22];
app.Hyperlink.Text = 'available here';

% Create GeometryTab
app.GeometryTab = uitab(app.TabGroup);
app.GeometryTab.Title = 'Geometry';
app.GeometryTab.BackgroundColor = [1 1 1];

% Create Image
app.Image = uiimage(app.GeometryTab);
app.Image.Position = [3 248 80 73];
app.Image.ImageSource = 'site-removebg-preview.png';

% Create WallsEditFieldLabel
app.WallsEditFieldLabel = uilabel(app.GeometryTab);
```

```
app.WallsEditFieldLabel.HorizontalAlignment = 'right';
app.WallsEditFieldLabel.FontSize = 13;
app.WallsEditFieldLabel.FontWeight = 'bold';
app.WallsEditFieldLabel.Position = [147 242 39 22];
app.WallsEditFieldLabel.Text = 'Walls';

% Create WallsEditField
app.WallsEditField = uieditfield(app.GeometryTab, 'numeric');
app.WallsEditField.FontSize = 13;
app.WallsEditField.FontWeight = 'bold';
app.WallsEditField.Position = [201 242 113 22];
app.WallsEditField.Value = 1.16;

% Create RoofEditFieldLabel
app.RoofEditFieldLabel = uilabel(app.GeometryTab);
app.RoofEditFieldLabel.HorizontalAlignment = 'right';
app.RoofEditFieldLabel.FontSize = 13;
app.RoofEditFieldLabel.FontWeight = 'bold';
app.RoofEditFieldLabel.Position = [152 206 35 22];
app.RoofEditFieldLabel.Text = 'Roof';

% Create RoofEditField
app.RoofEditField = uieditfield(app.GeometryTab, 'numeric');
app.RoofEditField.FontSize = 13;
app.RoofEditField.FontWeight = 'bold';
app.RoofEditField.Position = [202 206 112 22];
app.RoofEditField.Value = 1.32;

% Create GroundEditFieldLabel
app.GroundEditFieldLabel = uilabel(app.GeometryTab);
app.GroundEditFieldLabel.HorizontalAlignment = 'right';
app.GroundEditFieldLabel.FontSize = 13;
app.GroundEditFieldLabel.FontWeight = 'bold';
app.GroundEditFieldLabel.Position = [135 173 52 22];
app.GroundEditFieldLabel.Text = 'Ground';

% Create GroundEditField
app.GroundEditField = uieditfield(app.GeometryTab, 'numeric');
app.GroundEditField.FontSize = 13;
app.GroundEditField.FontWeight = 'bold';
app.GroundEditField.Position = [202 173 112 22];
app.GroundEditField.Value = 1.7;

% Create WindowsEditFieldLabel
app.WindowsEditFieldLabel = uilabel(app.GeometryTab);
app.WindowsEditFieldLabel.HorizontalAlignment = 'right';
```

```
app.WindowsEditFieldLabel.FontSize = 13;
app.WindowsEditFieldLabel.FontWeight = 'bold';
app.WindowsEditFieldLabel.Position = [125 139 62 22];
app.WindowsEditFieldLabel.Text = 'Windows';

% Create WindowsEditField
app.WindowsEditField = uieditfield(app.GeometryTab, 'numeric');
app.WindowsEditField.FontSize = 13;
app.WindowsEditField.FontWeight = 'bold';
app.WindowsEditField.Position = [202 139 112 22];
app.WindowsEditField.Value = 1.757;

% Create infiltrationmasseflowKgsEditFieldLabel
app.infiltrationmasseflowKgsEditFieldLabel = uilabel(app.GeometryTab);
app.infiltrationmasseflowKgsEditFieldLabel.HorizontalAlignment = 'right';
app.infiltrationmasseflowKgsEditFieldLabel.FontSize = 13;
app.infiltrationmasseflowKgsEditFieldLabel.FontWeight = 'bold';
app.infiltrationmasseflowKgsEditFieldLabel.Position = [20 83 183 22];
app.infiltrationmasseflowKgsEditFieldLabel.Text = 'infiltration masse flow (Kg/s)';

