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AND

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INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

INTEGRATION OF SOLAR SPACE COOLING TECHNOLOGY IN MEXICO'S SOCIAL HOUSING SECTOR – FEASIBILITY STUDY IN A WARM HUMID REGION

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Gracias por darme sueños y luego hacerlos realidad. Por darme curiosidad a lo desconocido, y luego hacerme saltar al vacío para descubrirlo. Por mi familia que te ha visto caminar a mi lado, y por todas esas personitas que a lo largo de este tiempo han soñado a mi lado.

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ABSTRACT

The aim of this study is to analyze the feasibility of integrating a solar thermal power driven air conditioning system into Mexico's social housing dwelling. For this purpose, a new housing model is required. The selected case study is a typical two story social housing unit within a neighborhood development located in Playa del Carmen, in the state of Quintana-Roo. This existing dwelling is then the basis of design upon which proposed modifications, considered bioclimatic strategies, are applied.

The methodology is divided in five different phases. The first part involves obtaining energy consumption data from the families residing in these dwellings and identify their thermal comfort time schedule needs through a building occupant survey. In the second phase, architectural modifications are proposed to reduce the thermal cooling load requirements. Thirdly, a solar thermal system is designed. A comparison with a potential PV run system follows. Computer software simulations are performed in phases two through four in order to evaluate the performance behavior of each system. Finally in the fifth phase, an economical analysis is introduced.

Simulation results show that through architectural bioclimatic modifications, the cooling thermal load of a typical household in Mexico can be sharply reduced. However, the current cost standing and the system variability relying on solar irradiance still proves to be not technically feasible for the local conditions. However a further analysis into this housing prototype taking into consideration the thermal comfort levels without the use of air conditioning is recommended.

Key words: Bioclimatic architecture, social housing, solar active cooling.

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LIST OF ABBREVIATIONS AND ACRONYMS

INSTITUTIONS

ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning
CFE	Comisión Federal de Electricidad (Federal Electricity Comission)
INEGI	Instituto Nacional de Estadística, Geografía e Informática
INFONAVIT	Instituto del Fondo Nacional de la Vivienda para los Trabajadores (Institute of the National Housing Fund for Workers)
SENER	Secreatía de Energia (Ministry of Energy)

PROGRAMS / CODES

HV	Hipoteca Verde
NOM-020	NOM-020-ENER-2011 Official Mexican Standard for Energy Efficiency in Buildings
DUIS	Desarrollos Urbanos Integrales Sustentables (Sustainable Integrated Urban Developments)

MATERIAL / PRODUCT

CMU	Concrete block unit
EPS	Expanded polystyrene

AREA / VOLUME

A/V	Surface area to volume ratio
TFA	Treated Floor Area
WFA	Window to Floor Area

ENERGY / POWER

CoP	Coeficient of performance
PE	Primary Energy
EE	Energy efficiency
SC	Shading Coefficient

UNITS

(m2·K)/W	Square meter Kelvin per Watt
Kg/(m2a)	Kilogram per square meter annually
Kg/(m2y)	Kilogram per square meter per year
KgCO2/kWh	Kilogram carbon dioxide per kilowatt-hour
kWh/(m2y)	Kilowatt-hours per square meter per year
kWh/d	Kilowatt-hours per day
R value	Thermal resistance, (m2·K)/W
U value	Thermal transmittance, W/(m2·K)
W	Watt
W/(m2·K)	Watt per square meter Kelvin
W/(mK)	Watt per meter Kelvin
λ (Lambda)	Thermal conductivity, (W/mK)

OTHER

$/USD	United States American Dollar
Meteonom	Climatological dataset software

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CHAPTER 1. INTRODUCTION.

1.1. Problem statement.

As the extinction of land without previous human intervention intensifies in all regions of the globe, it can also be noticed that this reduction occurs parallel to the urban sprawl growth. A high percentage of this land does not have the ideal conditions to become sustainable human settlements, or have ideal characteristics that would promote a good quality of life (UN, 1996). In Mexico's case, a good part of the habitable spaces could hardly meet any sustainable standards, or even more critical some sort of energy efficiency standard. This despite that one of the most important micro scale sustainable indicators is the thermal comfort variable for family dwellings units.

This thesis project aims to research and analyze the applicability of solar energy technologies to actively condition habitable spaces without the use of greenhouse refrigerants. As for the case study, an urban area is chosen with a warm-humid climate, as the interaction of passive and active techniques will be modeled. The purpose is to evaluate optimal sustainable alternatives to raise the quality of life of the population and to raise the energy efficiency in urban areas. Thus, the main objective is to evaluate the solar cooling system and its energy flows in this type of dwelling. That is, up to what point the input energy flow to the building envelope, within a self-contained housing unit, can be translated into input energy to the indoor climate.

The above set of conditions are linked with the following: Inefficient cities, family dwellings without the ideal thermal comfort, inadequate urban design planning, and bad integration of housing design and technology. All of these conditions create a very inefficient scenario and an outstanding waste of energy, energy that is considered a valuable key element in the Mexico's economic growth.

1.2. Hypothesis & objectives

1.2.1 Hypothesis

Based on the above problem statement, this thesis postulates the following hypothesis:

> The integration of solar cooling technologies in social housing developments located in Mexico's warm-humid climates zones is a viable alternative to acquire comfort levels.

1.2.2 General objectives

Evaluate the viability of solar cooling technology implementation in multi-dwelling housing units in Mexico with warm-humid climate conditions.

1.2.3 Specific Objectives.

- Objective 1

  Determine the thermal load in a typical family housing unit located in a warm-humid climate region in Mexico.

- Objective 2

  Reduce the thermal load required for this housing unit by incorporating architectural bioclimatic modifications.

- Objective 3

  Design and size a solar active cooling system in the housing sector.

- Objective 4

  Explore the challenges of the incorporation of solar active cooling systems in Mexico's housing sector.

1.3. **Justification.**

Energy production and all the economic activities generated around it, are considered the means by which the rise of the country's development can be accomplished. That is why, now in the twenty-first century, with all the technological advancements available there is no a valid reason by which a country such as Mexico, which has a tremendous potential to use solar renewable energy, denies itself of the potential of reigniting its economy based on solar technology implementation (Dorian et al, 2006). Also, given the fact that the housing market in Mexico is the only economic sector that has not stopped growing in the last decades, energy efficient measures need to be applied in the construction industry as well. Another factor to consider is that as a consequence of this intense solar radiation condition along with the country's geographic characteristics, a broad spectrum of hot-humid climate types are displayed all around the territory. Thus solar cooling technology can prove an effective tool to alleviate thermal comfort population needs while reducing pressure to economic dependency of oil and the environment. If applied, solar technologies such as active solar cooling could have a positive economic impact in the country (Callarotti, 2010).

Therefore, the following statements come as part of the conclusion:

- Justification 1

  It is required to develop a new city model that is efficient, and that incorporates and makes use of the alternative technology innovation.

- Justification 2

  Social housing development in Mexico should incorporate sustainable planning practices from the micro-scale to the site scale that that result in the increase of indoor comfort levels.

- Justification 3

  The adequate use of thermal solar energy will efficiently help to elevate human thermal comfort levels.

1.4. **Structure of the Thesis.**

This document is broken into five chapters. The first chapter –*Introduction*- lays out the formal grounds and the purpose of this study. Chapter two –Reference Framework- covers the two main background topics within this project, *Social housing in Mexico* and solar energy related topics, and then goes into the specific solar cooling technology. The third chapter touches base in the case study location and its characteristics, as well as in the proposed methodology. Then, on chapter four–*Results*- the outcomes of the methodology (briefly described below) are exposed.

This analysis is developed in five partial stages. The analysis at this first stage consists of a building simulation of the existing case study in order to determine thermal comfort hours, the thermal load, as well as the energy consumption of an air conditioning scenario. Secondly, the information obtained during the survey phase helps on refining the energy demand load. Finally, the sizing and simulation of the solar cooling system will determine the appropriateness of the system in each of these units. A comparison with a photovoltaic run system is then briefly discussed, and finally end with an energy yield and simple payback economic analysis.

Lastly, chapter five closes out this document with the discussion and observation par.

1.5. **Limitations.**

This study aims at analyzing the viability of the integration of a solar active cooling system into the typical Mexican housing unit, specifically a thermal ran system. However, it was deemed important to provide a comparative analysis against its counterpart: a photovoltaic ran system. The photovoltaic system configuration offers its own set of complexities, worthy of a whole research itself, and therefore each of the subsystems are not described in detail. The comparative in this document between both thermal and photovoltaic system is therefore executed in a general concept and only at an energy production level. Regarding the PV system, no theoretical framework was provided, until the system description, since the photovoltaic concept and technology is nowadays widely spread. Therefore the reader is expected to understand the interpretation of the results.

CHAPTER 2. REFERENCE FRAMEWORK

2.1. Theoretical framework

The purpose of this thesis is to analyze the viability of solar cooling technology to alleviate human thermal comfort conditions in household interior areas in locations with warm-humid climates. The efficient control of the heat transfer building elements is also considered a main focus in this thesis. By incorporating sustainable building design principles to the equation, the interior required thermal load could be matched to the cooling load generated by the solar cooling system. Underlying at the backbone of the conceptual framework, are the following concepts.

2.1.1 Mexico's current standing: social housing.

Since the 1960's and up until today, global environmental events have made the society aware of the fragile ecosystem we live in and made us conscious as well of our limited natural resources. At a settlement planning standpoint, urban sustainability theories now abound that proper actions have to be implemented at every different dimension by which a city's sustainability is measured in order to achieve a balanced urban ecosystem: First at the micro regional scale, second at the city scale, then at a sector scale, and lastly at a micro scale: The family dwelling unit. And within the second layer, the urban socio-environmental structure of the city must have good strategic urban planning, with a diverse mobility scheme integrated to the built environment. In reality, many of these adopted policies have had a socio-economic impact in nowadays post-modern society, but seldom have they had a direct impact in modifying the urban built environment to the good. This is due mainly because of an unbalanced and disturbed economical metabolism that keeps being translated into the social and urban fabrics (IISD, 2012) (SUME, 2012)

With some exceptions in Europe, most of the globe's urban areas are still fed with electrical power obtained mainly from burning fossil fuels. So it is logic to expect a rise in energy consumption as a consequence of population growth, and the expansion of urban sprawl in cities. But the biggest element that determines the impact level in energy consumption is the improvement in the population's quality of life. And it is within the last dimension addressed in the previous paragraph, the family dwelling unit, that the level in quality of life is translated into energy consumption. Fortunately, today's integration of technological evolution with recycling and material reuse strategies put together with ancestral architectural passive techniques can give form to a holistic dwelling design that can counterbalance this ailment (GIVONI, 1998).

In Mexico's case, its "sustainability policies" have been following the global environmental trend without really putting in practice its dogma. Cities in Mexico, no matter the size, have grown over this same 60 year timeline under an expansive and inefficient model, making use of a great amount of energy and resources. One of the sectors that consumes most of the energy within cities is the residential sector. The lifestyle and the lack of environmental education from both the population and design professionals promote an unsustainable urban development.

Figure 2-1. Villa de las Misiones, Baja California.

Source: CFE

Fraccionamiento del Valle de las misiones, in Mexicali, in the state of Baja California, is the first photovoltaic integrated housing project in Mexico, and is a great example of what public policy can do without a proper integration of technology and passive design. The incorporation of photovoltaic panels over each conventional housing unit does not maximize to the fullest its energy potential. In terms of its physical aspect, this type of social housing projects can be seen all along the country, without any differentiation in housing design between one state to another since the planning and design of cities and dwellings seldom incorporate a sustainability focus. Puerta de Anza is another example of many being built in recent years incorporating green building principles into their discourse. It is located in the city of Nogales in the state of Sonora. It is a DUIS project (Desarrollos Urbanos Integrales Sustentables) but despite this label, this project is built in the outskirts of the city pushing the dependence in automobile transportation and thus contradicting urban sustainable principles. And In terms of climate, Mexico is conformed by a wide range of climates zones, with very peculiar characteristics within each one. That is why the Köppen climate system was modified in Mexico soon after its implementation into subtypes by Enriqueta Garcia. Despite this condition, there has not been any consideration in establishing and enforcing a regional public policy when designing dwellings in cities around the country having all these different climate conditions. This, in turn has caused a big amount of investment in subsidies from CFE's side, Mexico's government owned and government controlled energy enterprise (SENER, 2012).

Figure 2-2. incorporation of solar system in rooftops.

Source: CFE.

As previously mentioned, the main approach of this solar cooling system performance analysis is to provide an assessment of the energy flows of this type of dwelling. With that said, the input energy flow within a self-contained in the housing unit of the heat production sub-system

Since the 1960's and up until today, global environmental events have made us aware of the fragile ecosystem we live in and made us conscious as well of our limited natural resources. While some of these events have been unforeseen catastrophic ones such as nuclear plant explosions, many others had to do with the implementation of environmental policies decided in international conferences and panels worldwide. For example, at a settlement planning standpoint, urban sustainability theories now abound that proper actions have to be implemented at every different dimension by which a city's sustainability is measured in order to achieve a balanced urban ecosystem: First at the micro regional scale, second at the city scale, then at a sector scale, and lastly at a micro scale: The family dwelling unit. And within the second layer, the urban socio-environmental structure of the city must have good strategic urban planning, with a diverse mobility scheme integrated to the built environment. In reality, many of these adopted policies have had a socio-economic impact in nowadays post-modern society, but seldom have they had a direct impact in modifying the urban built environment to the good. This is due mainly because of an unbalanced and disturbed economical metabolism that keeps being translated into the social and urban fabrics (IISD, 2012) (SUME, 2012)

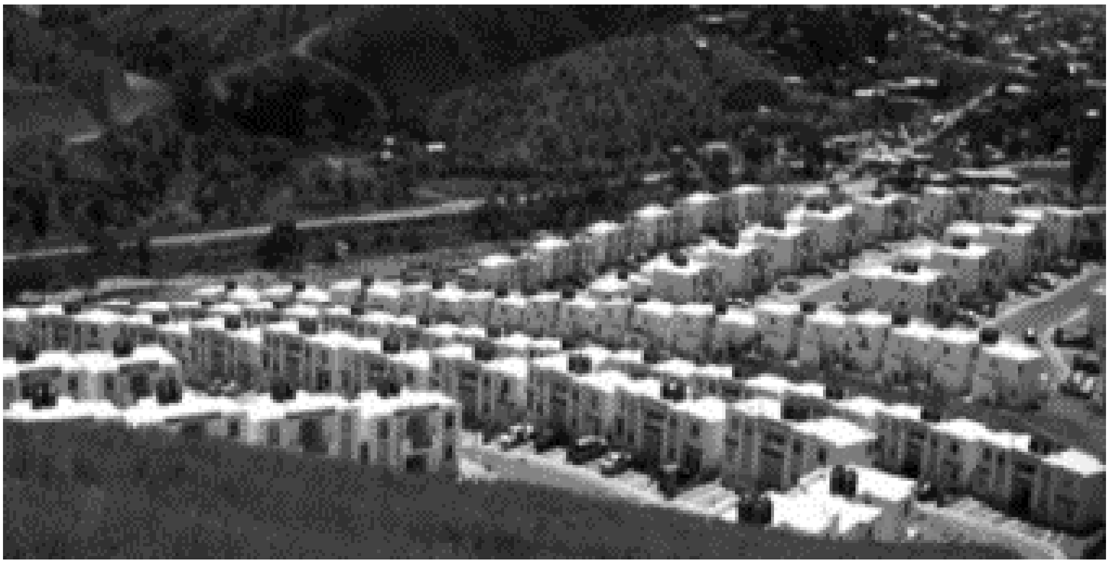

Figure 2-3. DUIS housing development in the state of Sonora.

Source: DUIS program.

During this same timeline, and mainly as a consequence in the rise of fossil fuel prices, alternative means to generate energy to feed our lifestyles have been rediscovered, and developed, to a point where, now, it is even possible to power up cities just by these means. In theory. Because, in spite of this potential market, this progress in the renewable energy field has not had a direct & significant impact in the urban fabric at a worldwide scale. With some exceptions in Europe, most of the globe's urban areas are still fed with electrical power obtained mainly from burning fossil fuels. So it is logic to expect a rise in energy consumption as a consequence of population growth, and the expansion of urban sprawl in cities. But the biggest element that determines the impact level in energy consumption is the improvement in the population's quality of life. And it is within the last dimension addressed in the previous paragraph, the family dwelling unit, that the level in quality of life is translated into energy consumption. Fortunately, today's integration of technological evolution with recycling and material reuse strategies put together with ancestral architectural passive techniques can give form to a holistic dwelling design that can counterbalance this ailment (GIVONI, 1998).

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2.1.2 **Mexico's current standing: Solar renewable energy technologies**

- Photovoltaic systems.

Solar cells, also called photovoltaic (PV) cells convert sunlight directly into electricity. Today, thousands of people power their homes and businesses with individual solar PV systems. Utility companies are also using PV technology for large power stations. Solar panels used to power homes and businesses are typically made from solar cells combined into modules that hold about 40 cells. A typical home will use about 10 to 20 solar panels to power the home. The panels are mounted at a fixed angle facing south. Many solar panels combined together to create one system is called a solar array. For large electric utility or industrial applications, hundreds of solar arrays are interconnected to form a large utility-scale PV system (NREL, 2013). IN 2007, it was estimated that in Mexico, the total capacity was 18.5 MW, generating 8,794.4 MWh per year. This was elevated to 25.12 MW in 2009 (SENER, 2009)

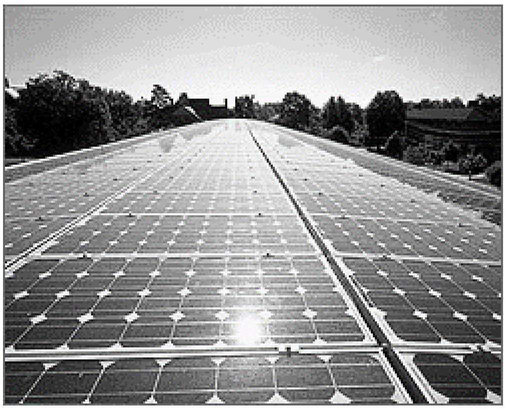


Figure 2-4. Example of a solar array.

Source: NREL.

- Solar hot water and space heating.

Solar hot water technology uses the sun to heat water used in buildings. Most solar water heating systems for buildings have two main parts: a solar collector and a storage tank, although in Mexico the system's design has many variations. The most common solar thermal collector is called a flat-plate collector. Mounted on the roof, it consists of a thin, flat, rectangular box with a transparent cover that faces the sun. Small tubes run through the box and carry the fluid — either water or other fluid, such as an antifreeze solution — to be heated. The tubes are attached to an absorber plate, which is painted black to absorb the heat. As heat builds up in the collector, it heats the fluid passing through the tubes, and then is brought inside to complement the water heating process (NREL, 2013). Mexico is within the ten countries with more solar water heaters with an estimated total panel surface of 650,000m2 (SENER, 2009).

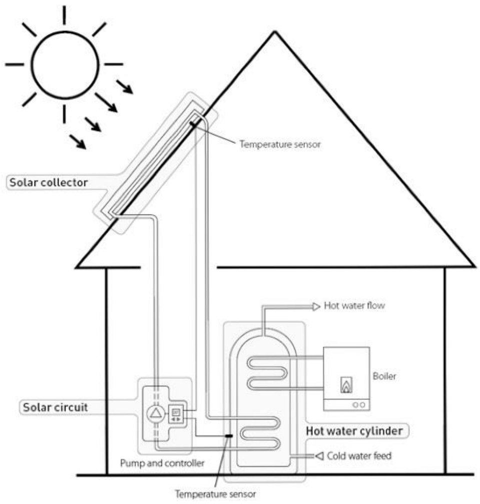


Figure 2-5. House water heater system

Source: APA PAC30

Solar thermal collectors, on the other hand, can also be used for space heating purposes. In principle, water is pre-heated using a solar system. This water can, in turn, be drawn to the interior space into a determined distribution system. So depending on a given location, a solar water collector system with heating support may achieve a sufficient amount of solar energy to cover a large indoor area. A large volume storage tank may be desirable, so that the remaining required heat may be produced by an auxiliary boiler. All modern heating systems have this configuration, so that this would enable the desired temperature control settings. This type of system should be carefully designed in order that the required energy matches the living area (DSG, 2005).

- Solar electricity.

Power plants generally use fossil fuels as a heat source to boil water. The steam from the boiling water spins a large turbine, which drives a generator to produce electricity. However, a new generation of power plants with concentrating solar power systems uses the sun as a heat source. Better known as Concentrated Solar Power (CSP), this system is subcategorized into three different design types: linear concentrator, dish/engine, and power tower systems (NREL, 2013). Currently, there are a few projects getting built in north Mexico, in the states of Sonora and Baja California that will use this technology (SENER, 2013)

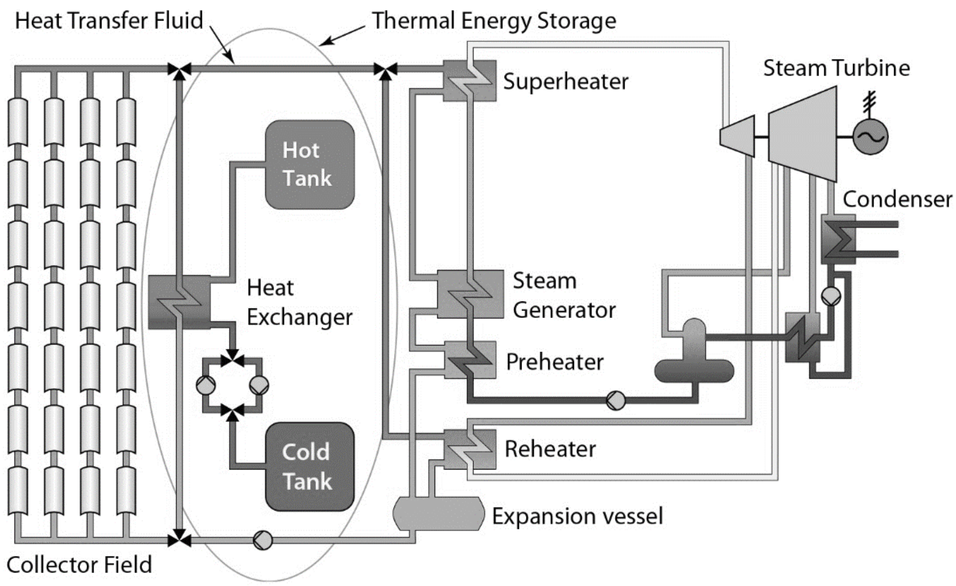


Figure 2-6. Parabolic through concentrated solar power plant diagram.

Source: NREL.gov

- Passive solar heating and daylighting.

Passive solar design takes advantage of a building's site, climate, and materials to minimize energy use. A well-designed passive solar home first reduces heating and cooling loads through energy-efficiency strategies and then meets those reduced loads in whole or part with solar energy. To be successful, a passive solar home design must include some basic elements that work together such as control, aperture, distribution, absorber, and thermal mass (DOE, 2013). Many of the passive solar heating design features also provide daylighting. Daylighting is simply the use of natural sunlight to illuminate a building's interior (NREL, 2013). In general, passive design and daylighting was practiced in Mexico many centuries ago before the modern era. This set of ancient knowledge principles in dwelling construction to counterbalance the micro-climate effects have now been discarded in government housing development policies.

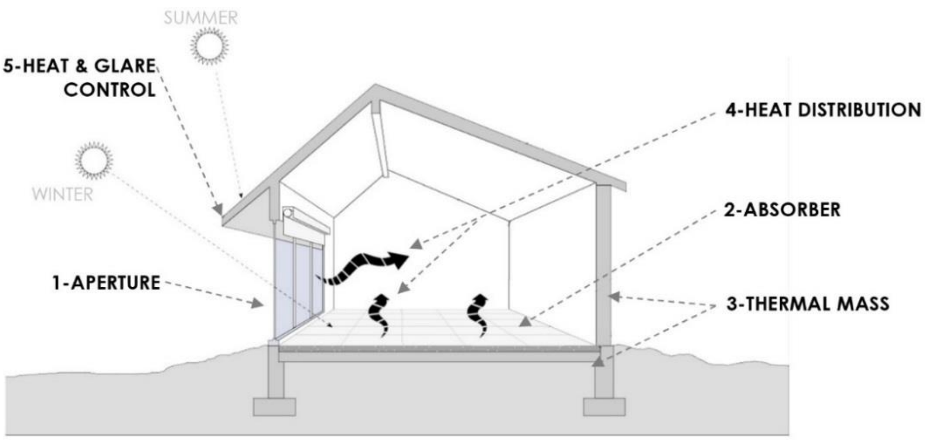


Figure 2-7. Elements of solar passive design

Source: DOE.org

- Active solar cooling

Solar cooling technology can prove an effective tool to alleviate thermal comfort in the indoor environment, in places where there is optimal solar radiation conditions. Knowledge of solar cooling systems is not well wide spread, despite its potential to provide thermal comfort without the use of extensive energy resources (MARINCIC, 2012). Coincidentally, the need for cooling is proportional to the solar intensity, thus matching the time of peak cooling demand with the time of maximum sunlight. The technology characteristics can be divided into roughly two approaches: heat-activated systems which rely on solar thermal energy, such as an absorption refrigeration cycle that is driven primarily by heat input, and work-activated systems like the conventional vapor-compression cycle which requires compressor work input that is generally electrically powered (OTANICAR, 2012). Today, it is believed that heat activated systems have many advantages over PV run ones, one of them being that a heat activated systems have a much better overall efficiency.

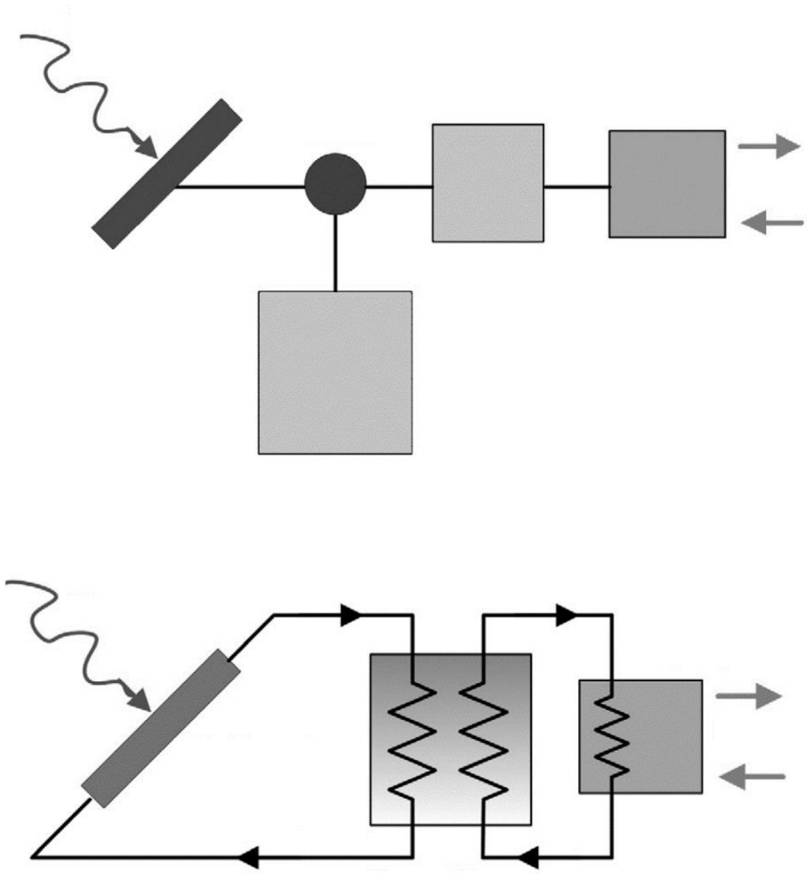


Figure 2-8.Solar active cooling – PV driven system (above) and a thermally driven system (below) example

Source: Adapted from OTANICAR (2011)

2.1.3 **Solar cooling – Thermal System**

2.1.3.1. System components

- Solar collectors

An extensive variety of solar thermal collectors is available for solar cooling purposes. Due to cost reasons stationary collectors can satisfy budget and performance demand. While it's most popular application is usually intended for domestic hot water production, flat-plate collectors, for example, are also used for solar active cooling systems. They require to be of a high performance quality, since it is necessary to couple their thermal captured energy with thermally driven chillers. Figure 2-9 shows the different types of collectors types used for solar cooling applications.