% Create infiltrationmasseflowKgsEditField
app.infiltrationmasseflowKgsEditField = uieditfield(app.GeometryTab, 'numeric');
app.infiltrationmasseflowKgsEditField.FontSize = 13;
app.infiltrationmasseflowKgsEditField.FontWeight = 'bold';
app.infiltrationmasseflowKgsEditField.Position = [218 83 100 22];

% Create ThermalresistanceKm2WLabel
app.ThermalresistanceKm2WLabel = uilabel(app.GeometryTab);
app.ThermalresistanceKm2WLabel.FontSize = 13;
app.ThermalresistanceKm2WLabel.FontWeight = 'bold';
app.ThermalresistanceKm2WLabel.Position = [181 272 193 22];
app.ThermalresistanceKm2WLabel.Text = 'Thermal resistance (K.m^2/W)';

% Create Surfacem2Label
app.Surfacem2Label = uilabel(app.GeometryTab);
app.Surfacem2Label.FontSize = 13;
app.Surfacem2Label.FontWeight = 'bold';
app.Surfacem2Label.Position = [370 273 92 22];
app.Surfacem2Label.Text = 'Surface (m^2)';

% Create EditField1
app.EditField1 = uieditfield(app.GeometryTab, 'numeric');
app.EditField1.FontSize = 13;
app.EditField1.FontWeight = 'bold';
app.EditField1.Position = [371 242 100 22];
app.EditField1.Value = 200;
```

```
% Create EditField2
app.EditField2 = uieditfield(app.GeometryTab, 'numeric');
app.EditField2.FontSize = 13;
app.EditField2.FontWeight = 'bold';
app.EditField2.Position = [371 208 100 22];
app.EditField2.Value = 50;

% Create EditField3
app.EditField3 = uieditfield(app.GeometryTab, 'numeric');
app.EditField3.FontSize = 13;
app.EditField3.FontWeight = 'bold';
app.EditField3.Position = [371 175 100 22];
app.EditField3.Value = 50;

% Create EditField4
app.EditField4 = uieditfield(app.GeometryTab, 'numeric');
app.EditField4.FontSize = 13;
app.EditField4.FontWeight = 'bold';
app.EditField4.Position = [371 139 100 22];
app.EditField4.Value = 6;

% Create SolarinputsTab
app.SolarinputsTab = uitab(app.TabGroup);
app.SolarinputsTab.Title = 'Solar inputs';
app.SolarinputsTab.BackgroundColor = [1 1 1];

% Create BetaLabel
app.BetaLabel = uilabel(app.SolarinputsTab);
app.BetaLabel.HorizontalAlignment = 'right';
app.BetaLabel.FontSize = 13;
app.BetaLabel.FontWeight = 'bold';
app.BetaLabel.Position = [124 263 51 22];
app.BetaLabel.Text = 'Beta (°)';

% Create BetaEditField
app.BetaEditField = uieditfield(app.SolarinputsTab, 'numeric');
app.BetaEditField.FontSize = 13;
app.BetaEditField.FontWeight = 'bold';
app.BetaEditField.Position = [190 263 100 22];
app.BetaEditField.Value = 36.72;

% Create Ro_gEditFieldLabel
app.Ro_gEditFieldLabel = uilabel(app.SolarinputsTab);
app.Ro_gEditFieldLabel.HorizontalAlignment = 'right';
app.Ro_gEditFieldLabel.FontSize = 13;
```

```
app.Ro_gEditFieldLabel.FontWeight = 'bold';
app.Ro_gEditFieldLabel.Position = [135 173 38 22];
app.Ro_gEditFieldLabel.Text = 'Ro_g';

% Create Ro_gEditField
app.Ro_gEditField = uieditfield(app.SolarinputsTab, 'numeric');
app.Ro_gEditField.FontSize = 13;
app.Ro_gEditField.FontWeight = 'bold';
app.Ro_gEditField.Position = [188 173 100 22];
app.Ro_gEditField.Value = 0.3;

% Create gammaLabel
app.gammaLabel = uilabel(app.SolarinputsTab);
app.gammaLabel.HorizontalAlignment = 'right';
app.gammaLabel.FontSize = 13;
app.gammaLabel.FontWeight = 'bold';
app.gammaLabel.Position = [106 219 68 22];
app.gammaLabel.Text = 'gamma (°)';