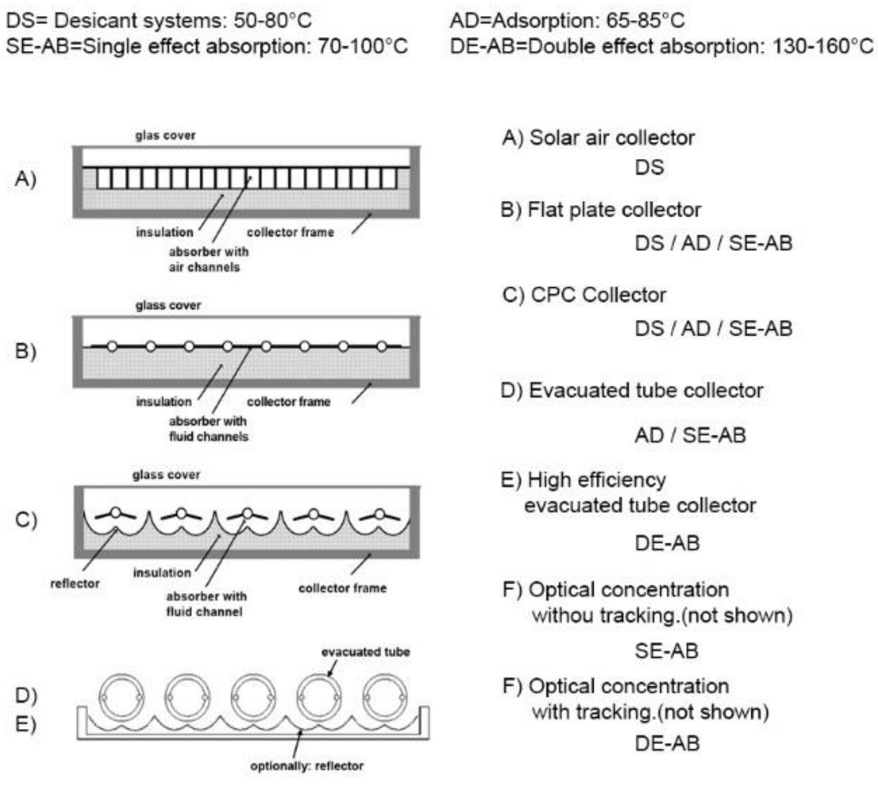


Figure 2-9. Stationary collectors for solar cooling applications.

Source: Modified from SOLAIR / Fraunhofer ISE

When selecting the appropriate panel for solar cooling, a selective coating, with an improved insulation, and a high stagnation safety should be considered (SOLAIR, 2009). The chiller lowest driving temperature requires the media output to be approx. above 60°C, and this maybe in direct correlation to the site and climatic conditions. Flat plate collectors can also be used as solar air collectors as shown in the image, although its construction is limited to desiccant cooling systems, since these types of systems require the lowest driving temperatures, starting at approx. 50°C and allows under special conditions the operation without thermal storage.

A common understanding on the solar production areas is required when selecting a panel type. The gross, the aperture, and the absorber area are key definitions to understand when limited in space, performance, or budget factors. The most critical issue affecting the performance of the collector is the heat transfer circulation with the absorber, although different solutions and collectors types such as the solar air and evacuated tube collectors are available on the market at different costs (TREBERSPURG, 2011). For example, evacuated tube collectors, unlike their flat plate counterparts, may have their absorber area increased due to their pipe shape, may deviate by more than 25% (SOLAIR, 2009).

Concentrating collectors, have the greatest potential for solar cooling, since they can provide steam of hot water at driving heat temperatures above 150°C for 2-effect absorption chillers. This configuration can be expected to drive the COP-thermal higher than 1.0, with less driving installed heat capacity and with a smaller heat rejection system. Double-effect chillers, however are not available in the small capacity range, and therefore this may apply to high capacity chillers only. Concentrated collectors can also provide driving heat for ammonia/water absorption chillers, where a high temperature lift from chilled water temperature to heat rejection temperature is required. Finally, tracked concentrating collectors are generally more appropriate at sites with a high direct radiation fraction at global diffusion (SOLAIR, 2009).

- Chiller Systems

(Adsorption) Market available adsorption chillers use water as a refrigerant and silica gel as a sorbent. The machine consists of two sorbent compartments, one evaporator and one condenser (see figure 4.3.4.1). The chiller usually can achieve a thermal COP of about 0.6 (with a driving heat temperature of about 80°C), and operation is still possible at a heat source temperature of approx. 60°C. For small systems under 30kW of cooling capacity, the adsorption chiller chillii STCR, for example, with a cooling capacity of 7.5 kW is the appropriate device for small capacity projects. Some of its advantages is its simple mechanical construction, and that there is no danger of crystallization and thus no limitations in the heat rejection temperatures. Also, an internal solution pump does not exist and hence only a minimum of electricity is consumed. However, this equipment is much heavier than its counterparts (TREBERSPURG, 2011).

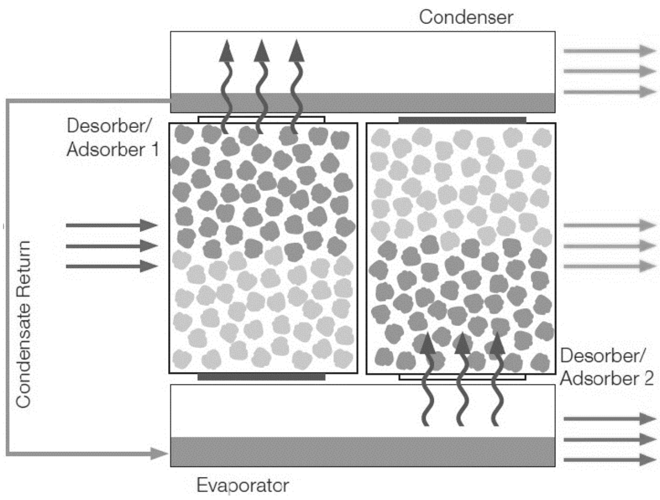


Figure 2-10. Adsorption chilled process.

Source: Solarnext, 2013.

- Storage and back-up system

The main purpose of the storage buffer tank, hot or cold, in a solar-active cooling system is to overcome mismatches between solar gains and cooling loads (REICHARDT, T.F. (2010). That is, they can be used if the demand for cold water does not match the availability of the heating, or in order to equalize the needed heating (or cooling) power due to the specific demand of each system. In the case, for example, that the sun is not shining but you need the cold water for the load subsystem, and cold water can be drawn from the cold water storage tank. Depending on the cold production needed to continue providing chilled water, a larger storage tank for times without cold production from the chiller system to continue to provide chilled water may be needed. A hot water storage tank can, on the other hand, be useful when drawing hot water to the chiller system when there is not sun availability. On the other hand, a back-up-system such as a gas or electric-ran water heater could be used if the hot water production is idle and or cannot provide the needed heating power to the chiller.

2.1.3.2. Building integration.

The planning and design for solar air conditioning systems is considerably complex. Within a solar cooling system, there are various subsystems involved which are interconnected to each other. The heat production subsystem is the one directly related to the solar collectors. The cold production subsystem, on the other hand, may vary in size, capacity, and technology development. Finally, integrating and distributing the cooling effect generated by the cold production system is the task of the load distribution subsystem.

In order to produce a successful solar cooling project many factors need to be fine-tuned. One of them is the cooling load to be considered. But unlike solar water heating systems, where the most significant difference involves the number of persons and its resulting hot water consumption, a solar cooling system requires its cooling load to be precisely determined. Typically, for the design of a standard cooling system average values are many times used for determining internal cooling loads depending on the use. These rules of thumb, as a matter of principle, can only be used as rough reference values. It is in reality the design of the building envelope and the local climate that significantly influence the resulting cooling needs of the system, and so the same applies to a solar cooling system, but in a more intrinsic manner (DSG, 2005).

Many external building factors are key to accurately predict the correct load. External shading devices over an extensively glazed building can significantly reduce the required cooling load. Building shadowing, as well, throughout the day can bring the building load requirement downward. On the other hand, depending on the integration of the solar array, if the shadowing remains persistent over it, this may translate in significant power reduction of the cooling system. And these are precisely the factors that oblige the planner to plan holistically a solar cooling system (DSG, 2005).

Determining the cooling capacity according to peak load methods, and to a certain extent, the frequency at which these occur is advisable in order to avoid over dimensioning system. Paradoxically, this same rule applies for calculating the heat production subsystem capacity for a solar cooling system. 1000 W/m2 may occur for only for a few short period each day in moderate climates. In the latter case, simulation software with coupled subsystem simulation, are advisable in order to avoid over dimensioning of any of the sub-system, leading to more precise results (DSG, 2005).

2.1.3.3. System approaches.

The following system configurations are capable of providing solar cooling: Systems with solar liquid collectors, with solar air collectors, with solar heat input only via the heat storage tank, and systems with direct input of the solar heat into the air-conditioning technology. In addition some systems can also have auxiliary heating in the heat storage tank for a prolonged used beyond the direct solar gain period. Hybrid versions based on these systems are also available (DSG, 2005). ________________ without getting into its hydraulic components, further describes these schematic diagrams so to simplify the integration of the solar technology understating. This is the most important part of the system, since the solar technology implemented will determine the capacity of the system.

Solar cooling system configuration	Collector type	Cooling Production	coupling/ decoupling	Pros / Cons
SCS with solar liquid collectors, where the solar heat input is only via de heat storage tank. There is also aux heating in the storage tank.	*etc, fpc*	Ab/Adsorption chillers, solid/liquid desiccant cooling systems.	HPs»CPs decoupling trough heat storage tank.	Increased heat storage loss through auxiliary heating in the buffer storage tank.
SCS with solar liquid collectors, where the solar heat input is only via the heat storage tank, but with no auxiliary heating in the heat storage tank.	*etc, fpc*	Ab/Adsorption chillers, solid/liquid desiccant cooling systems.	HPs»CPs decoupling trough heat storage tank.	Reduced heat storage loss through auxiliary heating outside the heat storage tank.
SCS with solar liquid collectors, where there is direct solar input and solar heat input via the heat storage tank, without auxiliary heating.	*etc, fpc*	Ab/Adsorption chillers, solid/liquid desiccant cooling systems.	HPs»CPs direct coupling trough heat storage tank.	Storage tank only contains solar heat. Cons: Collector yield is potentially higher, as the direct connection of solar heat is possible.
SCS with solar air collectors equipped with an ambient air intake, with direct solar heat input but no heat storage tank.	*sac*	Solid/liquid desiccant cooling systems.	HPs»CPs»LDs direct coupling.	Pros: Storage free system; Solar air system w/ ambient air temperature; Very low investment costs.
SCS with solar air collectors equipped with a regeneration air intake, with direct solar heat input, but no heat storage tank. When cooling, regeneration air is drawn into the solar air collector after the heat recovery wheel.	*sac*	Solid/liquid desiccant cooling systems.	HPs»CPs»LDs direct coupling.	Pros: higher collector outlet temperatures are attired. Cons: Duct additional investment.
SCS with solar air collectors equipped with ambient air intake, with direct solar heat input, and a heat storage tank, but not auxiliary heating.	*sac*	Solid/liquid desiccant cooling systems	HPs»CPs»LDs direct coupling	Pros: When in heating mode, diffuse irradiance is also usable in the system.

SCS=Solar Cooling System, HPs=Heat Production sub-system, CPs=Cold production sub-system, LDs=Load Distribution sub-system, etc=evacuated tube collector, fpc=flat plate collector,

Table 2-1. Solar thermal cooling, system configuration.

Source: from author. Information adapted from (DSG,2005)

2.2. Previous studies

The following table shows several case studies that conform the literature review upon which the methodology was built.

Author	Year	Article title	System Type	Analysis Type
He et al.	2000	*A solar cooling project for hot and humid climates*	Solar passive design strategies	Testing - Human comfort
Masson & Qu & Archer	2006	*Performance modeling of a solar driven absorption cooling system for carnegie mellon university's intelligent workplace*	Active cooling system - Absorption	Simulation - Cooling performance
Syed et al.	2006	*A study of the economic perspectives of solar cooling schemes*	Solar active cooling system - Absorption, ejector, compression	Life cycle cost analysis
Velazquez	2007	Desarrollo de un sistema de aire acondicionado solar por absorcion avanzado	Solar active cooling system - Absorption	Design & testing - Cooling performance
Luo et al.	2007	*An efficient solar-powered adsorption chiller and its application its application in low-temperature grain storage*	Solar active cooling system - Adsorption	Design & testing - Cooling performance
Vasta et al.	2009	*Simulation of a small size solar assisted adsorption air conditioning system for residential applications*	Solar active cooling system - Adsorption	Simulation - Cooling performance
Mengistu	2010	*Study of solar cooling alternatives for residential houses in Bahir Dar city*	Solar active cooling system - Adsorption	Design - Cooling performance
Reichardt	2010	*Technical and economic assessment of medium sized solar-Assisted air-conditioning in Brazil*	Solar active cooling system - Absorption	Design & LCC
Teo & Lee & Hawlader	2011	*An active cooling system for photovoltaic*	Hybrid PV/T System	Simulation - Cooling performance
Otanicar & Taylor & Phelan	2012	Prospects for solar cooling – *An economic and environmental assessment*	Solar thermal and non-thermal systems	Environmental & LCC analysis
Serag-Eldin	2012	*Design of heat storage for a solar concentrator driving an absorption chiller*	Solar thermal storage	Design & simulation
Suleiman et al.	2012	*Transient simulation of a flat plate solar collector powered adsorption refrigeration system*	Solar active cooling system - Adsorption	Simulation - Cooling performance
Sayfikar & Behbahani-nia	2013	*Study of the performance of a solar adsorption cooling system*	Solar active cooling system - Adsorption	Simulation performance & cost analysis
Al-Mogbel et al.	2013	*The potential of solar adsorption air-conditioning in Saudi Arabia: A simulation study*	Solar active cooling system - Adsorption	Simulation - Cooling performance
Athukorala & Sarathchandra & Chiu	2013	*Feasibility study on absorption cooling based thermal energy storage .*	Solar active cooling system - Absorption & storage	Simulation performance & cost analysis

Table 2-2. Case studies – Literature review.

Source: from authors

From the literature review shown above, the following solar cooling studies have been chosen as the most representative examples of its applicability and the different approaches to analyze its advantages over the conventional systems. The first representative study was done in Mexico by the Universidad Autónoma de Baja California. It is titled as the development of a solar air conditioning system by advanced absorption (VELAZQUEZ, 2007). It focused in the evaluation of device prototypes as stand-alone units to measure their efficiency. Another study done by the Loyola Marymount University in the year 2012 focuses in the environmental and economic assessment comparison against a photovoltaic run air conditioning system (OTANICAR, 2012). This study does not focuses on its applicability but rather in its economic and environmental advantages and disadvantages in the short, medium and long term. Finally, in Brazil a master thesis study made at the Pontifica Universidade Catolica de Rio de Janeiro titled “Technical and Economic Assessment of Medium Sized Solar-Assisted Air-Conditioning in Brazil” (REICHARDT, 2010) incorporates a whole building energy simulation prior to the solar cooling system sizing. Results obtained are then compared against a conventional cooling system. This study doesn’t integrate solar passive strategies into the building design prior to the System sizing.

Although this studies have given significant insight into the strengths and weaknesses of the current state of the art, the energy efficiency of the system vis-à-vis a less energy demanding area has not been address. Since the technology is now commercially available, a holistic approach that considers both the reduction of thermal load by making the envelope more efficient and maximizing the potential of the solar cooling gain is further suggested.

2.3. Conceptual framework

Based on the literature review, and other information looked for, Figure 2-11 shows the conceptual framework. The underlying principle around the conceptual framework is to not look at technology as the only basis of knowledge that will provide a solution to the human thermal comfort needs in human dwellings. On the other hand, design strategies cannot themselves alleviate this deficiencies either in certain location with harsh climate conditions such as warm-humid climates, where outdoor temperature is never within the thermal human comfort range, making it impossible to change this dynamic in the indoor space. It is imperative therefore to provide an integral housing design solution that is both efficient and that incorporates technological advancements.

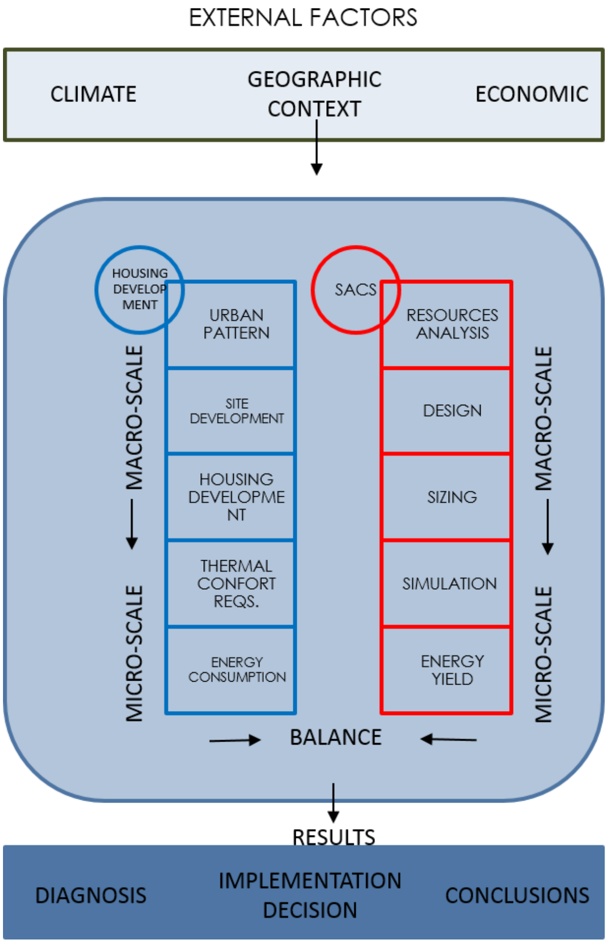


Figure 2-11

CHAPTER 3. CASE STUDY & ANALYSIS METHODOLOGY

3.1. Case study location.

Mundo Habitat, an existing urban multi-family housing development located in southeast Mexico was selected for the purposes of this study. This residential development was built in the outskirts of Playa del Carmen, a city that is part of Quintana Roo's state, and currently a tourist hotspot along the Mexican Caribbean in the Yucatan's Peninsula. At first, several different cities in Mexico where today is common the use mechanical air conditioning systems to cool down the indoor environment were considered. And in order to come down to the final city selection, the most important variables were taken into consideration.

The first set of conditions relevant to the selection of the case study location relate to weather. In general, warm cities are found in almost every corner of the Mexican territory. This depends in many physical, geographic and meteorological factors. The different solutions used by the population to level off the interior thermal comfort conditions are diverse, and many of these solutions could be as simple as to provide a natural ventilation flow within the room. However, the population living in cities with warm humid and warm sub humid climates are most of the time limited to mechanical solutions in order to provide themselves with a comfortable indoor environment. Some of these cities are Villahermosa in the state of Tabasco, Colima in the state of Colima, Mérida in the state of Yucatán, and Ciudad Valles in the state of San Luis Potosí. Therefore a high range of daily mean temperature value coupled with a high relative humidity factor was the first criteria for the city selection. Precise climatic description of the area is found in the annex section.

The second main variable has to do with the housing infrastructure. It is true that although the current technological advancements have allowed indoor environment to adequate their thermal comfort through mechanical means, the current housing infrastructure has not evolved to reduce the required cooling loads. In reality, in these last 25 years of housing development in Mexico, many things have change: from the housing typology, their reduction in size, their layout arrangement, their preferred location due to cites' expansion, and even the architectural style. Except housing interior thermal comfort conditions.

So considering the climatic variables as well as having one of the highest rates of housing demand and supply in the country, the initial search for a case study location focused within the city perimeters of Cancun. Cancun is also a touristic hotspot located just a few miles north of Playa del Carmen. But the reasoning behind selecting the housing case study location in Playa del Carmen derived that Cancun, having undergone a surplus of housing development already and having reached its city territorial limit cap, could serve as an example of years to come to Playa del Carmen in terms of the Housing market. Therefore the following section will provide a brief description of the Solidaridad Municipality, where Playa del Carmen is located. It will describe its economic relation within the whole Riviera Maya urban corridor, and will highlight its linked economic activities.

- Geographic context

Playa del Carmen' geographic reference position is between 20°45' and 19°46' north latitude, and between 86°57' and 88°05' west longitude. Its territorial expansion comprises 2,205 km2, which represent 4.33% off the total state territory. It counts with an 80km littoral at the Caribbean coastline. Its territorial boundaries are the following: Cancun to the North, Lazaro Cardenas to the north-east, Cozumel and the Caribbean Sea to the east, and Tulum to the south (SOLIDARIDAD, 2014).

Figure 3-1 in the upper image shows Playa del Carmen location in relation to Cancun and other important municipalities along the Mayan Riviera corridor. In contrast, the enlarged image displays Mundo Habitat location within the vicinity area. One main characteristic that one can observe, is the high degree of infrastructure development along the seaside in the whole corridor, which is can be is attributed to the high tourism activity that has boomed due to its archeological sites and beaches. Notice that the site of study is located in the periphery of the city as a result of housing demand years earlier and therefore recent population settlement in search for work opportunities in that area.

- Demographics.

Playa de Carmen total population comprises 193,805 habitants, of which 30.2 % were between the 15 and 29 age ranges. Its population annual growth rate is within the 6.8% (INEGI, 2013). The amount of households has increased from 78794 in 1995 to 188522 in 2010, with an average of 3.5 occupants per household. However, only 176623 of households had access to electricity. In 2010, the State of Quintana Roo had a 12.60% immigration rate which was the second highest amongst all 32 States. (INEGI, 2013).

Its main economic activities are tourism, with agriculture and livestock breeding coming in second place as well as commerce. Due that the entire urban corridor has experienced an uninterrupted and steady touristic growth, all of the nearby municipalities have a very high and steady growing economic activity as well, as its territorial expansion continues and pushes this area to become a merged metropolitan region in the near future.

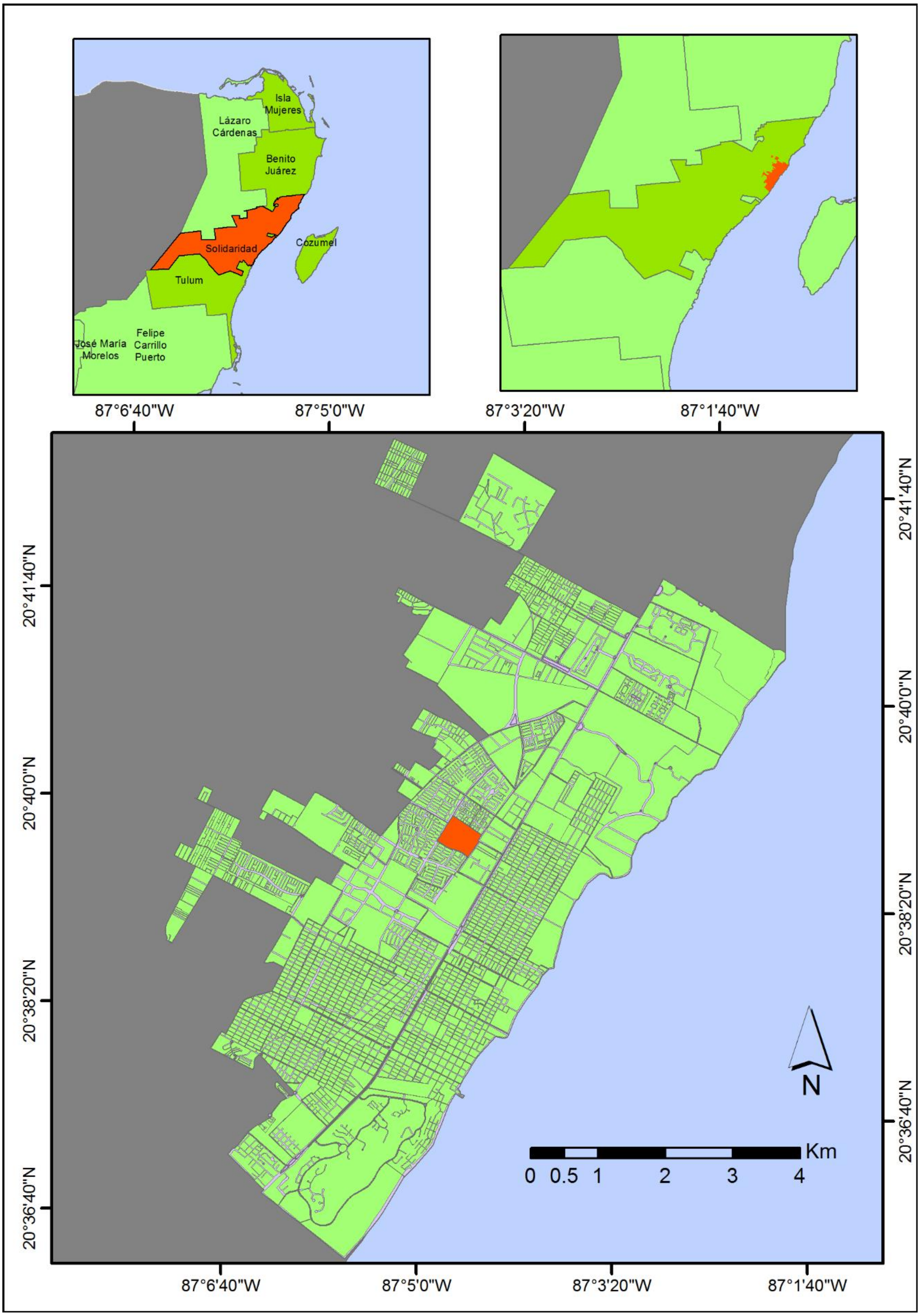
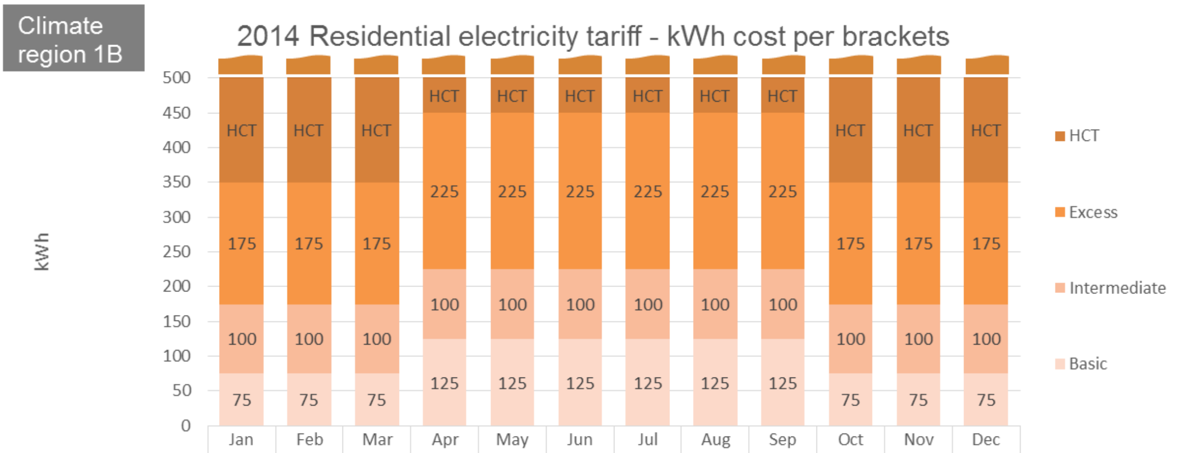


Figure 3-1. Case study Location - Regional vicinity map.

Source: by author, with information provided by INEGI.

3.1.1 **Energy balance – Electricity**

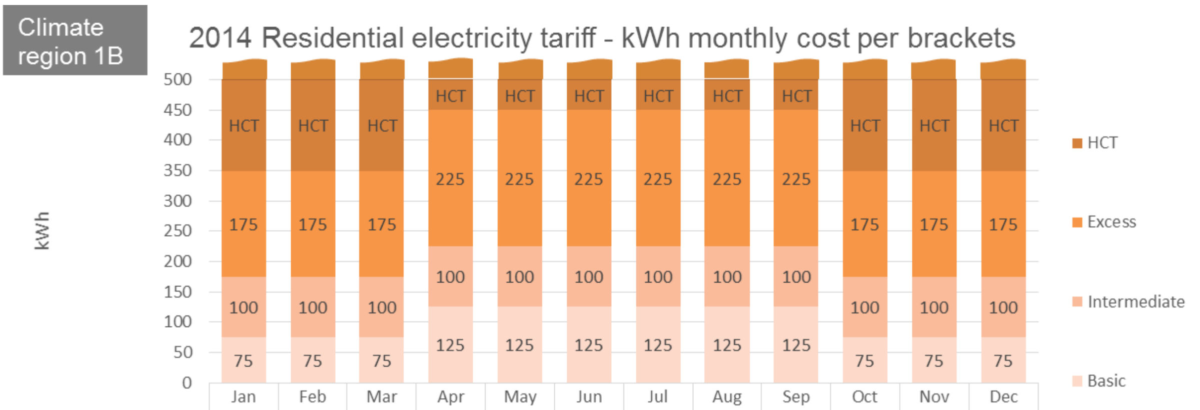
The current 2014 electricity residential tariff is as shown below:



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Excess	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Intermediate	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.08	0.08
Basic	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06
HCT price per kWh	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Figure 3-2. 2014 Residential electricity tariff – kWh cost per brackets.

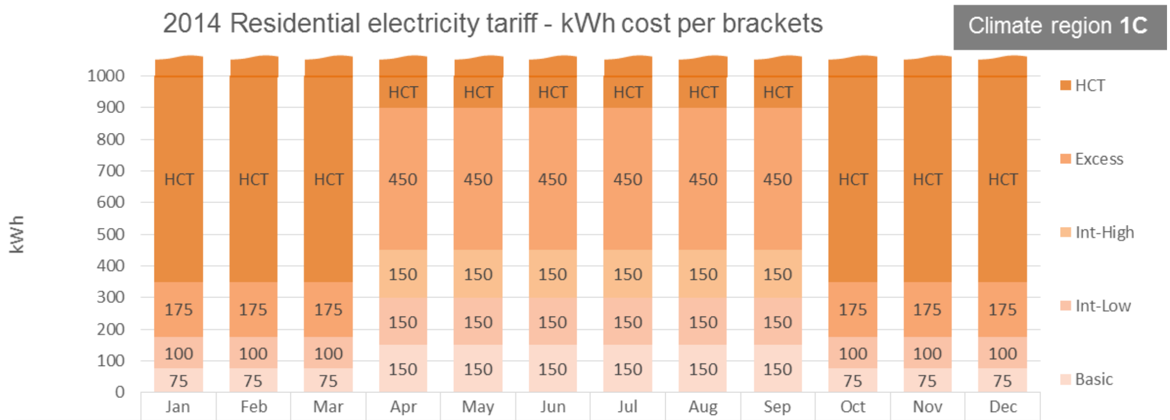
Source: By author with information obtained from CFE.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Excess	37.80	37.92	38.05	49.05	49.21	49.37	49.52	49.68	49.84	38.89	39.01	39.13	Tot monthly
Intermediate	7.38	7.41	7.43	6.38	6.40	6.42	6.45	6.47	6.49	7.59	7.61	7.64	
Basic	4.55	4.58	4.59	6.80	6.81	6.84	6.85	6.88	6.89	4.71	4.73	4.75	
TOTAL	49.73	49.91	50.07	62.23	62.42	62.62	62.82	63.03	63.22	51.19	51.34	51.52	680.00 USD
HCT price per kWh	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	Tot Annual (w/out HCT)

Figure 3-3. 2014 Residential electricity tariff – kWh monthly cost per brackets.

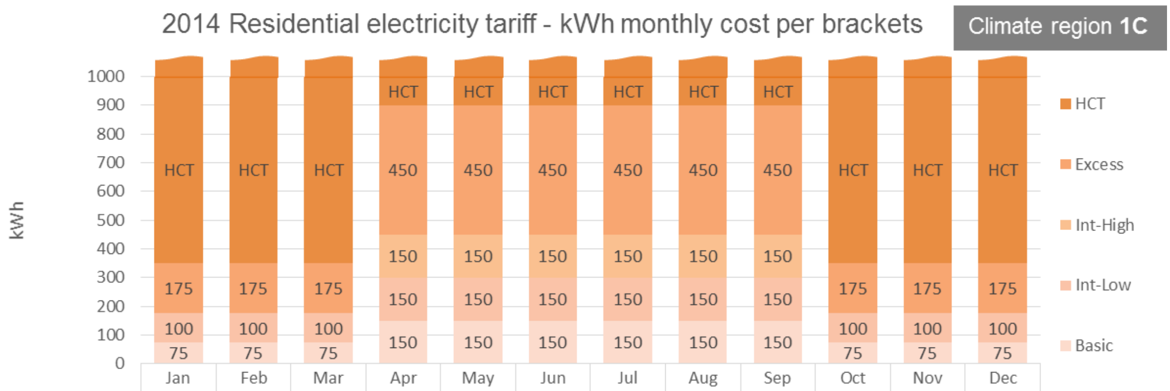
Source: By author with information obtained from CFE.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HCT per kWh	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Exc	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Int-H				0.08	0.08	0.08	0.08	0.08	0.08			
Int-L	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.08	0.08
Bas	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06

Figure 3-4. 2014 Residential electricity tariff – kWh monthly cost per brackets.

Source: By author with information obtained from CFE.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Exc	37.80	37.92	38.05	98.10	98.42	98.73	99.05	99.36	99.68	38.89	39.01	39.13	Tot monthly
Int-H				12.24	12.27	12.30	12.35	12.39	12.44				
Int-L	7.38	7.41	7.43	9.57	9.60	9.63	9.68	9.71	9.74	7.59	7.61	7.64	
Bas	4.55	4.58	4.59	8.16	8.18	8.21	8.22	8.25	8.27	4.71	4.73	4.75	
TOTAL	49.73	49.91	50.07	128.07	128.46	128.87	129.29	129.71	130.11	51.19	51.34	51.52	1078.25 USD
HCT per kWh	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	Tot Annual

Figure 3-5. 2014 Residential electricity tariff – kWh monthly cost per brackets.

Source: By author with information obtained from CFE.

3.1.2 **Solar resource assessment.**

Figure 3-6represents the monthly average insolation incident on a horizontal surface, in terms of the solar radiation potential at the case study location. Depending on the proposed active solar cooling system, weather a thermally or photovoltaic driven system, each system's efficiency will determine the percentage of this energy resource that could potentially be used for the cooling load generation.

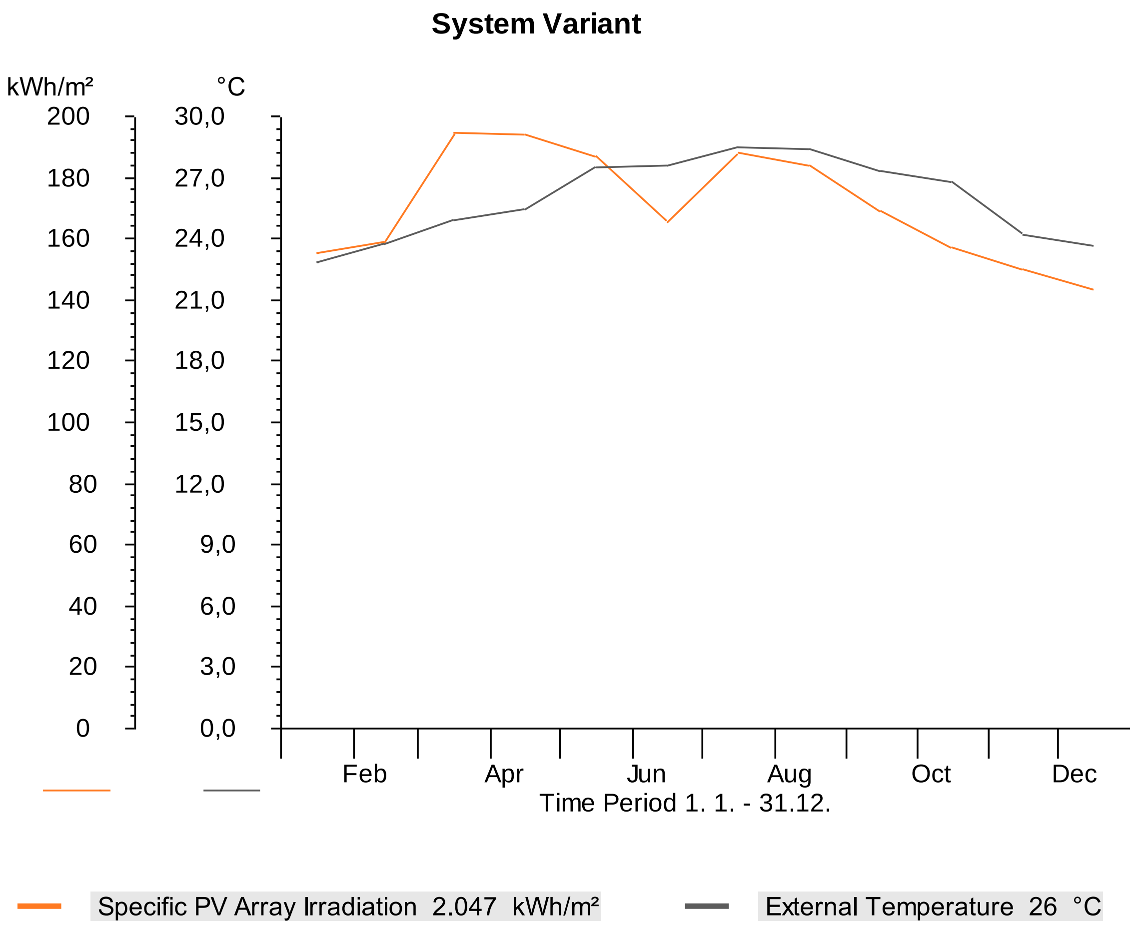


Figure 3-6. Playa del Carmen monthly average temperature vs. Solar radiation.

Source: PVSol software.

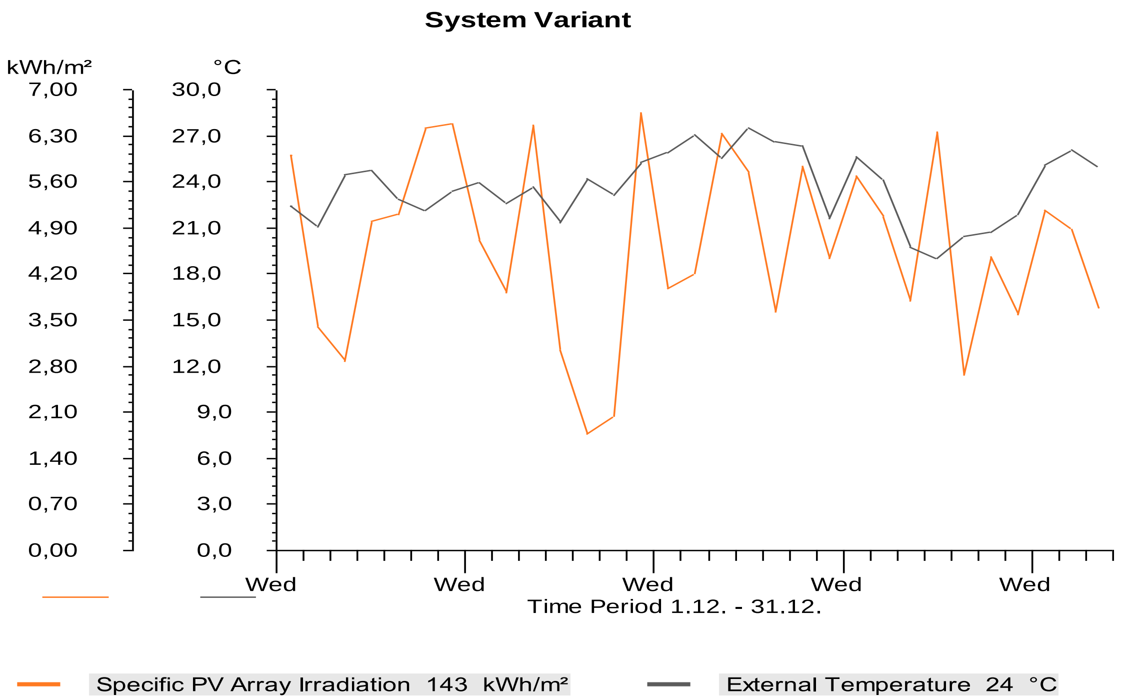


Figure 3-7. Playa del Carmen weekly average temperature vs. solar irradiance – December.

Source: PVSol software.

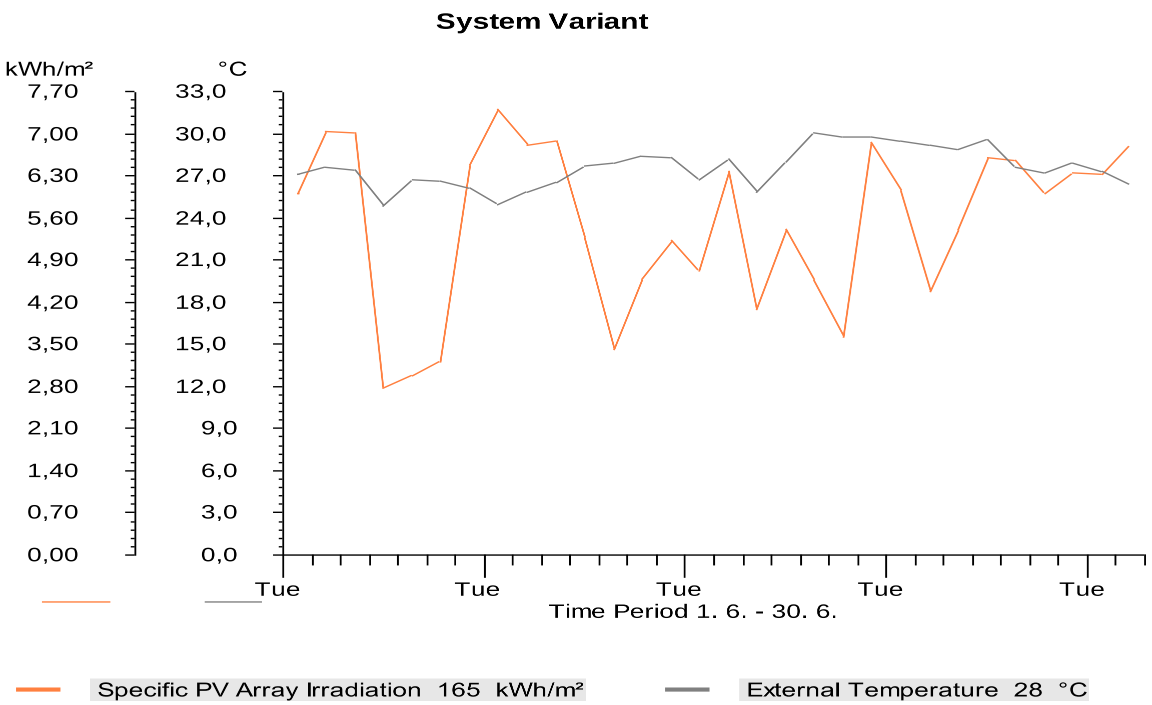


Figure 3-8. Playa del Carmen weekly average temperature vs. solar irradiance – June.

Source: PVSol software.

3.1.3 **Multi-family housing dwelling**

Mundo Habitat is a residential housing development completed in 2010 by Grupo VIVO Inmobiliario S.A de C.V. This housing development comprises a total of 215 housing units with different styles, completed in 2010. This housing development comprises a total of 215 housing units, with three main different model prototypes.

3.1.4 **Location**

The residential development lies 2 km. westward from Playa del Carmen commercial district, between 28 de Julio Street from the northbound, and south bounded by Luis Donaldo Colosio Street. Its east boundary is the Cancun-Chetumal highway, and westward is bounded by Libramiento Playa del Carmen highway.

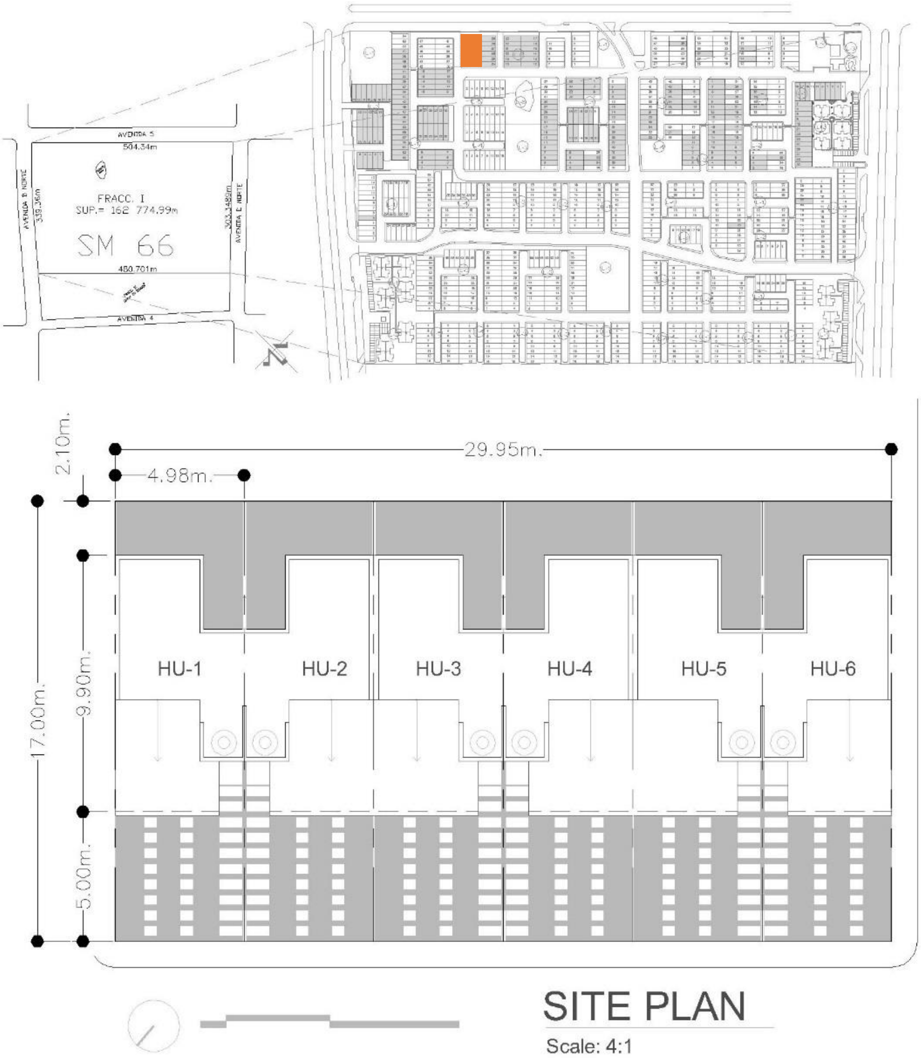


Figure 3-9. Mundo Habitatt. Esmeralda housing type location and site plan.

Source: Modified by author from Grupo VIVO drawings.

The project case study location is considered to have a warm-humid climate. For the purposes of this study, the climate data of Juarez International Airport was used for the building simulation study, as well as for the photovoltaic and solar thermal study. This climatic data was provided by the Meteonorm, a software company that provided several climate parameters such as Irradiation, temperature and more from a typical year of the study area.

3.1.5 **Building type – Row housing unit**

The building type subject to this study, named the Esmeralda style by the developers, consists of a two story family housing unit. The study will be done choosing one existing building complex that groups, sidewall to sidewall in a single axis layout, six of these units. It is common to see around the residential development building complexes that group two, four, six, and even up to 10 housing units. Some of the building complex site arrangement include double side (double row) layouts, However, this study considers pertinent to evaluate the heat transfer effect that undergo end housing units as well as the center core ones. Therefore the building complex is considered to house a row housing unit housing topology. Six to be precise, which comprise one building complex. Throughout Mundo Habitat Esmeralda style housing is also laid out in -Every two units each house consists of 74 m2 of floor area. The intent is to mimic all existing interior and exterior conditions putting an emphasis on the following:

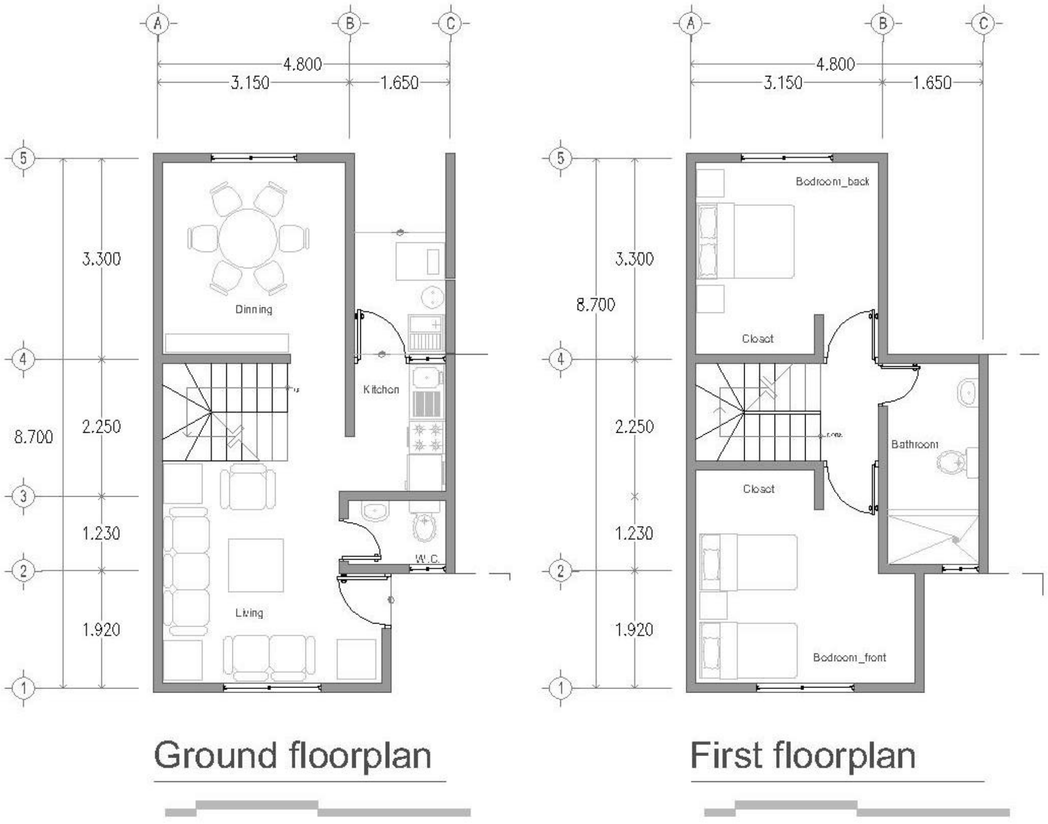


Figure 3-10. Esmeralda housing prototype – Floor plans.

Source: Grupo VIVO

Figure 3-11. Esmeralda housing prototype – Façade view.

Source: photo taken from author.

3.2. **Methodology.**

This phase will focus on selecting a case study location based on several factors that preclude a household to self-maintain an ideal internal comfort. The main decisive factor that will be taken into consideration is the climate conditions of the area. A high range of daily mean temperature value coupled with a high relative humidity factor was the first criteria for the city selection. The main byproduct of these climate conditions is the regular usage of mechanical air conditioning systems to cool down the indoor environment. Therefore a location with warm-humid or warm-sub humid climate such as Villahermosa in the state of Tabasco, Colima in the state of Colima, Mérida in the state of Yucatán, and Ciudad Valles in the state of San Luis Potosí are being considered. However, others cities with a steady economic activity and therefore a potential for future territorial expansion will also be considered to be selected. This is a main decisive factor to be considered. A location where the social housing development growth is within the highest at a national level will be sought.

Within the city location selected for the case study, a housing development already constructed and habited will be sought after, in order to comply with the following phase of the project methodology. The housing typology that is being considered is for the medium income family, with around 60 to 80 square meters of living space. Nowadays, this type of family dwelling is a two story housing unit, and it is built one next to the other, sometimes sharing a common bearing wall. Such units sometimes are called duplex, although, when built in groups of four or more are typically considered one axis row housing complexes. The housing model that is being looked after for purposes of this study is one between four and six housing units. This, in order to thermally simulate each household individually so that the thermal behavior of each can be evaluated. It is important to note that a social housing development containing several of these complexes with different building orientations is required for this study, as mentioned in the following phase for the survey phase.

3.2.1 **Phase 1: Energy consumption survey and demand forecast analysis.**

A survey sampling many of these housing units with the same building typology at the project location will take place with the approval of the construction developer. The purpose of this survey is to obtain quantitative as well as qualitative data. From one hand, the quantitative data needed is mainly related to the electricity consumption historical data (monthly bill where available) and schedule of use of the air conditioning units, which could help determine the impact on the load that the cooling equipment has in household electricity overall consumption. Additionally, this survey will also contribute to investigate other high consumption electric equipment that is regularly used.