% Create gammaEditField
app.gammaEditField = uieditfield(app.SolarinputsTab, 'numeric');
app.gammaEditField.FontSize = 13;
app.gammaEditField.FontWeight = 'bold';
app.gammaEditField.Position = [189 219 100 22];

% Create Acm2EditFieldLabel
app.Acm2EditFieldLabel = uilabel(app.SolarinputsTab);
app.Acm2EditFieldLabel.HorizontalAlignment = 'right';
app.Acm2EditFieldLabel.FontSize = 13;
app.Acm2EditFieldLabel.FontWeight = 'bold';
app.Acm2EditFieldLabel.Position = [331 263 61 22];
app.Acm2EditFieldLabel.Text = 'Ac (m^2)';

% Create Acm2EditField
app.Acm2EditField = uieditfield(app.SolarinputsTab, 'numeric');
app.Acm2EditField.FontSize = 13;
app.Acm2EditField.FontWeight = 'bold';
app.Acm2EditField.Position = [407 263 100 22];
app.Acm2EditField.Value = 4;

% Create a0EditFieldLabel
app.a0EditFieldLabel = uilabel(app.SolarinputsTab);
app.a0EditFieldLabel.HorizontalAlignment = 'right';
app.a0EditFieldLabel.FontSize = 13;
app.a0EditFieldLabel.FontWeight = 'bold';
app.a0EditFieldLabel.Position = [367 219 25 22];
```

```
app.a0EditFieldLabel.Text = 'a0';

% Create a0EditField
app.a0EditField = uieditfield(app.SolarinputsTab, 'numeric');
app.a0EditField.FontSize = 13;
app.a0EditField.FontWeight = 'bold';
app.a0EditField.Position = [407 219 100 22];
app.a0EditField.Value = 0.73;

% Create a1Wm2KLabel
app.a1Wm2KLabel = uilabel(app.SolarinputsTab);
app.a1Wm2KLabel.HorizontalAlignment = 'right';
app.a1Wm2KLabel.FontSize = 13;
app.a1Wm2KLabel.FontWeight = 'bold';
app.a1Wm2KLabel.Position = [305 175 87 22];
app.a1Wm2KLabel.Text = 'a1 (W/m^2.K)';

% Create a1Wm2KEditField
app.a1Wm2KEditField = uieditfield(app.SolarinputsTab, 'numeric');
app.a1Wm2KEditField.FontSize = 13;
app.a1Wm2KEditField.FontWeight = 'bold';
app.a1Wm2KEditField.Position = [407 175 100 22];
app.a1Wm2KEditField.Value = 4.003;

% Create a2Wm2KEditFieldLabel
app.a2Wm2KEditFieldLabel = uilabel(app.SolarinputsTab);
app.a2Wm2KEditFieldLabel.HorizontalAlignment = 'right';
app.a2Wm2KEditFieldLabel.FontSize = 13;
app.a2Wm2KEditFieldLabel.FontWeight = 'bold';
app.a2Wm2KEditFieldLabel.Position = [301 133 91 22];
app.a2Wm2KEditFieldLabel.Text = 'a2 (W/m^2.K)';

% Create a2Wm2KEditField
app.a2Wm2KEditField = uieditfield(app.SolarinputsTab, 'numeric');
app.a2Wm2KEditField.FontSize = 13;
app.a2Wm2KEditField.FontWeight = 'bold';
app.a2Wm2KEditField.Position = [407 133 100 22];
app.a2Wm2KEditField.Value = 0.015;

% Create Image2
app.Image2 = uiimage(app.SolarinputsTab);
app.Image2.Position = [3 219 106 100];
app.Image2.ImageSource = 'solar-removebg-preview(1).png';

% Create RunandsimulationTab
app.RunandsimulationTab = uitab(app.TabGroup);
```

```
app.RunandsimulationTab.Tooltip = {''};
app.RunandsimulationTab.Title = 'Run and simulation';
app.RunandsimulationTab.BackgroundColor = [1 1 1];

% Create Image3
app.Image3 = uiimage(app.RunandsimulationTab);
app.Image3.Position = [2 240 81 78];
app.Image3.ImageSource = 'images.jpg';