On the other hand, qualitative data will be obtained in order to understand the contextual challenges of these household units, such as comfort and discomfort areas within the dwelling, as well as hours of use for each room.

3.2.2 **Phase 2: Building Modeling and Thermal load simulation analysis.**

Once the construction parameters (e.g. Computer Aided Design or paper based documentation) have been obtained from the construction developer under a confidentiality agreement, the selected existing multi-housing building complex will be digitally modeled using the Energyplus-Designbuilder interface software in order to perform a series of thermal load analysis for space cooling purposes. This consists in a holistic energy modeling taking into consideration several parameters including time-dependent envelope heat transfer, as well as internal heat gain from users and equipment in order to determine a more accurate thermal performance of the housing models when calculating required thermal loads. All main constructability and site specific aspects will be replicated in this model, such as:

-Interior floor area and type of occupancy,

-Climatic data of the typical year of the area of study.

-Latitude and longitude.

-Exterior envelope material thermal properties.

-Building site orientation.

-Occupancy time schedule.

-Other site specific information.

Selection of the Baseline case. With all these factors incorporated to the building complex model, a thermal load simulation will be run in each of the housing units that are part of the building complex. This in order to find the house unit with the highest cooling load requirement. This selected household will be considered for the Baseline case simulations.

Baseline case - Cooling load simulation. All the above mentioned existing aspects will be attributed to the baseline case digital model. All existing interior and exterior conditions are replicated in this first model, and the previous thermal load analysis to find out the required cooling load performed for the selection of the Baseline case will be now part of this Baseline case.

Proposed case – Cooling load simulation. Based on the spatial and material characteristics of the baseline case, a proposed (modified) case with design modifications will be then modeled, applying architectural bioclimatic strategies as follows:

Improved condition 1: Building orientation

Improved condition 2: Roof re-design for incorporation of solar cooling system

Improved condition 3: Solar protection of openings (windows).

Improved condition 4: Envelope surface color treatment

Improved condition 5: Building envelope materials

It should be noted that each sequence of the improved condition simulation runs is accumulative to the next one, meaning that at the simulation of the last proposed improved condition step, all other four proposed improved conditions will have already been incorporated.

3.2.3 **Phase 3: Solar cooling system – Thermal system design, sizing, and simulation.**

During this phase, the equipment layout will be guided by following several of the guidelines for the design of small load equipment, published by the SHC Task 48 program. Once a design layout is finalized, a system simulation will be performed using the Polysun thermal analysis software. To corroborate the design as well as the simulation, a professional opinion will be requested from equipment manufacturers. The subsystems are as follows:

-Heat production sub-system: Solar collector.

-The Cold Production Sub-System: adsorption system.

-The load sub-system: air-conditioning equipment.

3.2.4 **Phase 4: Solar cooling system – Photovoltaic system design, sizing, and simulation.**

During this phase, unlike the previous one, the equipment layout will be guided by literature review pertaining the best practices. It will also be proportionally related to the solar panel area to be used for this purpose. Once a design layout is finalized, a system simulation will be performed using the PV-Sol analysis software.

3.2.5 **Phase 5: Results compiling and payback analysis.**

Although the discussion of the feasibility study touches briefly in the relationship of the environmental and technical dimensions, the expected results from this feasibility study attempts to focus mainly in the performance of the systems, once the efficiency strategies have been applied to the building model. A short socioeconomic analysis focusing on a simple payback analysis will then follow.

The reduced thermal load will directly influence on the sizing and price of the solar cooling system, both thermal and photovoltaic equipment. Depending on this factor, the system could be subject for Mexico's green subsidies for new housing units and will prove its feasibility.

CHAPTER 4. **RESULTS**

4.1. **Thermal load analysis.**

In order to size the solar active cooling system accordingly, the thermal cooling load required for the “Esmeralda” building prototype will be determined using a building energy simulation tool. Moreover, since one of the objectives is to analyze the feasibility of small capacity active cooling systems, the cooling system design will be sized for each of the housing units addressing each of its specific cooling loads. That is why after a preliminary building simulation of each of the housing units (HU-1 through HU-6) the one with the highest thermal load requirements will be selected for the analysis. The objective of this subchapter is then to use proven architectural bioclimatic strategies in order to reduce the cooling load in this housing unit, where such final decreased cooling load can be used for the solar active cooling system basis of design.

- Simulation procedure.

-Designbuilder release version 3.4.0.033

The software that will be used to run the building simulations in order to obtain the projected cooling loads required for each of these housing units is EnergyPlus. This software is interfaced with the Designbuilder software platform and is capable of executing a holistic energy modeling taking into consideration several parameters including actual constructability parameters, time-dependent envelope heat transfer using site climatic information, as well as internal heat gain from users and equipment in order to determine the thermal performance of the housing models. (DOE, 2013). Simulation of all housing units will be run under the same software setting, unless otherwise noted.

-Climatologic information: Meteonorm weather data for Benito Juarez.

The climatic data used for the simulation was obtained from Meteonorm, and addresses all key climatic information needed for the simulation. This Meteonorm was obtained from the closest location of our case study area which was Cancun International Airport, located 46 kilometers north of Playa del Carmen.

-Cooling time.

A proposed cooling time of 10 hours during the peak cooling load is proposed in order to be able to compare these results with the proposed solar cooling systems. This was derived of a preliminary simulation (see annex 4-E and 4-F) showing that the house unit could become comfortable after this time range.

4.1.1 **Basis of design – Cooling system**

The Air conditioning system's basis of design (BoD) is modelled using the Compact HVAC template option in Designbuilder which provide ideal settings for EnergyPlus (DESIGNBUILDER, 2014). All simulation tests were ran using the environmental cooling temperature control setting at 24° C for cooling, with a setback point at 26°C to reflect the requirements of the ASHRAE adaptive thermal comfort analysis (see annex). The predetermined settings of the fan coil unit design (CoP of 1.67) was set to 1.0 in order to obtain cooling load values and be able to compare them with other CoP's from the preceding simulations. Also, a dehumidifier control system was added to the simulation.

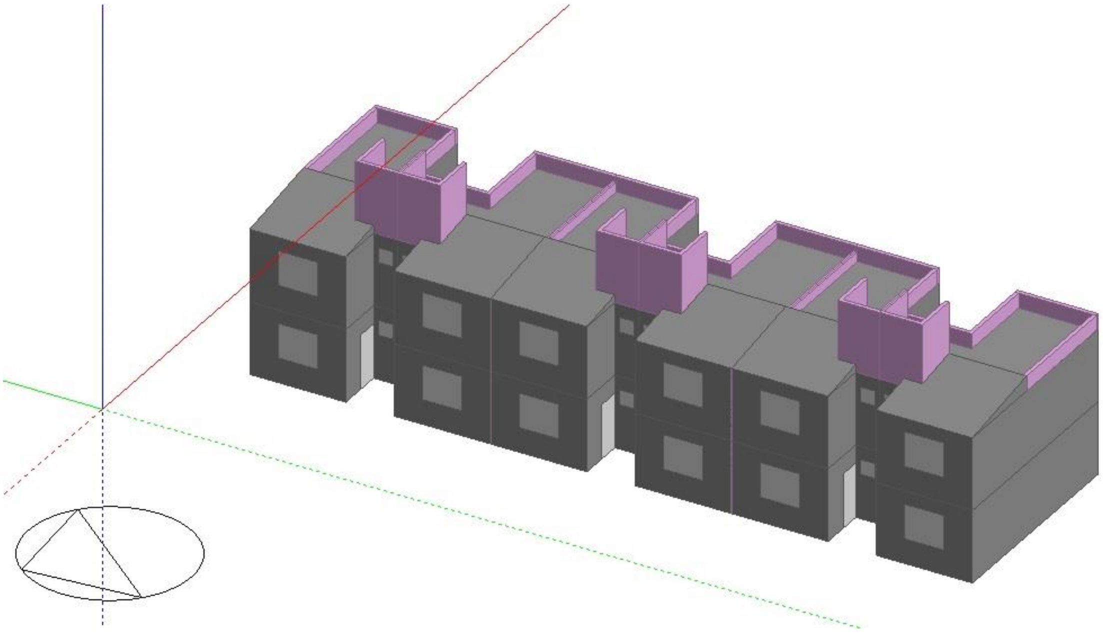


Figure 4-1. Row housing unit three-dimensional model.

Source: by author, created in Designbuilder software with Grupo Vivo information.

- Housing unit baseline case selection.

Figure 4-1 shows the 3-D model. The thermal cooling demand load analysis for all six baseline case results showed a load increase in each of the wing housing units. However, Housing Unit 6 shown highlighted in Figure 4-3 was held as one with the highest thermal load requirement, thus becoming the subject of this further analysis. This housing unit was also subject of further analysis in an isolated configuration, denoting through the cooling load results shown in Figure 4-2 that stand-alone buildings, if not carefully design, can be subject to extreme external thermal loads from a space cooling standpoint.

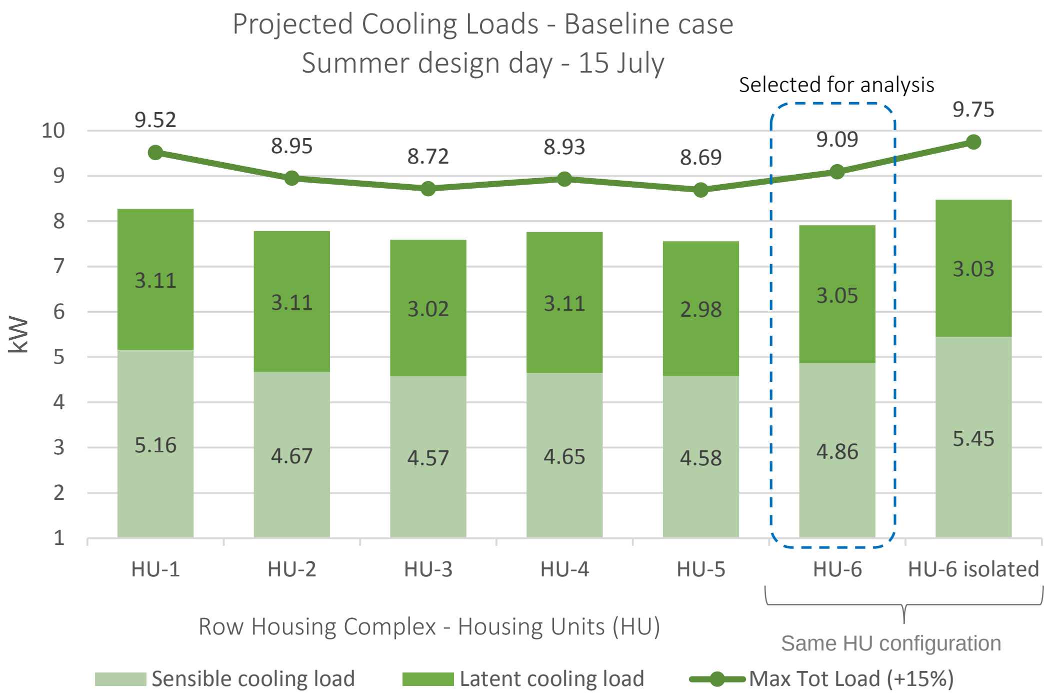


Figure 4-2. Selection of housing unit for analysis. Projected cooling loads over summer design day (July 15) Designbuilder simulation.

Source: by author, with information from Designbuilder software.

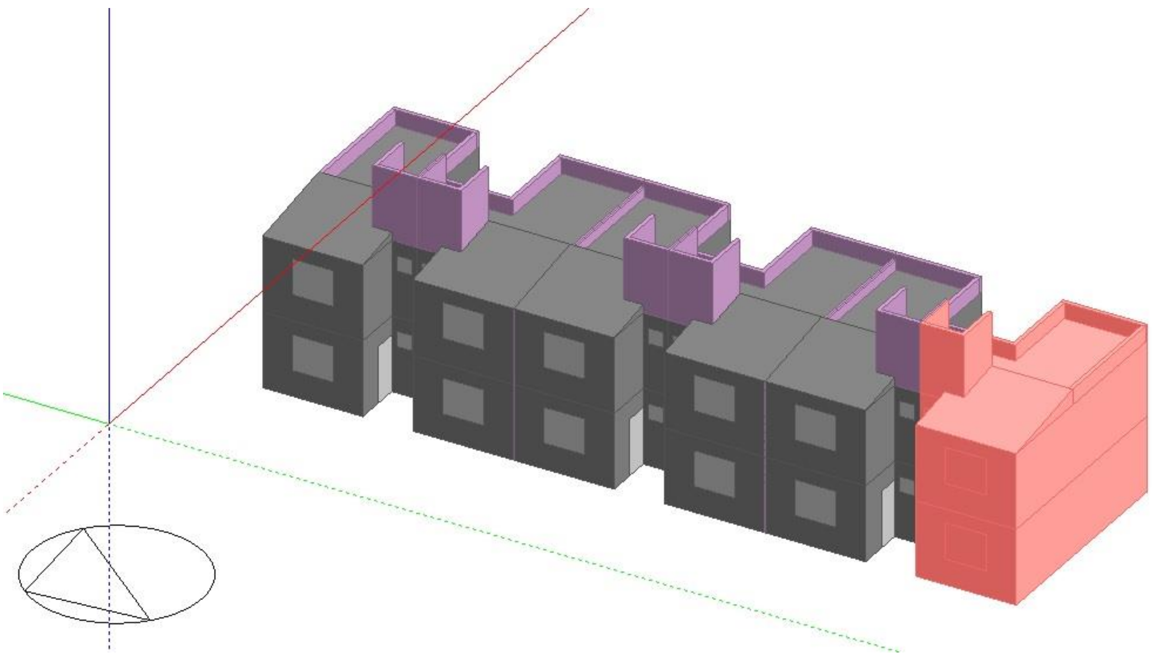


Figure 4-3. Image of row housing building with selected housing unit (HU-6) for further analysis highlighted.

4.1.2 **Proposed case – Improved conditions.**

Following the selection of Housing Unit 6 (HU-6) for further simulation analysis, some architectural bioclimatic strategies were selected in order to reduce the load before moving forward in the solar cooling design. The following improved conditions address issues from the current conditions such as envelope material thermal properties in Table 4-5, building orientation in Table 4-1-, solar protection of openings and walls in Table 4-3-, envelope surface color in Table 4-4 and roof composition (Building envelop re-design) in Table 4-2. This simulation is described below in five proposed modifications and is titled as a Proposed case model with indoor controlled temperature as described in the following five tables.

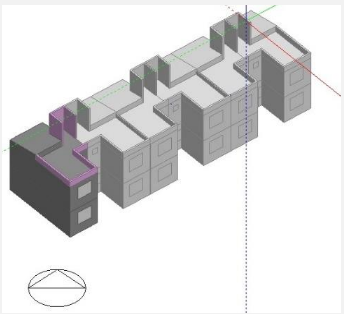
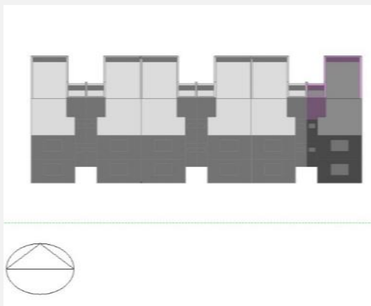
IC - 1	BUILDING ORIENTATION			
STRATEGIES	The solar direct exposure of the building envelope will be minimized by laying out the building most elongated footprint in an east-west axis orientation. As a consequence, the increased northern wall area direct sun heat gain will be significantly reduced. This measure also allows to provide consistent shading opening strategies in all four sides rather than to customize shading control measures for each opening.			
IMPLEMENTATION	Baseline case actual conditions		Proposed modifications	
	The actual building orientation is 50° East of North 		The new building shape orientation is now facing south. 	
IMPLEMENTATION TIMELINE	Pre-Design (Programming - Site)	Design (SD - DD - CD)	Construction (Bidding - Construction)	O & M (Occupancy)
	●			
COST	No additional costs	$	$$	$$$
	●			
SIMULATION RESULTS	Baseline cooling load	Previous cooling load reduction	Updated cooling load requirement	
Sensible load	4.86 kW		4.67 kW	
Latent load	3.05 kW		3.19 kW	
Total cooling load	7.91 kW		7.86 kW	
Max Tot Load (+15%)	9.09 kW	0.0 kW _% load reduction	9.04 kW 1 % load reduction	
COMMENTS	While this strategy may seem it does not have an impact in the reduction of the thermal cooling load capacity at an individual housing unit basis, it does drastically influence the results in a holistic manner at the building level.			
Pros	No modifications in the building design is required.			
Cons	Decision makers need to address this issue since the land acquisition process.			

Table 4-1. Housing unit six (HU-6). Improved condition one (1) evaluation data.

Source: By author with information obtained from Designbuilder simulation

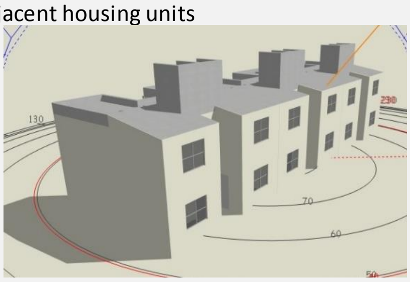
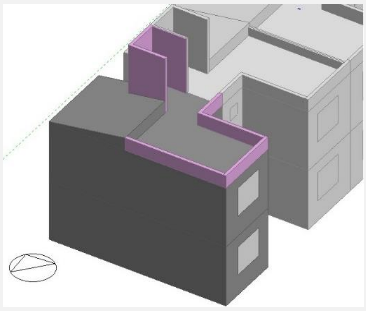
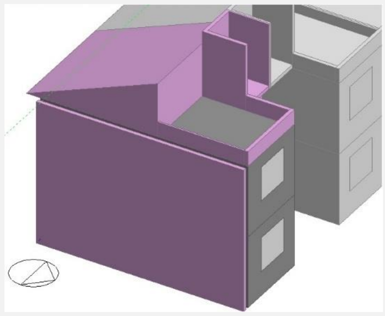
IC - 2	**BUILDING ENVELOPE RE-DESIGN**			
STRATEGIES	In order to provide shading protection to the building envelope, the building roof and the building's extreme (east & west) end walls are modified. A continuous thermally broken upper tilted roof is laid along all the building complex over each of the housing units flat roofs. The tilt angle for this upper roof is ideal for the installation of the solar system, whereas photovoltaic panels or solar collectors. Additionally, the purpose of the void interior space of this upper roof system is dedicated to the active cooling system equipment and is exposed to exterior conditions thus providing for adequate ventilation to the underneath roof. Finally, a green wall system is proposed at the both extreme building end walls.			
IMPLEMENTATION	Baseline case actual conditions		Proposed modifications	
	The actual roof system is only shared between adjacent housing units 		The proposed roof system is continuous throughout the building complex 	
	The actual east and west end wall conditions do not have any special treatment for sun protection. 		To mimic the green wall conditions, a semi-translucent wall (east& west end walls) with a transmittance coefficient of 0.5 was 	
IMPLEMENTATION TIMELINE	Pre-Design (Programming - Site)	Design (SD - DD - CD)	Construction (Bidding - Construction)	O & M (Occupancy)
		●		
COST	No additional costs	$	$$	$$$
			●	
SIMULATION RESULTS	Baseline cooling load	Previous cooling load reduction		Updated cooling load requirement
Sensible load	4.86 kW			3.88 kW
Latent load	3.05 kW			3.16 kW
Total cooling load	7.91 kW			7.03 kW
Max Tot Load (+15%)	9.09 kW	9.04 kW 1 % load reduction		**8.09 kW 11 % load reduction**
COMMENTS	The roof redesign of the building complex comprises several benefits: A preparation for the installation of the solar system, as well as an insulation strategy for the roof system.			
Pros	The preparation for future solar energy equipment is now in place, and buildings modifications are not longer needed, making a savings impact in the long run.			
Cons	This measure requires to be approached since the design stage and it does increase, although not significantly, the construction budget.			

Table 4-2. Housing unit six (HU-6). Improved condition two (2) evaluation data.

Source: By author with information obtained from Designbuilder simulation

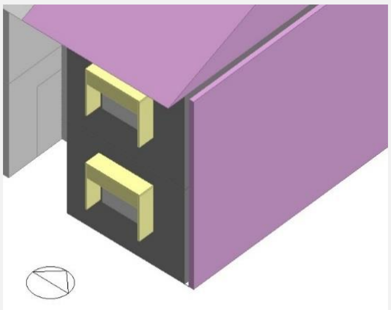
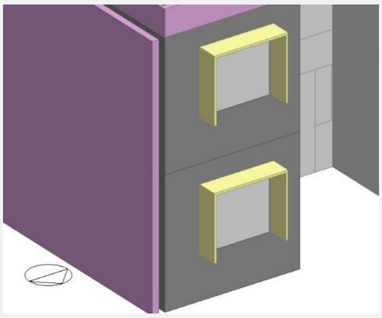
IC - 3	SOLAR PROTECTION OF OPENINGS			
STRATEGIES	Provide solar protection to windows during the high daily solar intensity periods throughout the months of March to October.			
IMPLEMENTATION	Baseline case actual conditions		Proposed modifications	
			Proposed solar protection system in the front façade of the housing unit.  Proposed solar protection system in the rear side of the housing unit. 	
IMPLEMENTATION TIMELINE	Pre-Design (Programming - Site)	Design (SD - DD - CD)	Construction (Bidding - Construction)	O & M (Occupancy)
		●		
COST	No additional costs	$	$$	$$$
		●		
SIMULATION RESULTS	Baseline cooling load	Previous cooling load reduction		Updated cooling load requirement
Sensible load	4.86 kW			3.76 kW
Latent load	3.05 kW			3.25 kW
Total cooling load	7.91 kW			7.01 kW
Max Tot Load (+15%)	9.09 kW	8.09 kW	11 % load reduction	**8.06 kW 12% load reduction**
COMMENTS	Depending on the glass and fenestration quality, this strategy can alleviate interior space hot discomfort periods during the long periods of direct sun exposure.			
Pros	Architectural styles can vary and can be incorporated to the housing prototype style.			
Cons	-			

Table 4-3. Housing unit six (HU-6). Improved condition three (3) evaluation data.

Source: By author with information obtained from Designbuilder simulation

IC - 4	ENVELOPE SURFACE COLOR TREATMENT			
STRATEGIES	Reduction of solar radiation absorption of the building envelope through the use of light colored surfaces.			
IMPLEMENTATION	Baseline case actual conditions		Proposed modifications	
	Exterior material: Cement plaster Color: light vanilla Surface properties: Thermal absorptance (emissivity) 0.900 Solar Absoprtance: 0.400 Visible absorptance 0.400		Exterior material: Cement plaster Color: white Surface properties: Thermal absorptance (emissivity) 0.900 Solar Absoprtance: 0.200 Visible absorptance 0.200	
IMPLEMENTATION TIMELINE	Pre-Design (Programming - Site)	Design (SD - DD - CD)	Construction (Bidding - Construction)	O & M (Occupancy)
			●	
COST	No additional costs	$	$$	$$$
	●			
SIMULATION RESULTS	Baseline cooling load	Previous cooling load reduction		Updated cooling load requirement
Sensible load	4.86 kW			3.15 kW
Latent load	3.05 kW			3.48 kW
Total cooling load	7.91 kW			6.63 kW
Max Tot Load (+15%)	9.09 kW	8.06 kW 12 % load reduction		**7.63 kW 16 % load reduction**
COMMENTS	Other light colors could be used other than white while being in the low solar absorptivity			
Pros	No additional costs in the budget.			
Cons	The monotony of having white buildings needs to be addressed by the architectural team.			

Table 4-4. Housing unit six (HU-6). Improved condition four (4) evaluation data.

Source: By author with information obtained from Designbuilder simulation

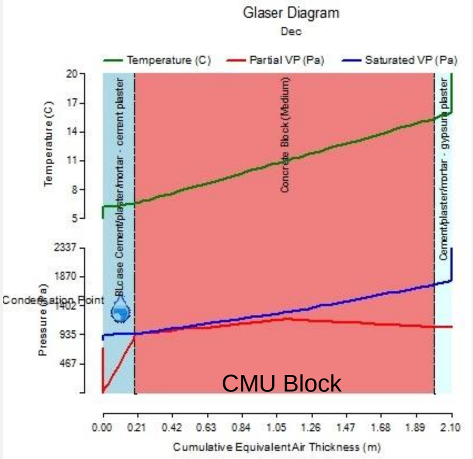
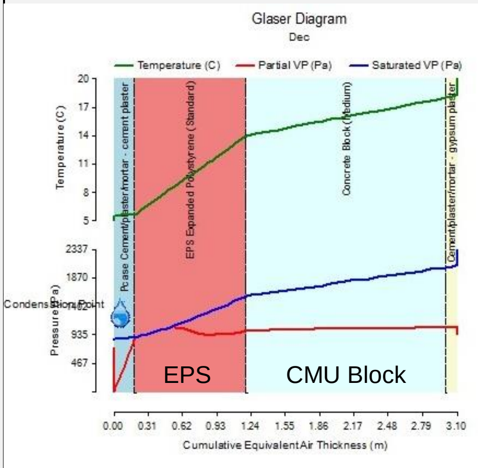
<table>
<tr><td>IC - 5</td><td colspan="4">BUILDING ENVELOPE MATERIALS</td></tr>
<tr><td>STRATEGIES</td><td colspan="4">Addition of an Extruded Polystyrene (EPS) insulation layer in the exterior side of the building envelope (walls and roof).</td></tr>
<tr><td>IMPLEMENTATION</td><td colspan="2">Baseline case actual conditions</td><td colspan="2">Proposed modifications</td></tr>
<tr><td></td><td colspan="2">Assembly description — Wall assembly
Number of layers — 3
Outermost layer — Cement plaster
Thickness — 0.01 m.
Layer 2 — Concrete Block (Med)
Thickness — 0.15 m.
Innermost layer — Gypsum plaster
Thickness — 0.01 m.

</td><td colspan="2">Assembly description — Wall assembly
Number of layers — 4
Outermost layer — Cement plaster
Thickness — 0.01 m.
Layer 2 — EPS Insulation
Thickness — 0.025 m.
Layer 3 — Concrete Block (Med)
Thickness — 0.15 m.
Innermost layer — Gypsum plaster
Thickness — 0.01 m.

</td></tr>
<tr><td>IMPLEMENTATION TIMELINE</td><td>Pre-Design
(Programming - Site)</td><td>Design
(SD - DD - CD)</td><td>Construction
(Bidding - Construction)</td><td>O & M
(Occupancy)</td></tr>
<tr><td></td><td colspan="4">●</td></tr>
<tr><td>COST</td><td>No additional costs</td><td>$</td><td>$$</td><td>$$$</td></tr>
<tr><td></td><td colspan="2">●</td><td colspan="2"></td></tr>
<tr><td>SIMULATION RESULTS</td><td>Baseline cooling load</td><td colspan="2">Previous cooling load reduction</td><td>Updated cooling load requirement</td></tr>
<tr><td>Sensible load</td><td>4.86 kW</td><td colspan="2"></td><td>2.78 kW</td></tr>
<tr><td>Latent load</td><td>3.05 kW</td><td colspan="2"></td><td>3.65 kW</td></tr>
<tr><td>Total cooling load</td><td>7.91 kW</td><td colspan="2"></td><td>6.43 kW</td></tr>
<tr><td>Max Tot Load (+15%)</td><td>9.09 kW</td><td colspan="2">7.63 kW 16 % load reduction</td><td>7.4 kW 19 % load reduction</td></tr>
<tr><td>COMMENTS</td><td colspan="4">Building envelope insulation can significantly reduce the thermal cooling load, while preventing concrete block to behave as a heat sink. as an indirect behavior.</td></tr>
<tr><td>Pros</td><td colspan="4">Increased interior thermal comfort</td></tr>
<tr><td>Cons</td><td colspan="4">Additional investment in materials and labor.</td></tr>
</table>

Table 4-5. Housing unit six (HU-6). Improved condition five (5) evaluation data.

Source: By author with information obtained from Designbuilder simulation

4.1.3 **Thermal load analysis – Results.**

Figure 4-4shows a comparative summary of the final cooling load requirements from the HU6 model, in the baseline case condition and the proposed case one. In this graphic it is also shown the decrease of cooling load requirement as each of the proposed modifications (improved conditions), one through five, is applied, in an additive manner. The idea is that all of the proposed modifications together, when evaluated, can make significant impact in the efficiency of the cooling system as a group of strategies and not as single solutions.

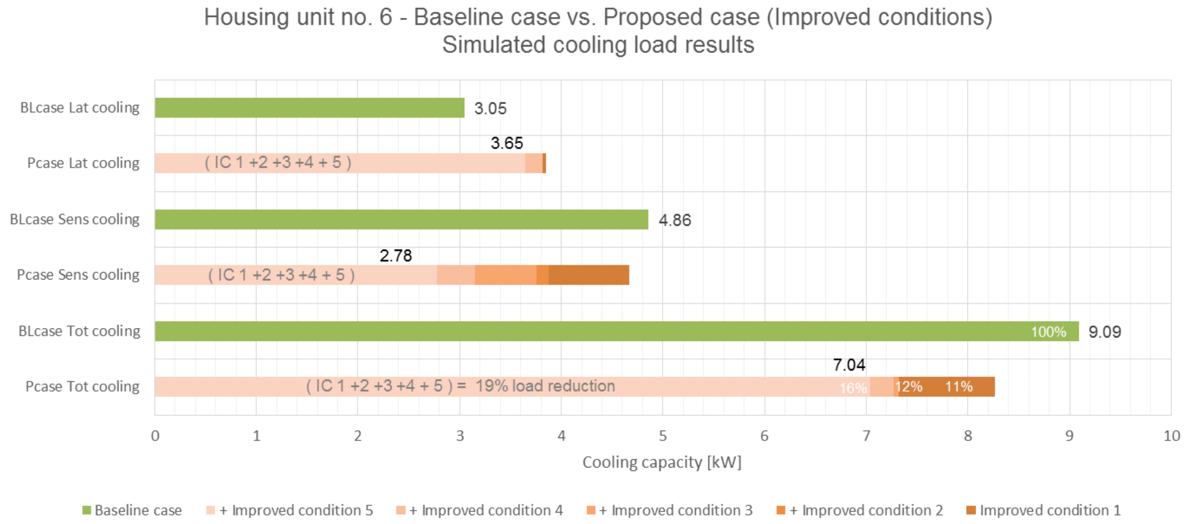


Figure 4-4. Housing unit 6 (HU-6). Baseline vs Propose case. Comparison of projected cooling loads over summer design day (July 15). Designbuilder simulation.

Source: By author with information obtained from Designbuilder simulation

As shown in Figure 4-5 and Figure 4-6, the monthly and annual energy cooling energy for the HVAC system has been projected. For each of the HU-6 simulation phases. From all simulated improved conditions, the one regarding the reorientation of the building proved being the more drastic energy savings strategy. The proposed modification with the least impact in the cooling load requirement is improved condition no. 3 (Sola protection of openings) with only 1% of cooling load reduction. However, when observing the monthly and annual energy consumption in Figure 4-5, its projected reduction in energy consumption is quite considerable.

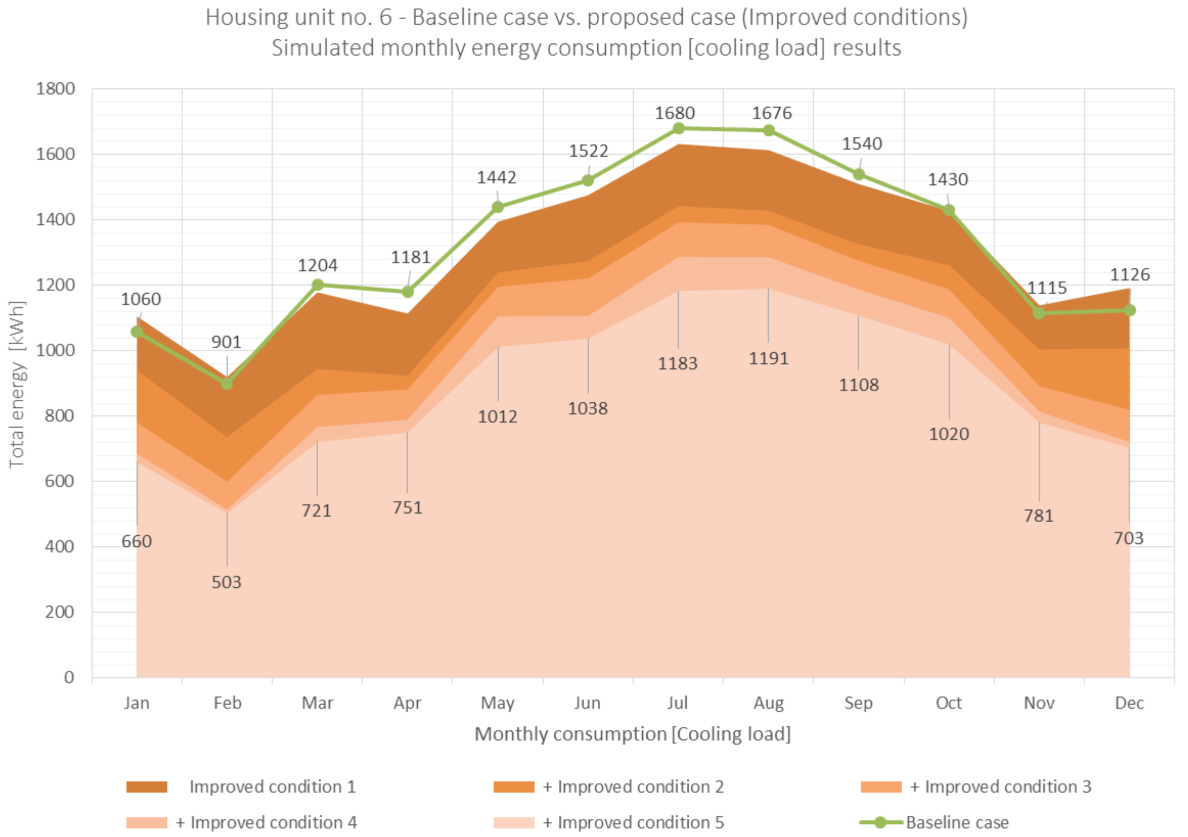


Figure 4-5. Housing unit 6. Baseline vs Propose case. Comparison of projected cooling loads over summer design day (July 15). Designbuilder simulation.

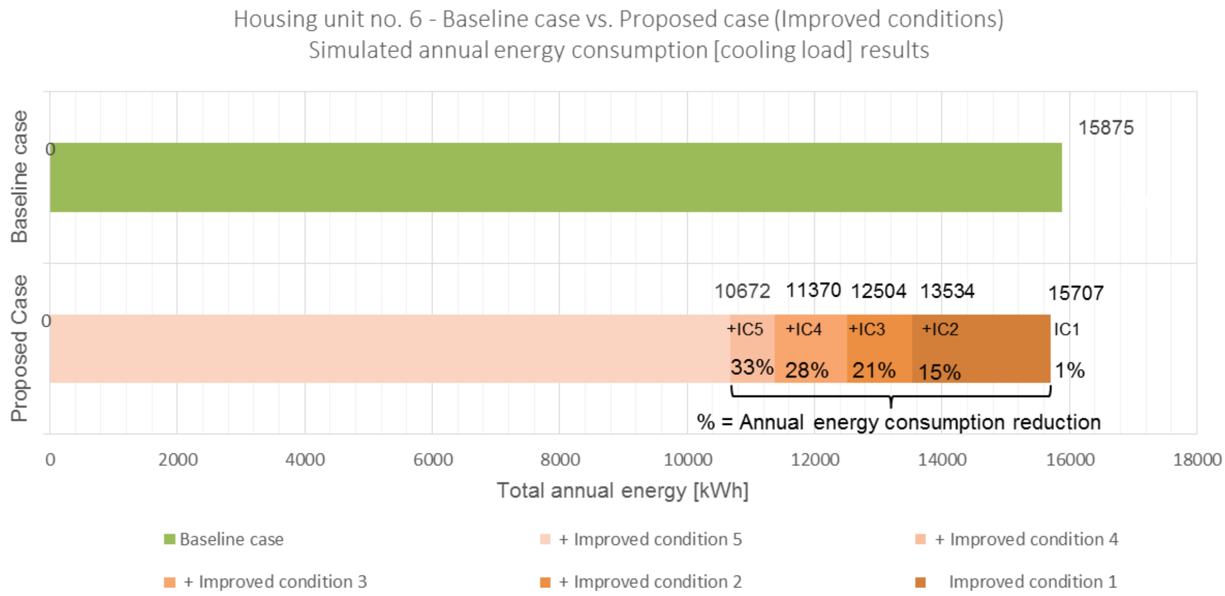


Figure 4-6. Housing unit 6. Baseline vs Propose case. Comparison of projected cooling loads over summer design day (July 15). Designbuilder simulation.

As a conclusion, Figure 4-7 shows both simulation cooling load (Baseline and Proposed case scenarios) results. The projected cooling load now set to 7.04 kW. This load is a more feasible and attainable goal to cover with a small capacity solar cooling system than with the previous 9.09 kW projected with the initial simulation of the baseline design model. It is worth noting that the latent cooling load was minimally altered by all of the five main proposed strategies, due that it is a load related to the outdoor environment and infiltrated in the form of air with high moisture content into the building.

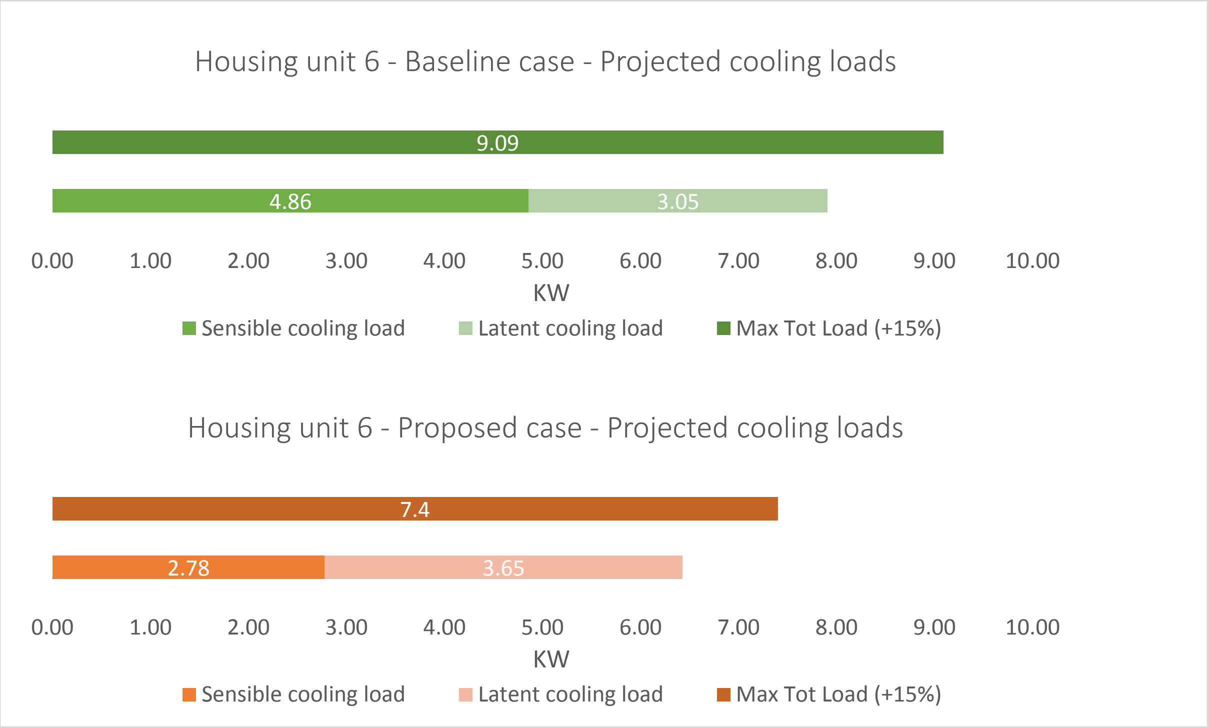


Figure 4-7. Projected cooling loads over summer design day (July 15) simulation.

Within the simulation by zone analysis shown in Figure 4-8 and Figure 4-9, it is important to highlight the outcome in the projected cooling load reduction in the upper floor rooms. Almost half of the project cooling load requirement in the upper floor front bedroom was reduced. This indicates a very positive signal, not only for the purposes of the projected load, but as well for the human comfort level that can be attained in this portion of the housing unit, as this room was reported to be one of the most thermally uncomfortable ones during the survey analysis made at the case study location.

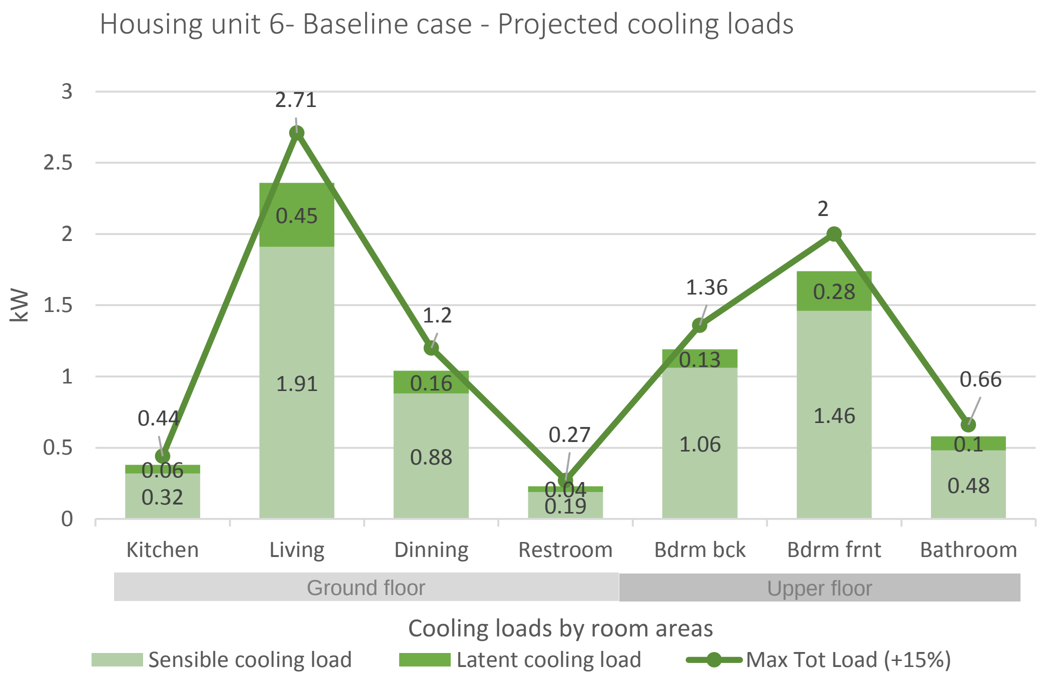


Figure 4-8. Projected cooling loads over summer design day (July 15) simulation.

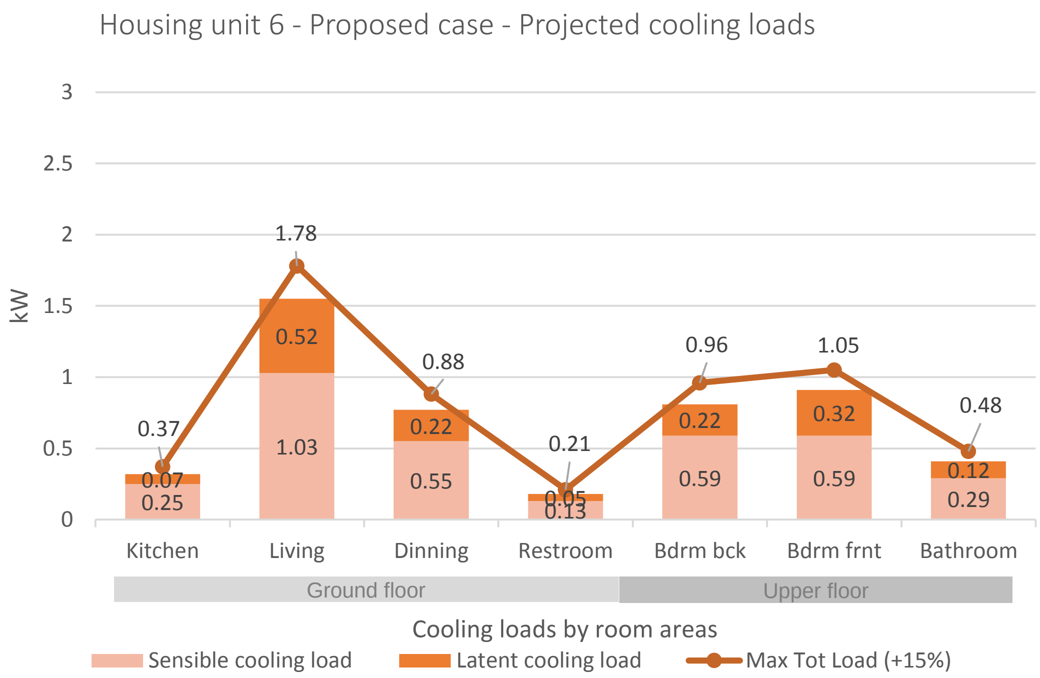


Figure 4-9. Projected cooling loads by room type over summer design day (July 15) simulation.

4.2. “Esmeralda” at Mundo Habitatt – Energy survey & forecast analysis.

4.2.1 Energy survey.

In March 2014 a survey to families currently residing at *Mundo Habitatt*, where the case study location in Playa del Carmen is found, was conducted. The survey targeted families dwelling in the “Esmeralda” housing prototype, of which this study is performing the solar cooling system integration analysis. In *Mundo Habitatt*, only 50 “Esmeralda” housing prototype units were built from the 215 total housing units. In this neighborhood development all housing units’ prototypes, which vary in size, are intermingled with each other including the “Esmeralda” prototype, and laid out as building complexes in a single and double row axis with different lengths. The orientation of each of the housing units varied also.

The survey’s questionnaire (see annex document) included 5 main topics to consider as noted below. During three days, the survey was conducted in the morning, afternoon and evening. From the total amount of housing units of the sought prototype, only 17 surveys were completely answered. The following responses were obtained:

- Number of family members, and typical daily activity schedules.

The typical number of family members rounded about four, being both parents and two children, or a children and another family member, such as a grandmother, living with them. The male family member would go to work in the morning while the wife would take care of the housework and taking care of their children in the afternoon. The male parent would then get back from work in the evening (on average at 7 p.m.) from work. Most of the interviewed household reported most weekends as non-working. During these days all family members would stay at home.

- Ownership of the property.

From the 17 surveys taken all except two interviewed families, reported being house owners. More than half of these house owners had finish paying their mortgage. This multi-housing development was planned and built in the early 90’s, being one of the first multi-housing residential developments in this city.

- Air conditioning units, cooling capacities, and efficiency values, and usage schedules.

Among the 17 surveys, only 10 users reported to have air conditioning units. 1 of these systems was an old window unit, while the rest where heat-pump split systems. 5 of them knew the tonnage of cooling capacity of their system, being in all cases (except one of 1.75 tons of cooling capacity) of one ton cooling capacity. All interviewed families reported careful use of the A/C units only during the evenings, when they were going to sleep, but only for a few hours. This air conditioning unit was installed in one of the bedrooms. When asked what was the most uncomfortable time of the day and in what room 13 of the interviewed family members responded that the bedroom found in the second floor felt very uncomfortable during the day. However, all of the family dwellings that had an air conditioning split unit downstairs would not use it during the day when one or two family members were there, but rather at night when all of them were already at home. Regular self-standing fan units were used instead. They agreed that their thermal comfort level was not satisfied by the use of the fans, but only alleviate shortly the need for ventilation. On the other side, an interesting point from one of the surveyed families that reported having no air conditioning units in their dwelling mentioned their house unit was always kept fresh. This unit was located in the far end of a single row housing complex, with no adjacent house from one side, and a street perpendicularly aligned in front of the dwelling. This, according to his comment, provided him with enough natural ventilation to keep his dwelling comfortable all day long.

Finally, when all families asked if they would be willing to share a district controlled air conditioning system for the whole housing unit and its consumption regulated by CFE, 14 surveyed families answered they would be willing.

- Type of other high consumption appliances.

All of the families that were surveyed reported no high energy consumption appliances/equipment. The only two medium consumption appliances were the refrigerators and iron machines.

- Historical electricity monthly energy consumption, in KWh, through their electricity bill historical reading.

The CFE issues the electrical utility bill in bi-monthly periods to residential customers. In each bill historical monthly readings are also included. During the interview to each of the families, their most recent electric monthly bill was requested, and their monthly electrical consumption readings were recorded. Figure 4-10 shows monthly electricity consumption readings gathered from the survey. Since the monthly electricity consumption readings are also given bimonthly, each reading was divided into two so it can be easily interpreted in this graphic.

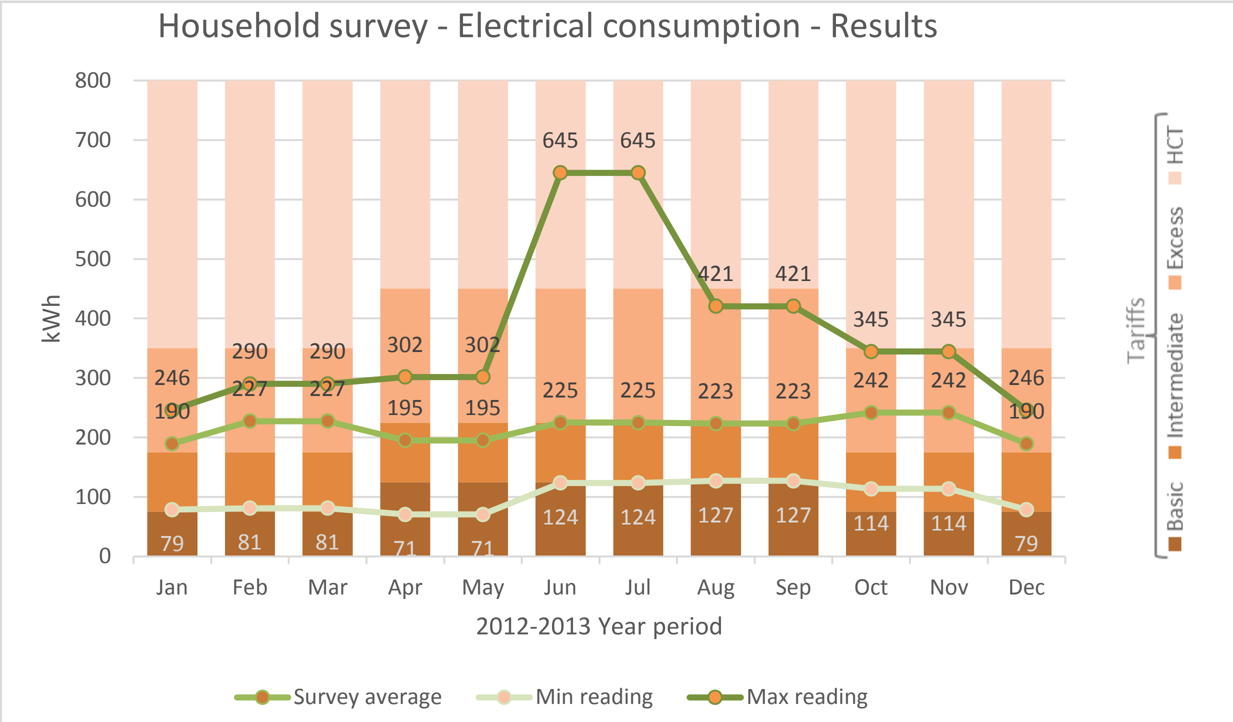


Figure 4-10. Playa del Carmen households survey results. Graph by author

Besides the average monthly electricity consumption reading shown in this graphic, two more readings were included: The highest and the lowest electricity consumption readings from among all questionnaires completed. It is worth noting that the user in the highest consumption reading reported regular use of their air conditioning at night during the hottest season of the year, while the lowest consumption reading came from a family that watched their electricity consumption carefully. In this graph the tariff price brackets for climate region 1B, enforced in Playa del Carmen by CFE, are also juxtaposed in the background. But it is clear that neither the average nor the high and low readings reflect a constant use of air conditioning system. They do not even reflect the time lapses where the housing units are under thermally uncomfortable levels and the vital use of air conditioning is needed. What it is obvious is that the air condition energy consumption has a tremendous economic impact on the households. To understand more this effect Figure 4-11 through Figure 4-13 were generated. These three graphics show the total annual average electricity consumption per Figure 4-10 as well as the pricing for each of the tariffs, with 2014 prices obtained in the CFE residential tariff section website. In each of these graphics the real cost of electricity, also called High Consumption Tariff (HCT), is shown. For CFE, a user is considered a HCT user when their average electricity consumption over a 12 month period surpasses the kilowatts of the excess tariff.

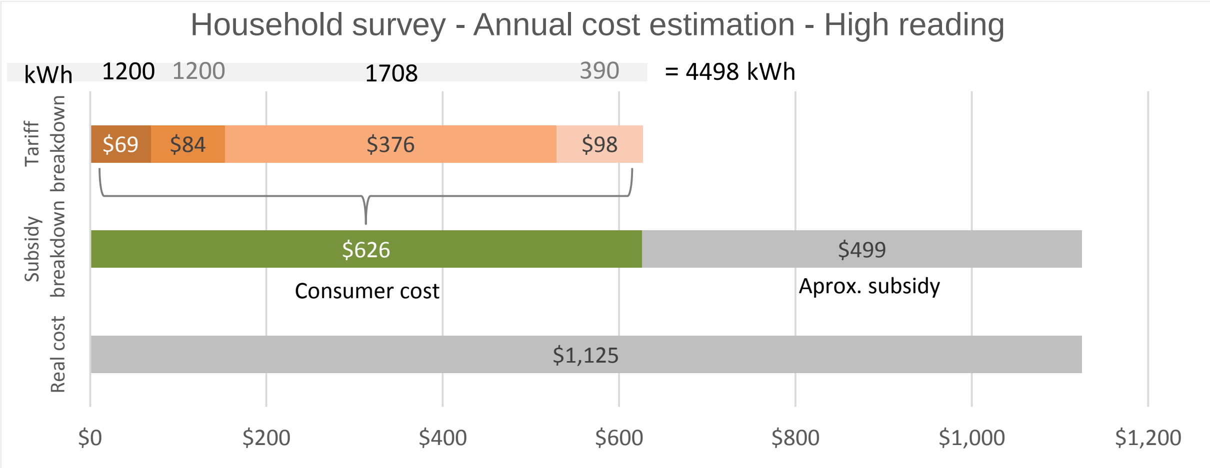


Figure 4-11. Estimated real costs, government subsidy, and final consumer price breakdown for the high end reading survey sample. Graph by author.