% Create Button_3
app.Button_3 = uibutton(app.RunandsimulationTab, 'push');
app.Button_3.ButtonPushedFcn = createCallbackFcn(app, @Button_3Pushed, true);
app.Button_3.Icon = '45773-green-plain-play-button-icon--clipart.png';
app.Button_3.Tooltip = {'Run'};
app.Button_3.Position = [272 104 39 42];
app.Button_3.Text = '';

% Create ChoosetheoutputfileLabel
app.ChoosetheoutputfileLabel = uilabel(app.RunandsimulationTab);
app.ChoosetheoutputfileLabel.FontSize = 13;
app.ChoosetheoutputfileLabel.FontWeight = 'bold';
app.ChoosetheoutputfileLabel.Position = [149 187 143 22];
app.ChoosetheoutputfileLabel.Text = 'Choose the output file';

% Create Button_4
app.Button_4 = uibutton(app.RunandsimulationTab, 'push');
app.Button_4.ButtonPushedFcn = createCallbackFcn(app, @Button_4Pushed, true);
app.Button_4.Icon = 'open-file-removebg-preview.png';
app.Button_4.Tooltip = {'insert'};
app.Button_4.Position = [292 162 44 45];
app.Button_4.Text = '';

% Create Label_2
app.Label_2 = uilabel(app.RunandsimulationTab);
app.Label_2.FontSize = 14;
app.Label_2.FontWeight = 'bold';
app.Label_2.FontAngle = 'italic';
app.Label_2.FontColor = [0 1 0];
app.Label_2.Position = [150 62 357 22];
app.Label_2.Text = '';

% Create StartDatePickerLabel
app.StartDatePickerLabel = uilabel(app.RunandsimulationTab);
app.StartDatePickerLabel.HorizontalAlignment = 'right';
app.StartDatePickerLabel.FontSize = 13;
app.StartDatePickerLabel.FontWeight = 'bold';
```

```
app.StartDatePickerLabel.Position = [108 240 35 22];
app.StartDatePickerLabel.Text = 'Start';

% Create StartDatePicker
app.StartDatePicker = uidatepicker(app.RunandsimulationTab);
app.StartDatePicker.FontSize = 13;
app.StartDatePicker.FontWeight = 'bold';
app.StartDatePicker.Position = [158 240 150 22];
app.StartDatePicker.Value = datetime([2022 1 1]);

% Create DesigntemperatureCEditFieldLabel
app.DesigntemperatureCEditFieldLabel = uilabel(app.RunandsimulationTab);
app.DesigntemperatureCEditFieldLabel.HorizontalAlignment = 'right';
app.DesigntemperatureCEditFieldLabel.FontSize = 13;
app.DesigntemperatureCEditFieldLabel.FontWeight = 'bold';
app.DesigntemperatureCEditFieldLabel.Position = [164 280 154 22];
app.DesigntemperatureCEditFieldLabel.Text = 'Design temperature (°C)';

% Create DesigntemperatureCEditField
app.DesigntemperatureCEditField = uieditfield(app.RunandsimulationTab, 'numeric');
app.DesigntemperatureCEditField.FontSize = 13;
app.DesigntemperatureCEditField.FontWeight = 'bold';
app.DesigntemperatureCEditField.Position = [333 280 100 22];
app.DesigntemperatureCEditField.Value = 21;

% Create EndDatePickerLabel
app.EndDatePickerLabel = uilabel(app.RunandsimulationTab);
app.EndDatePickerLabel.HorizontalAlignment = 'right';
app.EndDatePickerLabel.FontSize = 13;
app.EndDatePickerLabel.FontWeight = 'bold';
app.EndDatePickerLabel.Position = [319 242 30 22];
app.EndDatePickerLabel.Text = 'End';

% Create EndDatePicker
app.EndDatePicker = uidatepicker(app.RunandsimulationTab);
app.EndDatePicker.FontSize = 13;
app.EndDatePicker.FontWeight = 'bold';
app.EndDatePicker.Position = [364 242 150 22];
app.EndDatePicker.Value = datetime([2022 1 31]);

% Create ResultsSummaryTab
app.ResultsSummaryTab = uitab(app.TabGroup);
app.ResultsSummaryTab.Title = 'Results Summary';
app.ResultsSummaryTab.BackgroundColor = [1 1 1];