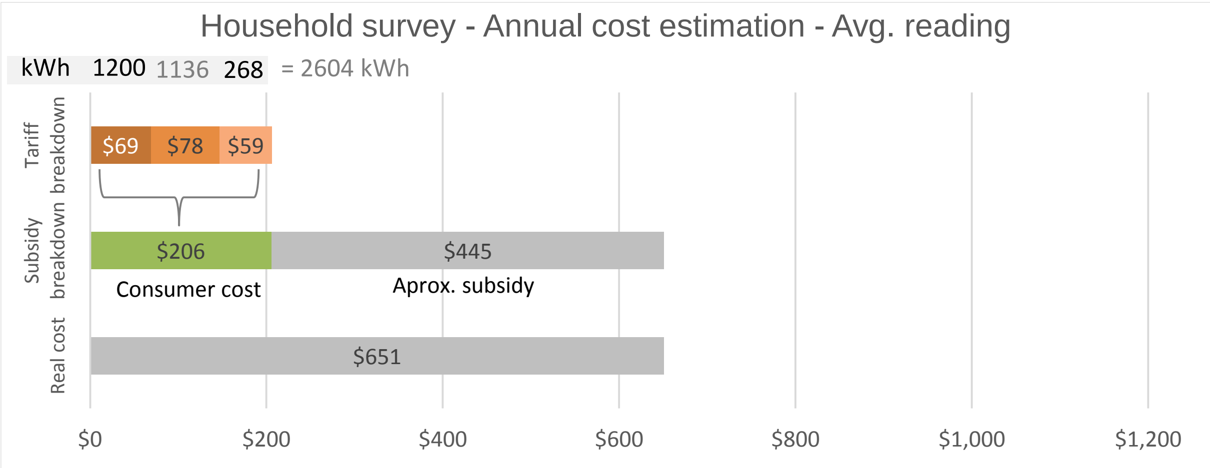


Figure 4-12. Estimated real costs, government subsidy, and final consumer price breakdown for the average reading survey sample. Graph by author.

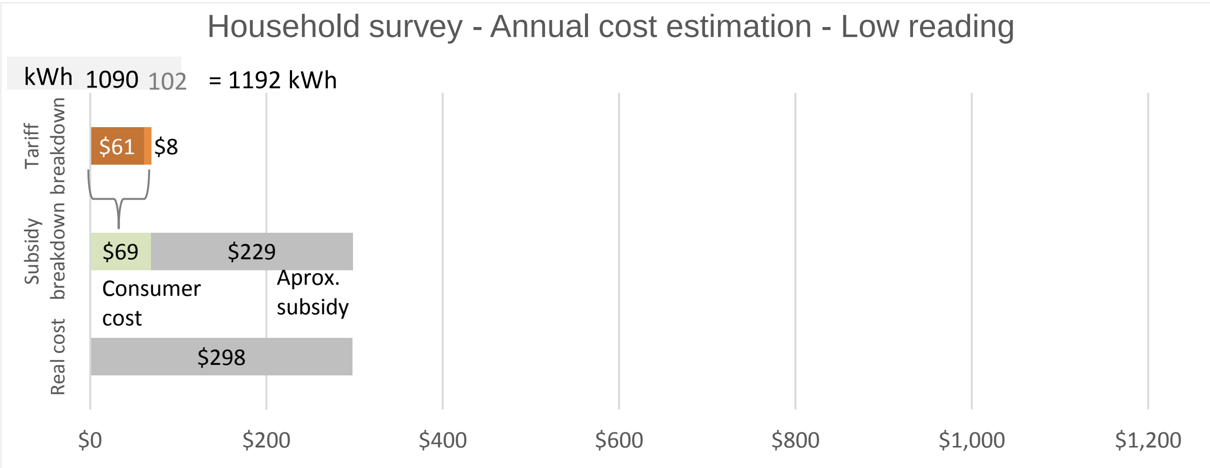


Figure 4-13. Estimated real costs, government subsidy, and final consumer price breakdown for the low end reading survey sample. Graph by author.

Looking at these three graphs it is now clear that the electricity consumption for each of the families is regulated by the tariff levels. Their regular usage of the air conditioning system is not based on comfort satisfaction levels but the price limits that each tariff imposes into the families' budget. Even in the high consumption user in Figure 4-11 one can see that the high price of the excess tariff limits its consumption. These graph shows how 390 kWh of electricity in the excess consumption range costs more than the first 1200 kWh of the Basic tariff level.

4.2.2 **Electricity demand load forecast**

One of the main objectives of performing the households' survey at the case study location was to arrive to a realistic estimation of electricity consumption. This, in hopes that the electrical consumption readings would reflect the air conditioning usage, as well as the cooling capacity according to the thermal conditions of the households. But it is now clear based in the previous discussion that the electrical consumption by the average user does not reveal this pattern.

However, for the purposes of establishing an electricity demand base load criteria with no air conditioning these values can be utilized since the electrical A/C consumption can be neglected in the electrical consumption of the average user. For that, the equipment and time usage from the households' data collected in the survey stage provides a clear panorama to build a daily consumption curve such as types of appliances (with high or low wattage) and working schedules (to determine peak load hours). When structuring the equipment schedule, it was observed that there is, in overall, a reduced number of appliances. Therefore, the proposed list was based mainly on the typical household needs. Figure 4-14 shows a structured list by type and subtotals. In this list the A/C unit capacity value was omitted since the proposed A/C curve discussed in the previous subchapter will be shown. Another observation is that appliances used by the group are not the most efficient because they are not from the newest generation. However some high consuming appliances like drying machines are not existent because of the economic situation that defines the lifestyle of the population.

One of the facts delineated in his table is, for example, that the kitchen items are the appliances that require the highest capacity. In contrast, power requirements for household water distribution is 0. This is due that water distribution is done through gravity since the water tank is found in the roof of each building. Finally for acclimatization purposes other than air conditioning units, self-standing fans are widely used to alleviate thermal unsuitable conditions.

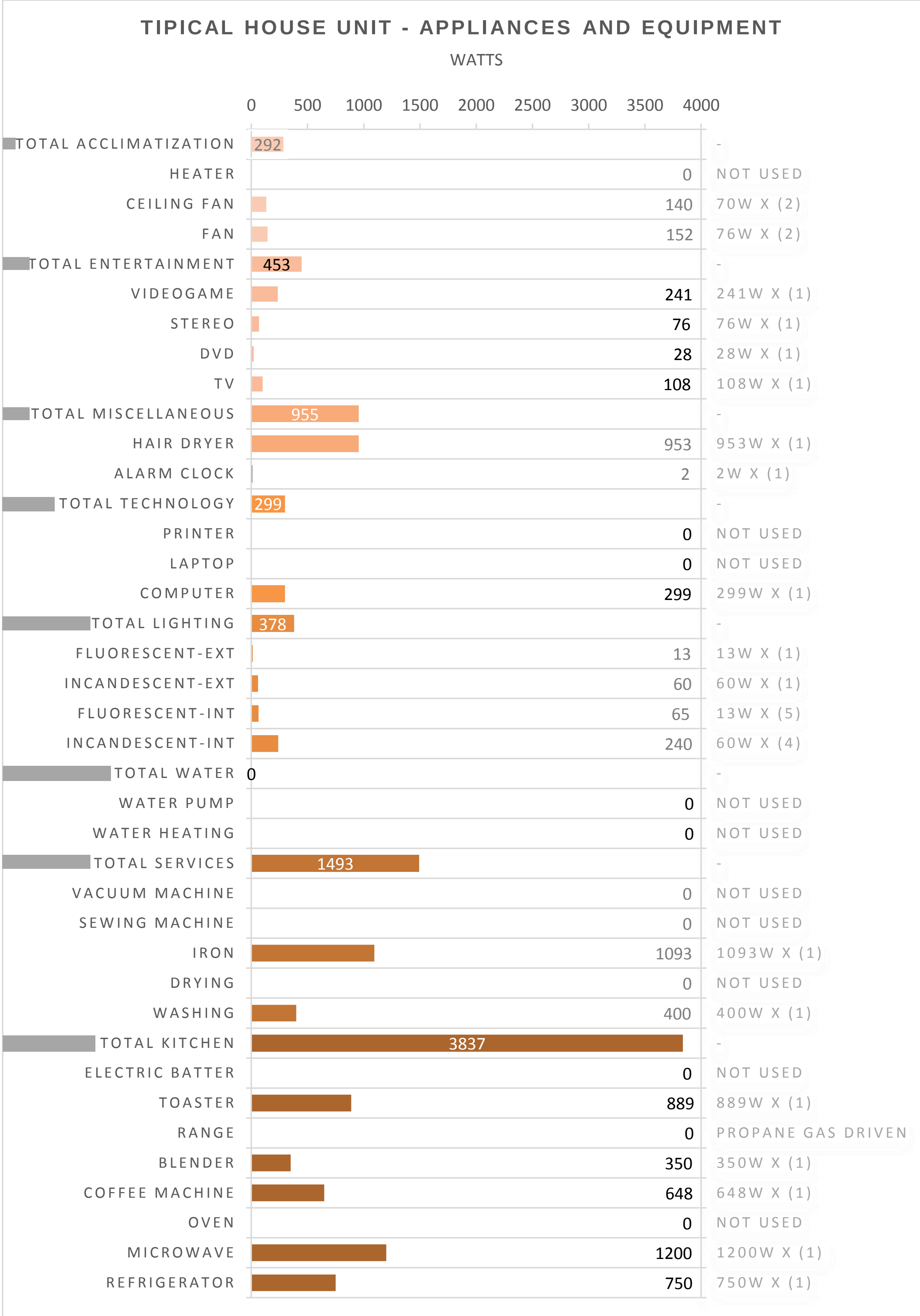


Figure 4-14. Typical household equipment list.

Based on the equipment schedule and the list provided, an approximate typical daily demand load was prepared as shown in Figure 4-15 and Figure 4-16.

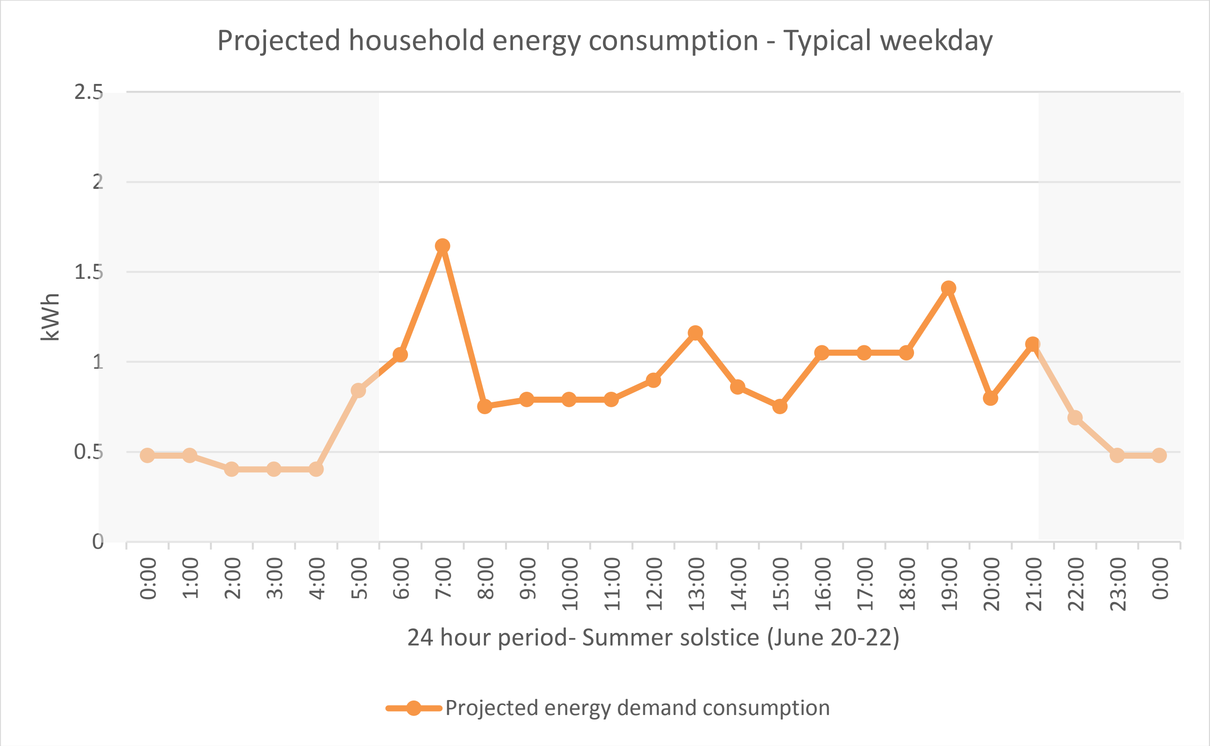


Figure 4-15. Daily household demand curve –Typical week day

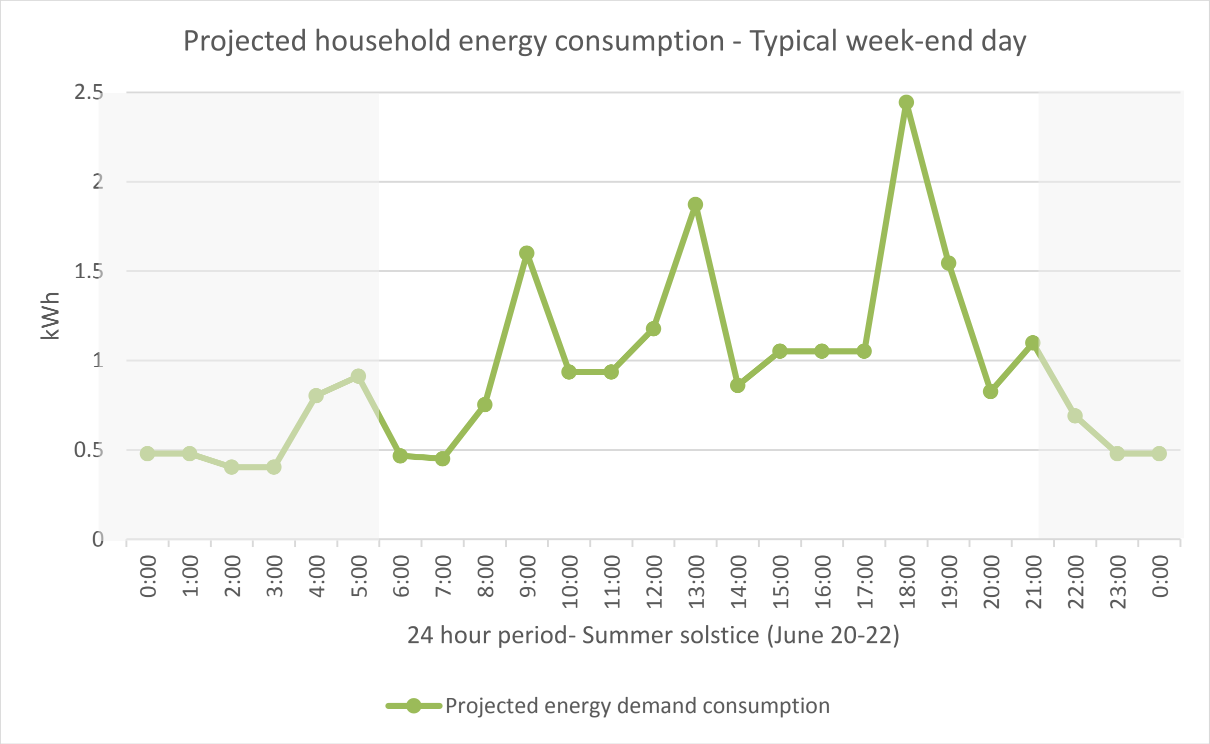


Figure 4-16. Daily household demand curve – Typical week-end day

The average annual consumption considering these two week and week-end daily demand curve values on Figure 4-15 and Figure 4-16 came out to 7791 kWh. For current trends this value should not be taken into consideration. However, if the system is planned for future potential needs then this daily curves should be taken into consideration.

On the other hand, when considering the real cost of having fully equipped with an air conditioning system correctly sized for the ”Esmeralda” housing unit, two more graphics are provided. Figure 4-17 and Figure 4-18 show the average monthly electrical demand curves obtained in the survey phase along with the potential consumption of the baseline and proposed design models.

These two examples show how expensive in the current Mexican electric tariff system is to maintain a comfortable setting in the household. Two examples in each of these graphs area shown. These are the lowest and highest consumption months included the energy consumption based on the cooling load. This amounts show how, for example, the Esmeralda building type with no proper architectural detailing and fully equipped with an air conditioning system would consume as much as one year worth of electricity consumption in a case where there would not be such an equipment.

The proven efficiency of the proposed case with the added five improved conditions shows that while there is a radical efficiency improvement, the budget is still way over surpassing the high consumption tariff level.

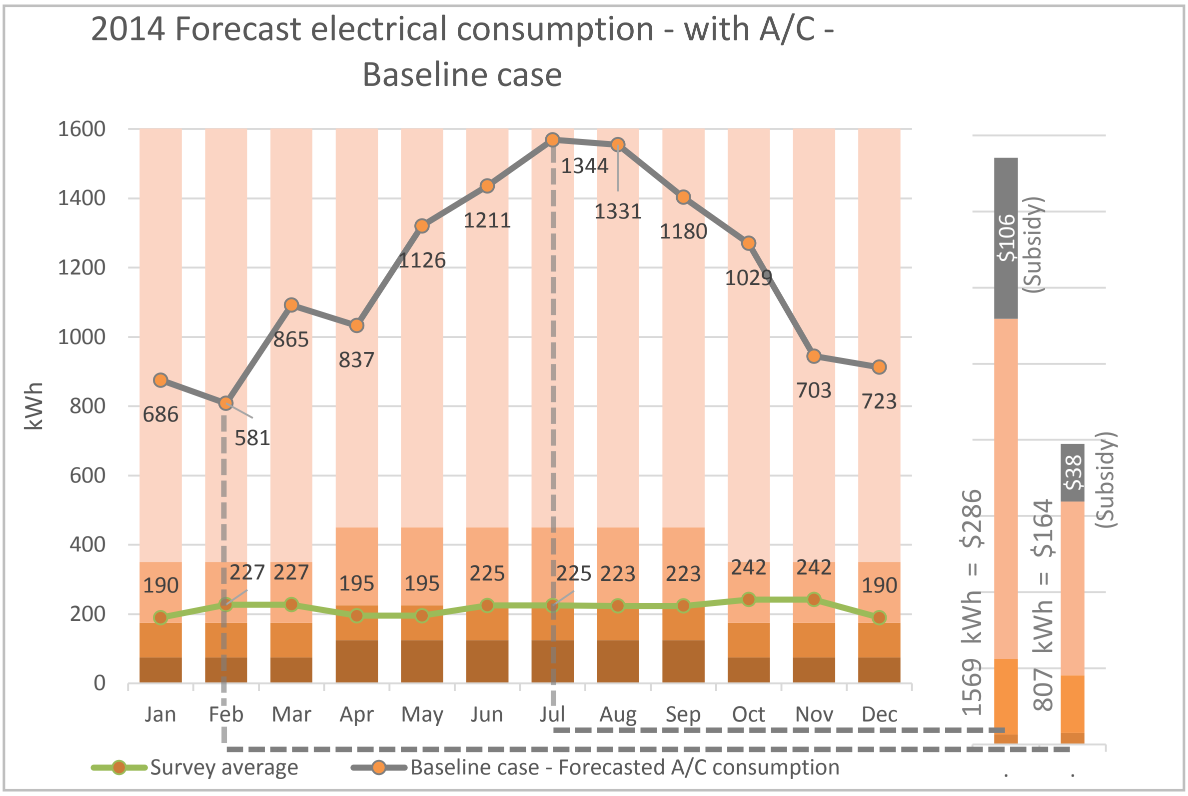


Figure 4-17. Forecasted monthly / annual energy consumption based on house type Baseline case.

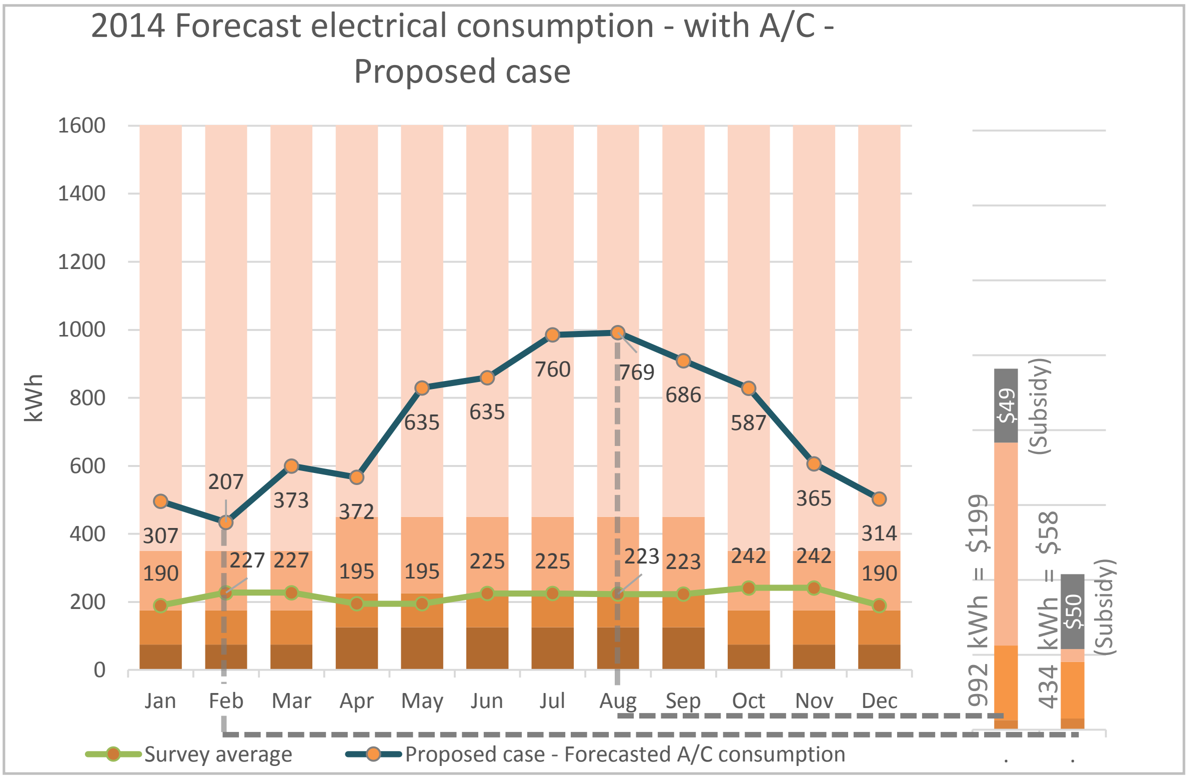


Figure 4-18. Forecasted monthly / annual energy consumption based on the house type proposed case.

4.3. Solar active cooling – Thermal system design, sizing, and simulation.

Based on the projected cooling load for the housing unit (proposed case) and after significantly reducing the cooling load capacity during the implementation of the five proposed improved conditions to the baseline case, the solar thermal cooling system was designed, sized, and simulated. The first system to be described is the heat production sub-system, consisting of a flat plate collector system and a heat storage tank system. Secondly, in the cold production sub-system, an adsorption chiller with a wet recooler unit, and a cold water buffer tank are specified. Finally, a fan coil system was specified for the load distribution sub-system. To arrive to this design, many equipment variables were considered and carefully chosen as described below. A careful literature review was also performed, mainly from the *SOLAIR* project online and books such as *Planning and Installing Solar Thermal Systems: A Guide for Installers, Architects, and Engineers* by DGE (2005) and the *solar assisted air conditioning in Buildings* by IEA (Henning, 2004). Finally, consulting with equipment representatives was the main information tool for decision making of the system configuration. Equipment comments came expressly from Sortech representative technical expertise advice unless otherwise noted.

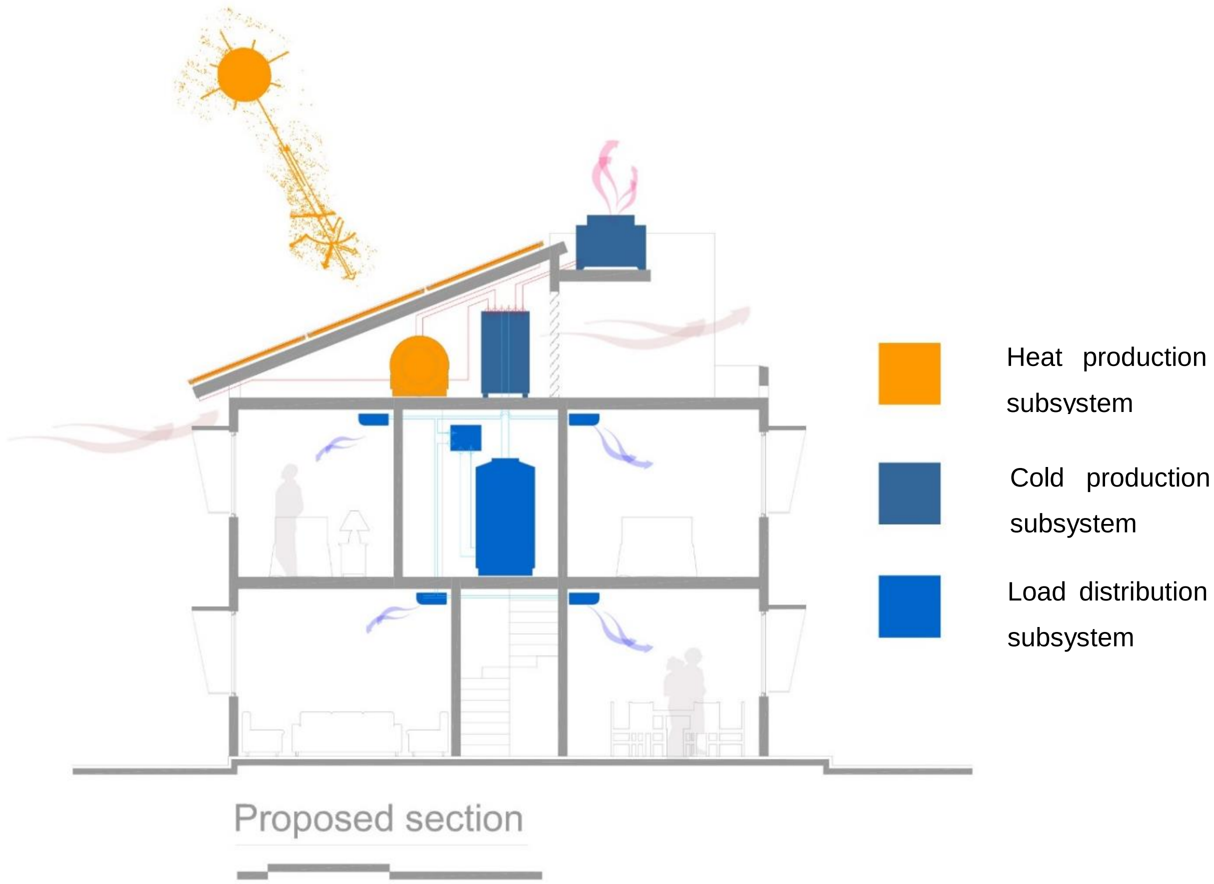


Figure 4-19. Solar cooling thermal system - Proposed subsystem spatial distribution.