% Create SFEditFieldLabel
```

```
app.SFEditFieldLabel = uilabel(app.ResultsSummaryTab);
app.SFEditFieldLabel.HorizontalAlignment = 'right';
app.SFEditFieldLabel.FontSize = 13;
app.SFEditFieldLabel.FontWeight = 'bold';
app.SFEditFieldLabel.Position = [209 124 25 22];
app.SFEditFieldLabel.Text = 'SF';

% Create SFEditField
app.SFEditField = uieditfield(app.ResultsSummaryTab, 'numeric');
app.SFEditField.FontSize = 13;
app.SFEditField.FontWeight = 'bold';
app.SFEditField.Position = [249 124 100 22];

% Create Image4
app.Image4 = uiimage(app.ResultsSummaryTab);
app.Image4.Position = [1 248 82 70];
app.Image4.ImageSource = 'results-removebg-preview.png';

% Create OverallheattransfercoefficientEditFieldLabel
app.OverallheattransfercoefficientEditFieldLabel = uilabel(app.ResultsSummaryTab);
app.OverallheattransfercoefficientEditFieldLabel.HorizontalAlignment = 'right';
app.OverallheattransfercoefficientEditFieldLabel.FontSize = 13;
app.OverallheattransfercoefficientEditFieldLabel.FontWeight = 'bold';
app.OverallheattransfercoefficientEditFieldLabel.Position = [32 160 202 22];
app.OverallheattransfercoefficientEditFieldLabel.Text = 'Overall heat transfer coefficient';

% Create OverallheattransfercoefficientEditField
app.OverallheattransfercoefficientEditField = uieditfield(app.ResultsSummaryTab, 'numeric');
app.OverallheattransfercoefficientEditField.FontSize = 13;
app.OverallheattransfercoefficientEditField.FontWeight = 'bold';
app.OverallheattransfercoefficientEditField.Position = [249 160 100 22];

% Create WKLabel
app.WKLabel = uilabel(app.ResultsSummaryTab);
app.WKLabel.FontWeight = 'bold';
app.WKLabel.Position = [358 160 29 22];
app.WKLabel.Text = 'W/K';

% Create Label_3
app.Label_3 = uilabel(app.ResultsSummaryTab);
app.Label_3.FontWeight = 'bold';
app.Label_3.Position = [358 124 25 22];
app.Label_3.Text = '%';

% Create Image6
app.Image6 = uiimage(app.UIFigure);
```

```
app.Image6.Position = [491 373 93 75];
app.Image6.ImageSource = 'Capture1.PNG';

% Create Label
app.Label = uilabel(app.UIFigure);
app.Label.FontName = 'Times New Roman';
            app.Label.FontSize = 16;
            app.Label.FontWeight = 'bold';
            app.Label.Position = [139 383 283 42];
            app.Label.Text = {'        Developped by Goumri Taki Eddine'; '                End of studies
project thesis'};

            % Create Image7
            app.Image7 = uiimage(app.UIFigure);
            app.Image7.Position = [1 373 91 75];
            app.Image7.ImageSource = 'Capture.PNG';

            % Create LGMDLabel
            app.LGMDLabel = uilabel(app.UIFigure);
            app.LGMDLabel.FontName = 'Times New Roman';
            app.LGMDLabel.FontSize = 15;
            app.LGMDLabel.FontWeight = 'bold';
            app.LGMDLabel.Position = [22 352 63 22];
            app.LGMDLabel.Text = 'L G M D';

            % Create ENPLabel
            app.ENPLabel = uilabel(app.UIFigure);
            app.ENPLabel.FontName = 'Times New Roman';
            app.ENPLabel.FontSize = 15;
            app.ENPLabel.FontWeight = 'bold';
            app.ENPLabel.Position = [514 352 43 22];
            app.ENPLabel.Text = 'E N P';

            % Show the figure after all components are created
            app.UIFigure.Visible = 'on';
        end
    end

    % App creation and deletion
    methods (Access = public)

        % Construct app
        function app = PFE

            % Create UIFigure and components
            createComponents(app)
```

```
            % Register the app with App Designer
            registerApp(app, app.UIFigure)

            if nargout == 0
                clear app
            end
        end

        % Code that executes before app deletion
        function delete(app)

            % Delete UIFigure when app is deleted
            delete(app.UIFigure)
        end
    end
end
```