Source: From author. Adapted from CAD drawings – Grupo VIVO.

In terms of the equipment location, Figure 4-19 shows a section diagram of the housing unit showing the spatial distribution of the equipment. For the heat production subsystem, the tilted roof system proposed during the improved conditions' phase is being utilized for the solar collector array. Enough clear space in the rear roof area, where the flat remainder roof area is found, was also taken into account. This in consideration for equipment operation and maintenance tasks. This factor, along with the domestic water tank tower (for domestic use) were a determinant factor when sizing for the maximum collector area. On the other hand, the interstitial space below the sloped roof, is being used to house the hot water storage tank. This interstitial area is also useful for equipment placement of the cold production subsystem, such as the adsorption chiller, as well as the water recooler unit, that is found just above where the louvering screen that encloses this interstitial space is placed. Finally, the load distribution system is located inside the living space. The cold water storage tank is the only equipment device that reduces the living area. The fan coil units are proposed to be ceiling mounted. Equipment sizing was dictated by the cooling capacity requirements, and well as per spacing constraints. However, the simulation of the equipment performance played a big role in determining the final configuration. Polysun 7.0 is a unique software tool that offers precise modeling of hydraulics' performance due to modularity and coupling of multiple systems. The system was built upon the basic template for an adsorption system included in the software. Figure 4-20 shows the final thermal system layout. This layout is schematic and only shows the system's main components and parts.

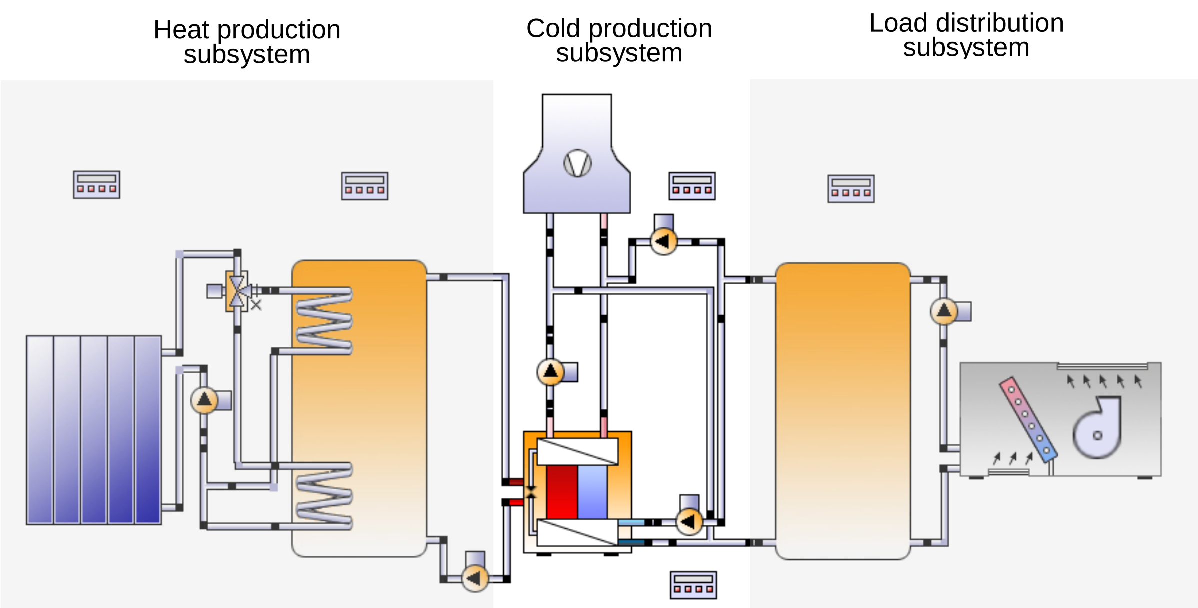


Figure 4-20. Solar cooling thermal system - schematic diagram.

Source: From author. Adapted from Polysun software.

Following is a brief description of each subsystem, the constraints and limitations, as well as two scenarios of the daily simulation results. No weekly scenarios were taken into consideration since the driving methodology is based on daily consumption. Annual scenarios will be discussed in the subsequent chapter.

4.3.1 **Heat production sub-system.**

- Flat plate collector

During this section, the integration of the solar system (here considered a subsystem element) to the house unit is explained. This by means of installing the solar collectors to the available roof area, in order to capture the self-contained energy yield within the building envelope. For that reason, proposed improved conditions one and two (see subchapter section 4.1.2 - Improved conditions) had the dual purpose of incorporating the solar system while reducing the thermal load of the building. With that said, it was planned that the solar collectors be integrated into the housing unit sloped roof. Thus the roof tilt angle of the roof was modified from the existing 6° to a 21.5° optimal angle of inclination, and the azimuth roof angle was established as 0° thus facing the same south direction during the whole year period. This measure meant obtaining the highest heating output. The roof area was also slightly increased above 30 m². These modifications were in order to improve the solar energy catchment area. The considered technologies were divided in two approaches where high efficient flat plate collectors (FPC) was the first option followed by evacuated tube collectors (ETC) as the most expensive but much more efficient one. These two types of solar heat-activated systems require low global irradiance to produce enough energy yield. There are many reasons as to why a flat plate collector system was selected over an evacuated tube collector one. While it's most popular application is for domestic hot water supply, flat-plate collectors are also considered for solar active cooling systems when climatic circumstances are most favorable.

Figure 4-21. Image of Buderus high performance flat plate collector.

Source: Buderus website.

The most critical issue affecting the performance of the collector is the heat transfer circulation with the absorber, although different solutions and collectors types (such as the solar air and evacuated tube collectors) are available on the market at different costs (TREBERSPURG, 2011). It was important, when selecting the type of solar collector system to make sure the gross collector area is within the roof parameters, and the aperture and absorber area have been maximized. From within the above mentioned solar collector options, high efficient flat plate collectors showed good potential performance of the solar cooling system showing higher efficiencies, and better efficiencies in the higher temperature ranges during the Simulation. Its costs, however, are usually higher. From within the evaluated panels, the Buderus, shown here in Figure 4-21 was selected for its optimal performance, competing in performance with its ETC counterparts.

- Heat storage tank (HWST)

For solar cooling systems, a Heat storage tank is required so that it can act as a as a buffer, in order to overcome mismatches between solar gains and cooling loads. For that reason, the storage tank should have a larger volume. The size of the HWST depends on the time difference required between the temperatures produced by the collector array and the cold water demand. This has the purpose of equalizing the temperature peaks resulting from the adsorption chiller. In order to size the HWST for a solar water heater system, a general rule of between 75-125 l/m^2 of collector area is applied. However, for the solar cooling system, a water tank of about 1 m^3 water capacity is required in order for the hot production subsystem to run properly. This in order for the circuit to run the FPC array circuit properly.

- Solar loop controller (C-SL)

In terms of the solar loop pump, this needs to work under match flow conditions, and not under a fixed power, in order to obtain the outlet water temperature from the solar array system with the highest temperature possible and prevent its shut down every time the temperature of the collector array would get too hot. This is also at a side from the safety precautions the system should have for preventing the fluid in the collectors to evaporate. Also, all modern heating systems nowadays enable the desired type of control to be set manually.

In summary, Table 4-6 below outlines the technical specifications for each of the main system components.

SAC - Thermal system	Heat production sub-system	
Collector type	Flat plate	
	Manufacturer	Bosch
	Model	SKC-w
	Absorber / Aperture area	2.256 m²
	Gross area	2.228 m²
	Eta0 (laminar)/(turbulent)	.77 / .77 s/m
	A1 with wind	3.681 Ws/m³/K
	A1 without wind	3.313 W/m²/K
	A2	0.0173 W/m²/K
	Dyn. Heat capacity	6,677.8 J/K
	Volume	1.92 l.
	Max. flow rate	157.9 l/h
	Max. temperature	180 °C
Array		
	Gross surface area	66.84 m²
	Aperture area	67.68 m²
	Absorber area	67.68 m²
	Number of collectors	30
	Number of arrays	2
	Wind speed at the collector array	50.0%
	Orientation	0.0°
	Inclination	21.5°
	Rotation	0°
	Tracking	No
Buffer	Hot water storage tank	
	Volume capacity	3000 lts
	Height	2 m.
	Bulge height	100 mm.
	Material	Stainless steel
	Wall thickness	2 mm.
	Insulation	Rigid PU foam
	Thickness of insulation	120 mm.
Heat exchanger 1	Coil no. 1 / Position	Medium @ 30%
Heat exchanger 2	Coil no. 3 / Position	Medium @ 90%

Table 4-6. Hot production subsystem technical specifications.

Source: from author, information obtained from Polysun software.

The following Figure 4-22 and Figure 4-23 show the hot production subsystem performance in two extreme weather conditions. The first one shows a system performance simulation during January 8th, considered as part of the winter design week. The next figure relates to the summer design day, on July 15th.

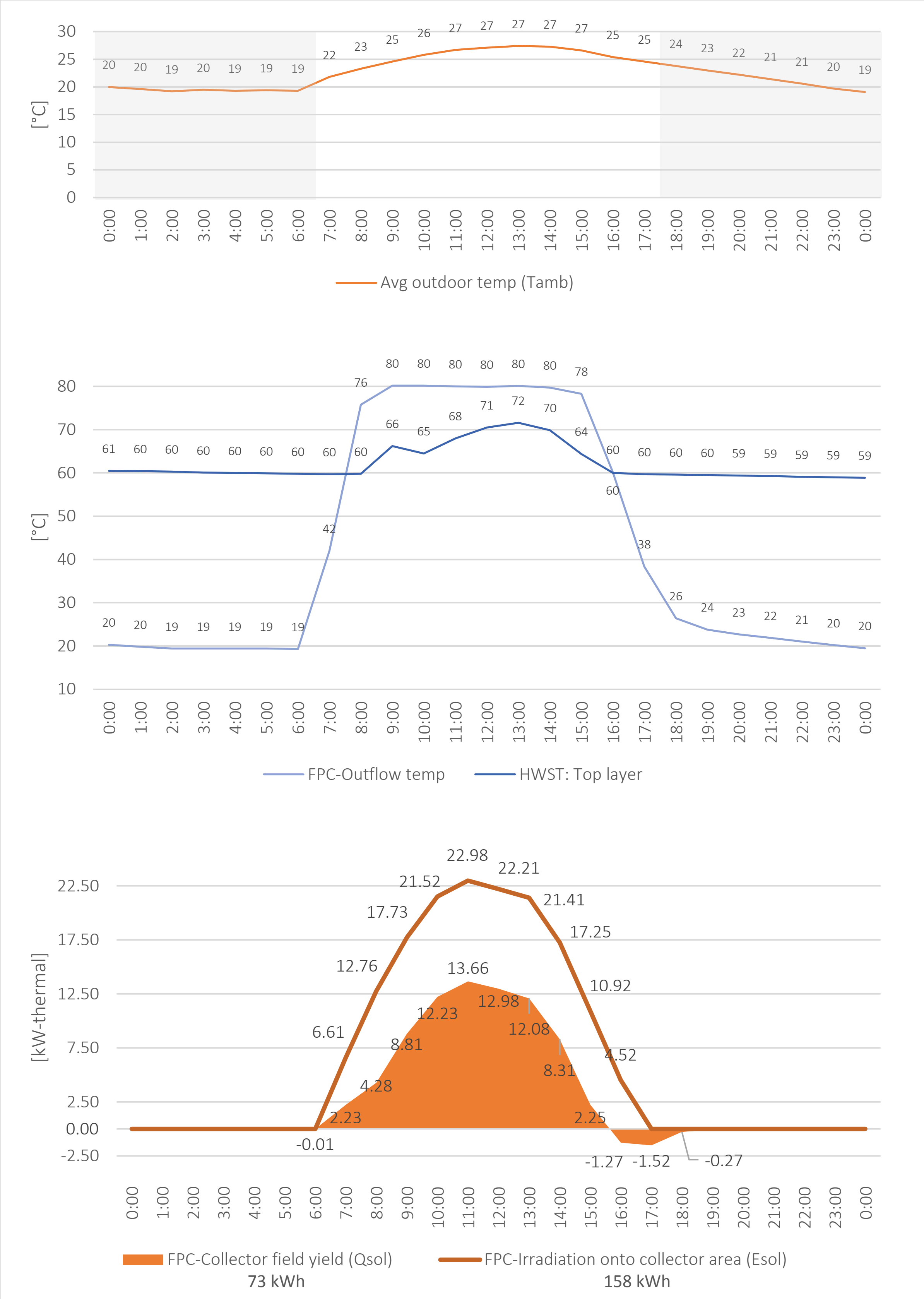


Figure 4-22. January 8 hot production subsystem performance.

Source: By author. Results obtained from Polysun software simulation.

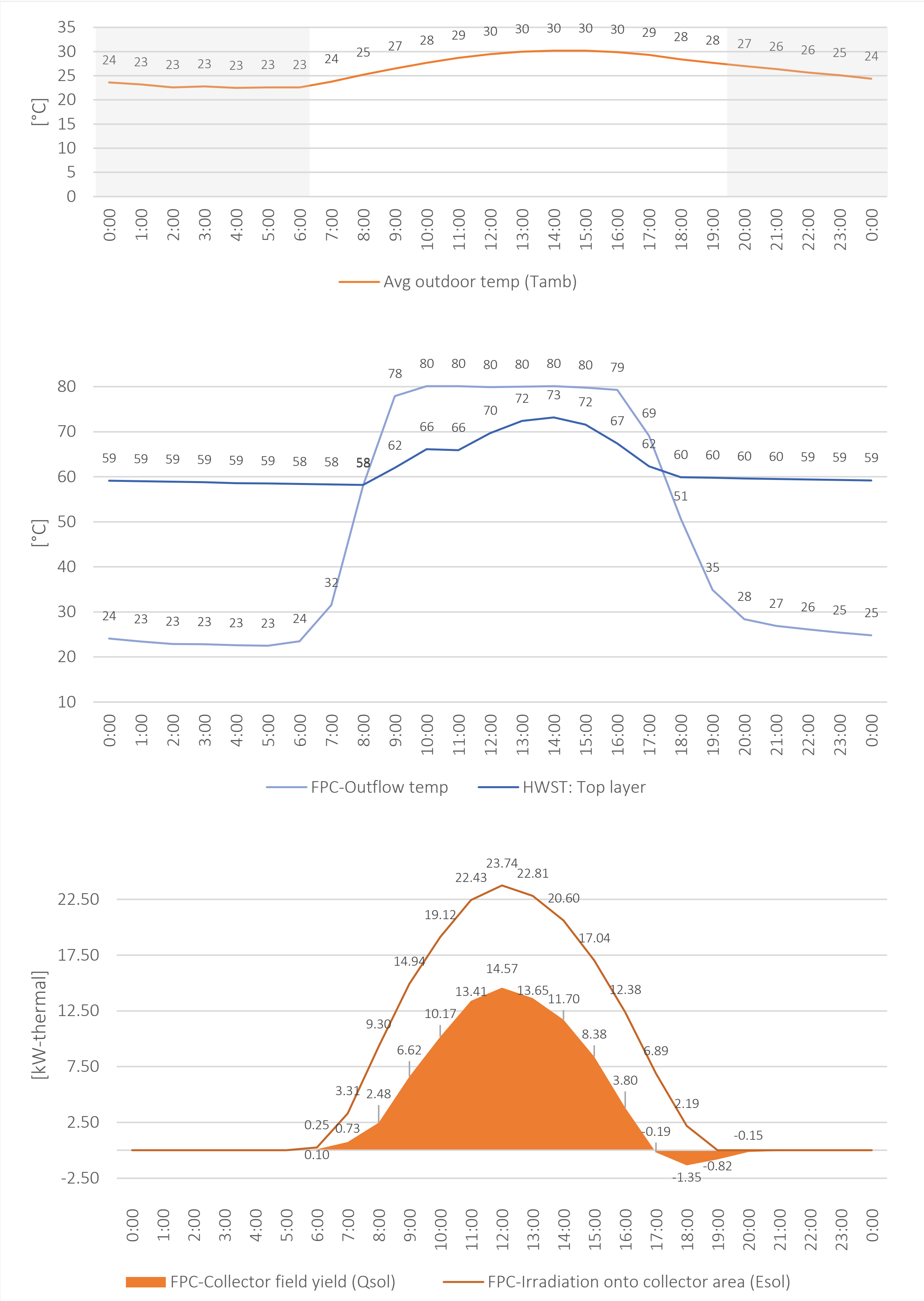


Figure 4-23. July 15th, hot production subsystem performance.

Source: By author. Results obtained from Polysun software simulation.

In these two graphics it can be observe that the production time lapse is very similar for both winter and summer typical day, being the later one, with an extra hour of hot production time. The summer design day simulation showed that the heat liquid starts after 8:00 a.m. and continuing until past 6 p.m. in the evening. At 9:35 the solar loop pump stabilizes the rate flow starting at 50 l/h until it reaches its peak flow of 960 l/h at 1:02 p.m. This heat production results in a steady 80°C water temperature for 7 hours. However, this heat increase is not able to reach the 80°C once it leaves the buffer tank, keeping itself steady only in the 65°C water temperature ranges. A solar system with heating support may then achieve a sufficient amount of solar energy to raise this level to the preferred 85°C at the HWST outside flow. However, an auxiliary water boiler system was discarded for the SCS design when contemplating on producing the remaining required energy by means of an auxiliary boiler. The reason is that the purpose of this study was to test its self-sufficiency, and adding external energy sources would deceive the results in terms of the system's efficacy.

4.3.2 **Cold production sub-system**

- Adsorption chiller (AdC)

From the pool of small capacity adsorption chillers available in the software equipment options for simulation, the ASC08 adsorption chiller has been chosen. Although nowadays newer and more efficient equipment is already available in the market, which starts operation at 55°C like is the case of the eCoo adsorption chiller, the ACS08 adsorption chiller works well for the purpose of this study (see Figure 4-24). For the ideal function of the adsorption chiller and in order to obtain an ideal capacity of cooling load, the following values are considered for the system design: Hot water at 80°C, re-cooling water at 31°C, and cold water at 12°C. According to Sortech equipment manufacturer, the best configuration would be to have a heat source with continuous high temperatures up to 95°C, a recooling system with low recooling temperatures and high cold water temperatures between 15-19°C. These conditions would be ideal for the adsorption chiller performance resulting in a high cooling power at the end. In terms of electricity consumption, the adsorption chiller in its maximum operation range consumes 410 W, plus the power consumption of the recooling unit.

Figure 4-24. Small capacity adsorption chiller.

Source: Sortech.

All three loops are directly connected together (except for the solar collector array), thus water can be used in the system as the driving fluid, except when there is a frost danger and especially when the chiller equipment is placed in an exterior environment. For these conditions, a glycol mix may be used as it may decrease the operation mode because of the lower heat transfer capacity of glycol. If this system separation is needed, then this would also need to be accounted for some electrical consumption. In warm climates, however, water can be used in the loop system from the HWST in the hot production subsystem to the fan coil loop in the load distribution subsystem.

There are specific elements of the solar cooling system design that need to be addressed for a warm-humid location. The recooling requirements for the cold production sub-system needs special attention. Depending on the actual conditions, a use of a dry recooling system may derive in problems. A wet recooling systems will probably be more adequate. More effective solutions, however, would be wells, bore hole heat exchangers, rivers, lakes, or sufficient dimensioned pools that could guarantee lower recooling temperatures. However, all of these would require greater effort and cost.

Below Table 4-7 shows the equipment parameters for the Cold production subsystem.

SAC - Thermal system	Cold production sub-system	
Chiller type	Adsorption	
	Manufacturer	SorTech AG
	Model	ACS08
	Refrigerant / absorbent	Water / Silicagel
	Chilled water setpoint temp	11°C
	Design chilled water flow rate	2000 l/h
	Design cooling water flow rate	3700 l/h
	Design hot water flow rate	1600 l/h
Full load cooling power	CH18CW25/30/35/40 HW65	8.53 / 5.54 / 2.55 / 0.0 kW
CoP	CH18CW25/30/35/40 HW65	0.55 / 0.51 / 0.38 / 0.01
Full load cooling power	CH18CW25/30/35/40 HW75	9.93 / 7.21 / 4.49 / 1.77 kW
CoP	CH18CW25/30/35/40 HW75	0.57 / 0.57 / 039 / 0.19
Full load cooling power	CH18CW25/30/35/40 HW85	10.4 / 7.74 / 5.07 / 2.41 kW
CoP	CH18CW25/30/35/40 HW85	0.49 / 0.44 / 0.36 / 0.24
Full load cooling power	CH18CW25/30/35/40 HW95	11.44 / 8.78 / 6.13 / 3.48 kW
CoP	CH18CW25/30/35/40 HW95	0.46 / 0.42 / 0.35 / 0.25
Wet recooler		
	Design cooling capacity	30 kW
	Design water flow rate	3,600 l/h
	Design air flow rate	140 l/s
	Design water inlet temperature	32°C
	Design water outlet temperature	25°C
	Design approach temperature	2°C
	Variable speed fan	Yes
	Max. fan power	0.65 kW

Table 4-7. Cold production subsystem technical specifications.

Source: from author. Information obtained from Polysun software equipment description.

Figure 4-25 show daily results for the cold production subsystem during January 8th. Here one can appreciate that the minimum required design variable of 65°C in the adsorption hot water inlet in order to perform with a CoP of .38, that is, about between 2.55 kW and 3.68 kW of cooling capacity, is only achieved between 10:00 a.m. and the 3:00 p.m. in the afternoon. This may be extended up to 5 p.m. for the summer design day, July 15th condition as shown in Figure 4-26. However the higher capacity value on January 8 is made evident due to the recooling incoming water is warmer, making the adsorption machine to become less efficient. In these two graphics it is also notorious the time lapse between the outside temperature raise and the rise of cooling capacity of the adsorption chiller. This is due to the buffer effect of the HWST in the hot production subsystem.

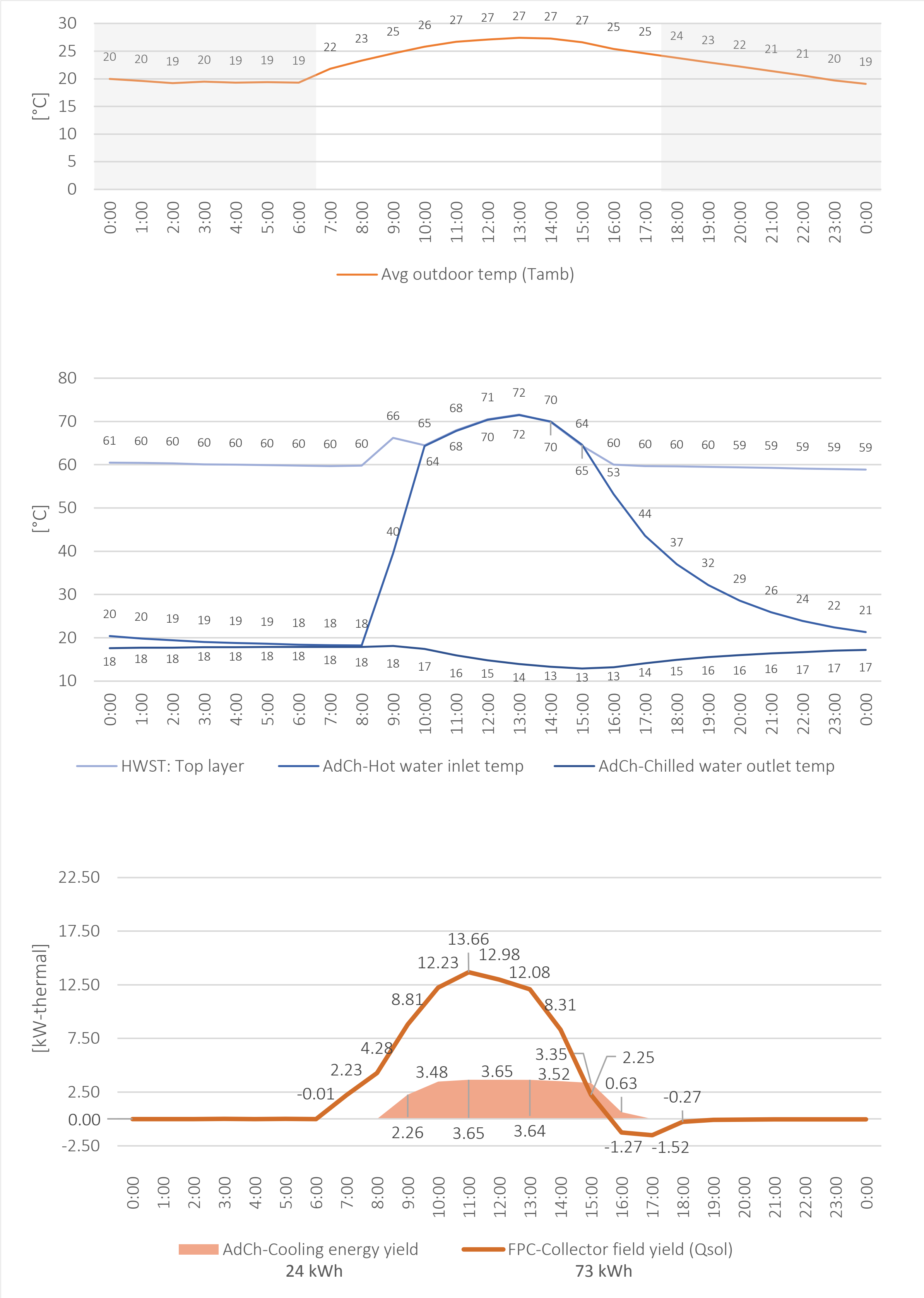


Figure 4-25. January 8th, cold production subsystem performance.

Source: By author. Results obtained from Polysun software simulation.

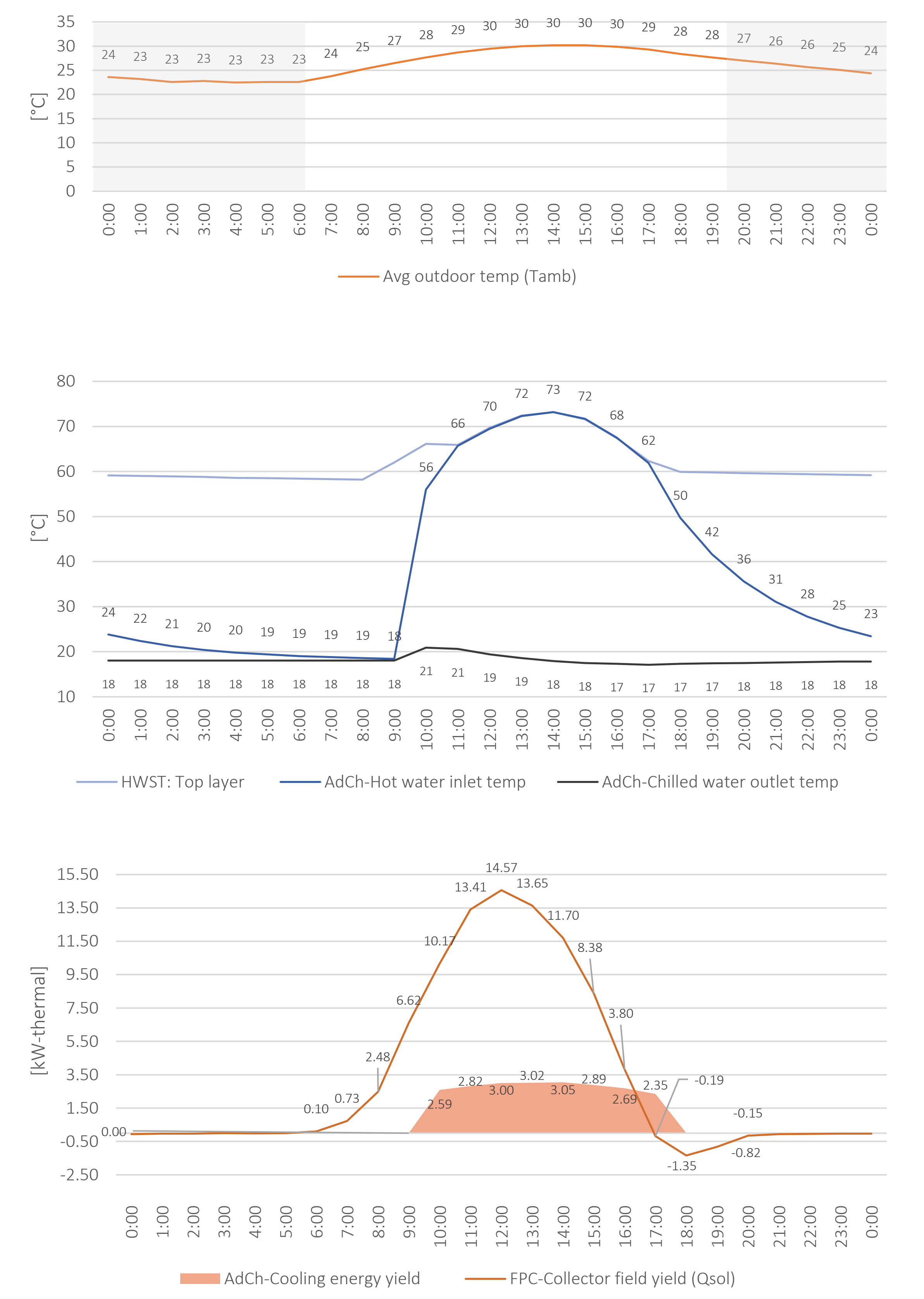


Figure 4-26. July 15th, cold production subsystem performance.

Source: By author. Results obtained from Polysun software simulation.

4.3.3 **The load subsystem – Air conditioning equipment**

According to the adsorption chiller manufacturer, a cold distribution with relatively high cold water temperatures, which translate in higher efficiencies and cooling power provided by the adsorptions chiller is advisable. Distribution systems with high efficiencies include chilled beams, cooling ceilings, or underfloor cooling system to name a few. Thermal mass as a cold distribution medium is also an option. For this system design, a 2-pipe fan coil distribution system, such as the one shown in Figure 4-27, has been selected with a Cold water storage tank (CWST); this is in order to store the excess cooling power in a cold storage unit. When using adsorption chillers, a cooling storage tank should definitely be integrated into the system in order to control the stability of the system (DSG, 2005). Thus The load distribution subsystem includes a cold production sub-system that contains 1000 liter cold water storage tank.

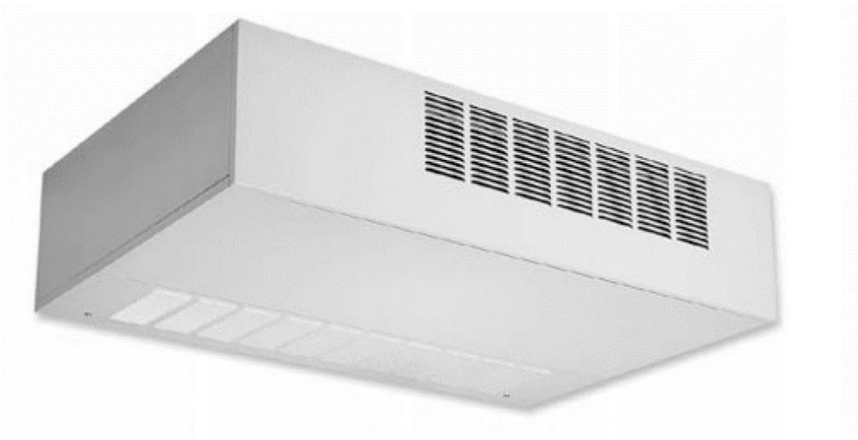


Figure 4-27. Example of a horizontal fan coil unit.

Source: Johnson Controls product website.

Table 4-8 below summarizes the proposed equipment specifications. In the performance results shown in Figure 4-28 and Figure 4-29 It is noticeable that the unmatched cooling load distribution of the fan coil units compared to the adsorption chiller water production. In terms of the temperature from the chilled water temperature coming from the adsorption chiller, the January 8th simulation provided a noticeable decrease having a sustained 14°C between 1:00 p.m. and 2:00p.m. This was elevated to 18°C in the July 15th condition; a temperature difference of 13°C degrees in the January 8th simulation versus 12°C in the higher temperature conditions.

It is thus inferred that the system has a better efficiency in the medium range outdoor temperatures than in the hotter days. In terms of the ideal 18°C or below range for the load distribution, this was only able to be maintained for just 4 hours in the July 15th simulation and 6 hours in the January 8th period.

SAC - Thermal system	Load production sub-system	
Module type	Fan coil	
	Number of units	9
	Manufacturer	GEA Happel Klimatechnick
	Model type	Four-pipe system size 1
	Number of cooling coils rows	3
	Cooling water volume	0.8 lts.
	Nominal cooling power	1,100 W
	Nominal cooling water flow rate	157 l/h
	Nominal air flow rate	42 l/s
	Nominal cooling water inlet temp	6 °C
	Nominal cooling water return temp	12° C
	Nominal air inlet temp - cooling	27°C
	Nominal air return temp - cooling	11°C
	Fan power input	41 W
Buffer tank	Cold water storage tank	
	Volume capacity	1000 lts
	Height	2 m.
	Bulge height	100 mm.
	Material	Stainless steel
	Wall thickness	2.5 mm.
	Insulation	Rigid PU foam
	Thickness of insulation	80 mm.
	Heat exchanger	No

Table 4-8. Load distribution subsystem speciicaitons.

Source: from author. Information obtained from Polysun software equipment description.

In conclusion, Figure 4-30 and Figure 4-31 shows the three subsystems' water temperature and cooling yield for the July 15th daily simulation. The annual energy simulation will be discussed in the final subchapter of this section. But from these two graphics it is evident that the 80°C water temperature from the solar collector system sustained over a period of approx. 8 hours in Figure 4-30, was only able to sustain approx. 2.5 kW of Cooling capacity for 4 hours in the fan coil unit. This load would not be nearly approaching the required load for the proposed housing unit. Also, It is evident here that the coupling with the housing unit dynamic loads obtained in the Designbuilder simulation were not able to thermally couple with this Polysun simulation since Polysun software models the building portion using building geometrical proportions, internal loads and generic U-values.

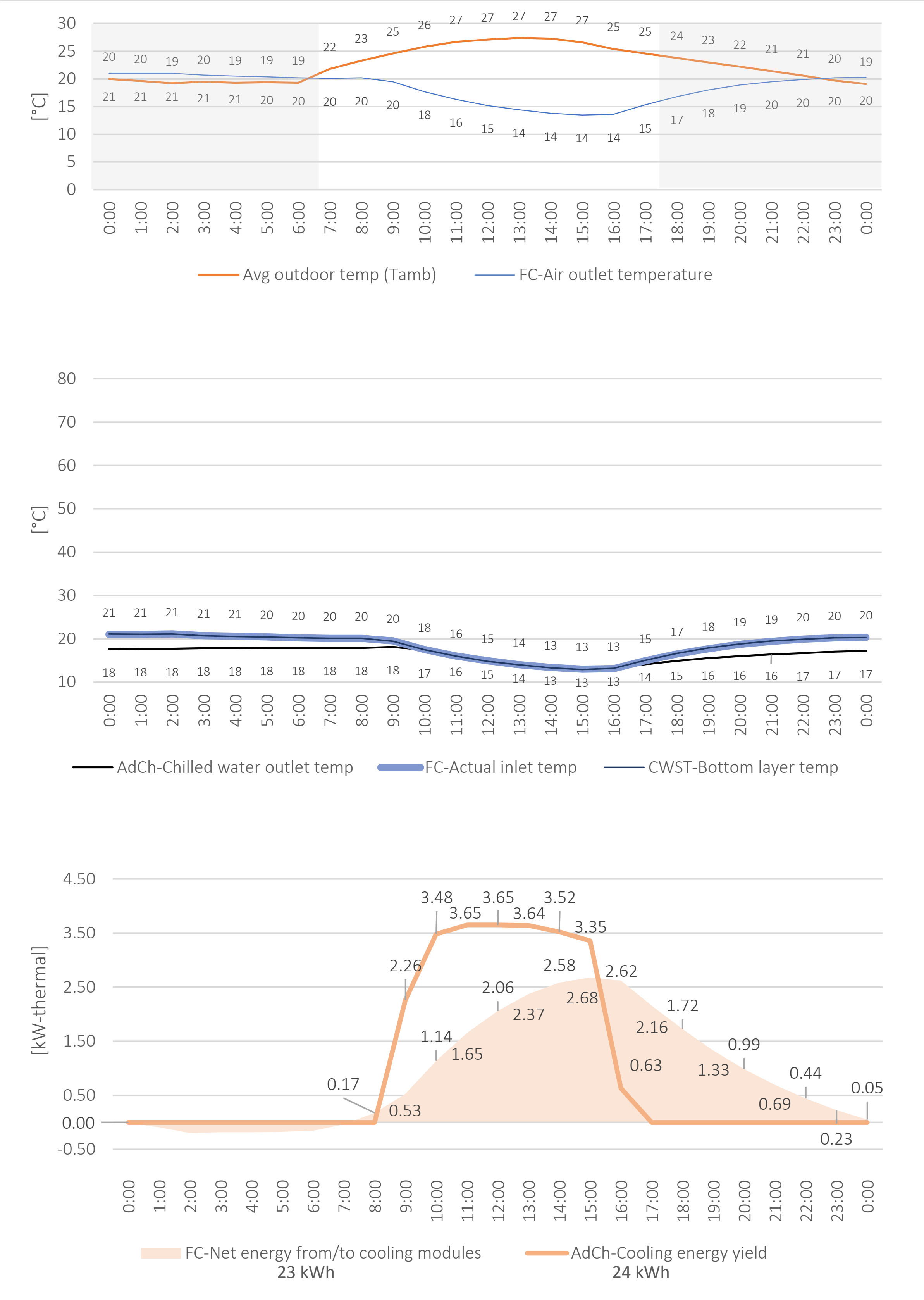


Figure 4-28. January 8th, load distribution subsystem performance.

Source: By author. Results obtained from Polysun software simulation.

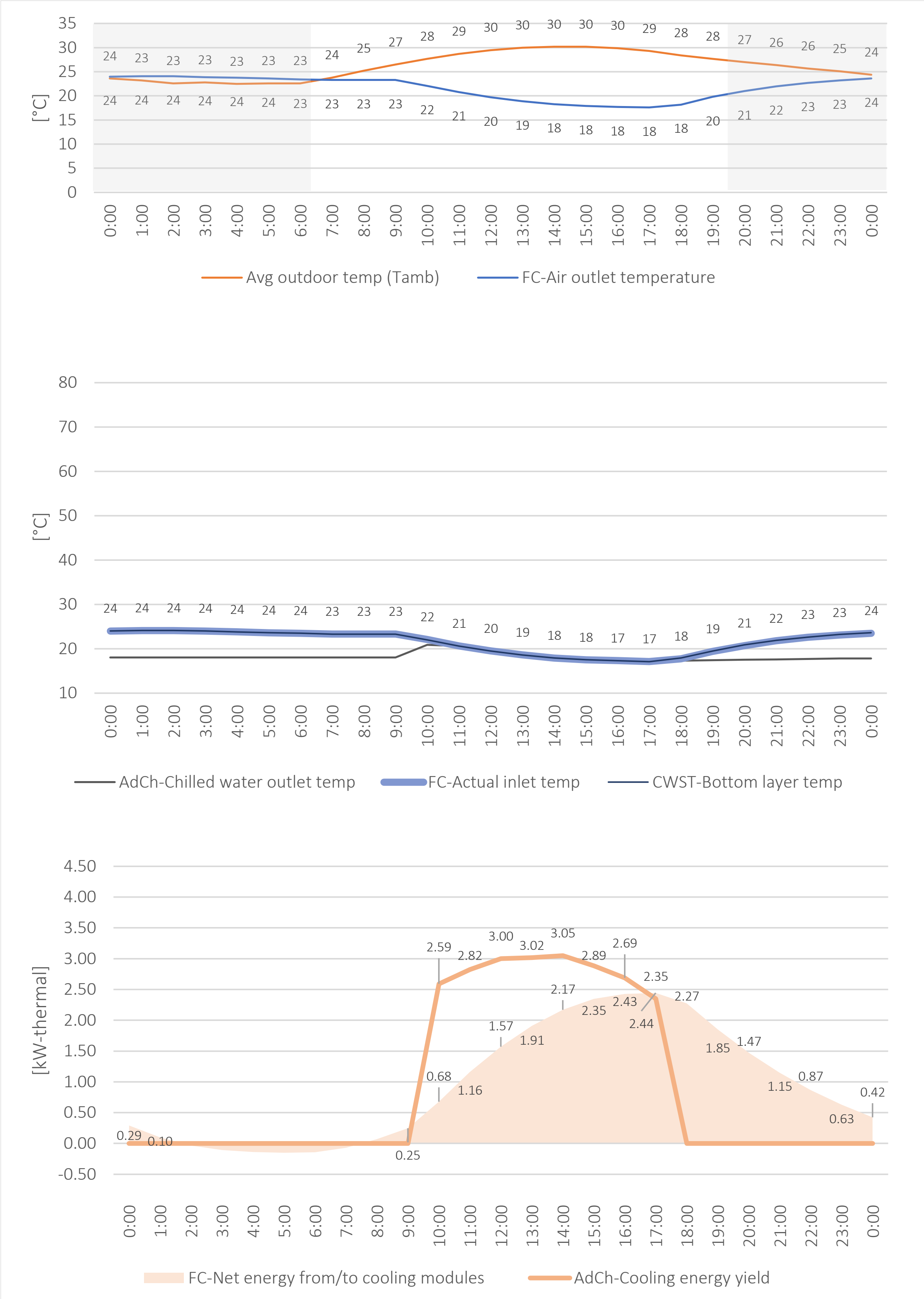


Figure 4-29. July 15th, load distribution subsystem performance.

Source: By author. Results obtained from Polysun software simulation.

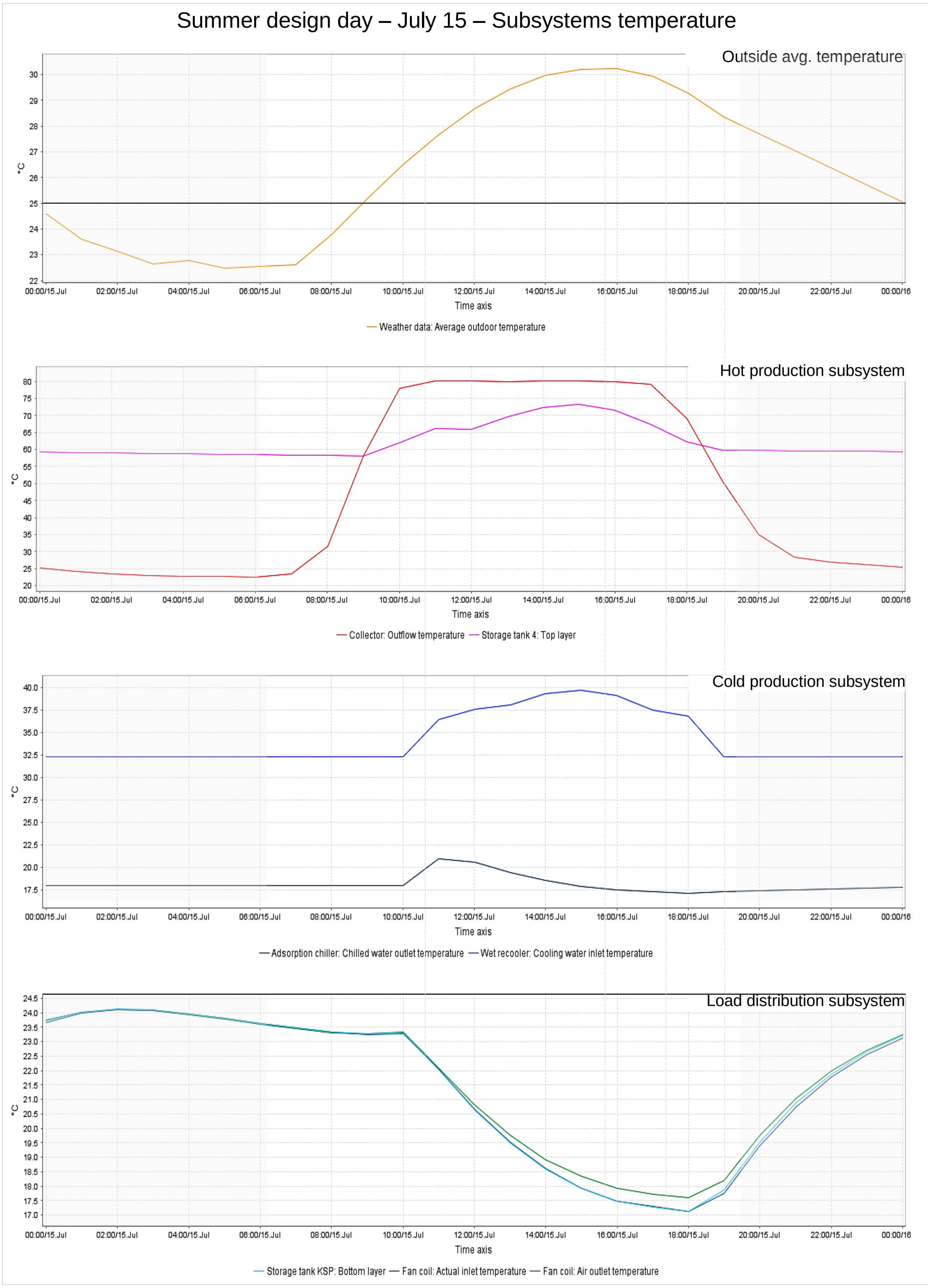


Figure 4-30. Summer design day - temperature ranges.

Source: By author. Graphics created using Polysun software.

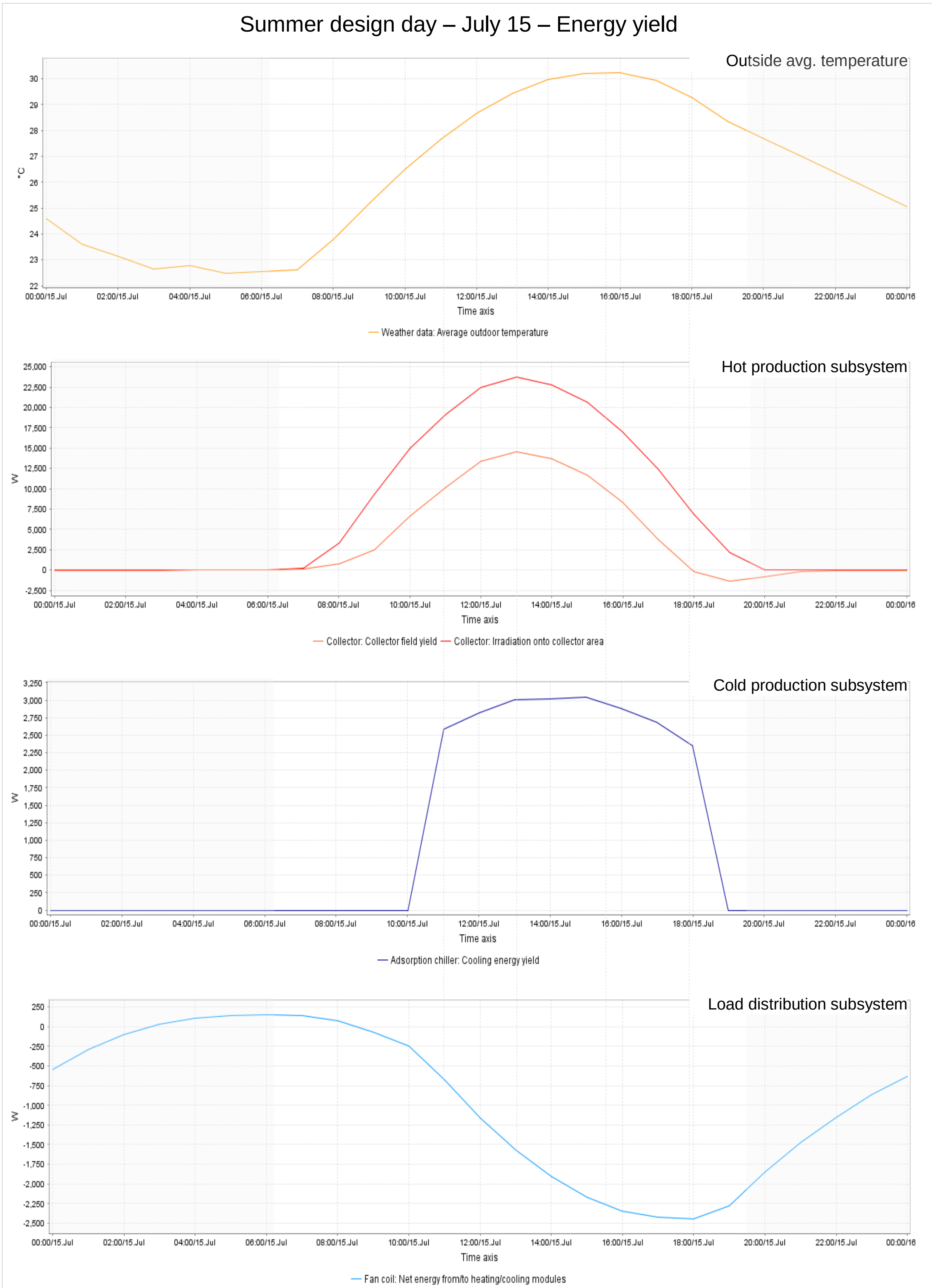


Figure 4-31. Summer Design day – Energy yield.

Source: By author. Graphics created using Polysun software.

4.4. Solar active cooling – Photovoltaic system design, sizing, and simulation.

As previously mentioned during the thermal load analysis phase, the roof area of each housing unit will be solely used for powering each dwelling's air conditioning system. The array, which consists of 21 photovoltaic panels as shown in Figure 4-32, is incorporated into the tilted roof configuration as shown in the improved condition number two phase executed during the thermal load reduction phase. Therefore since this project is in the north hemisphere, the roof's tilt angle which is equivalent to a 21.5° towards the south, will provide the highest power output.

4.4.1 Photovoltaic array subsystem

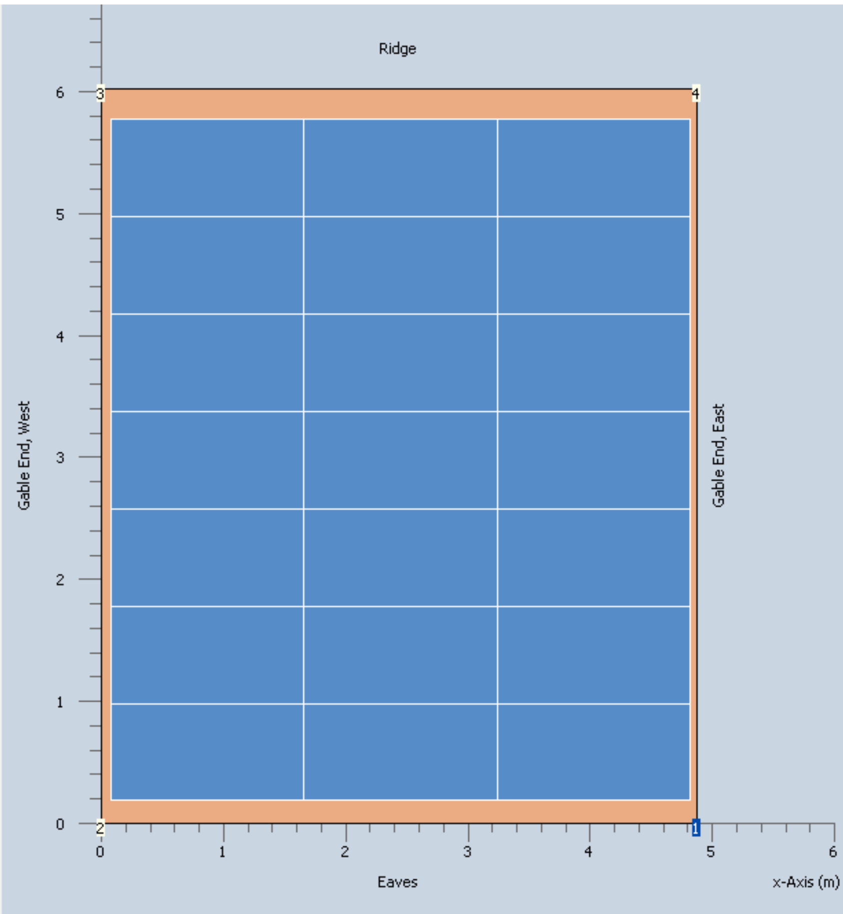


Figure 4-32. Proposed photovoltaic roof layout.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

As an alternative for a solar active cooling thermal system, a photovoltaic power fed system is now being explored. Although the main focus of this document is to unveil the complexities of a solar thermal system, it is also pertinent to establish a performance comparison between the energy production vis-à-vis a photovoltaic based energy production array. From one side, both photovoltaic technology and vapor compression air conditioning systems have become more efficient. On the other side, the working fluid being R134a, has long term implications in the environment. A general model of a solar active cooling is then here proposed.

It is worth noting that the roof itself that is part of the building envelope is flat. The tilted portion of the roof in each of the dwellings is hollow from the underside. This, in order to provide, spacing requirement for storage of the systems such as batteries. The productive surface then was maximized within the tilted roof parameters, and the remainder portion that was kept as a flat roof in order to be able to provide maintenance to the equipment supplier underneath.

- System scheme

Figure 4-33 shows the system scheme. Another aspect to distinguish from this system is that there is no inverter, since the power coming from a PV array is DC, and the A/C compressor is run in DC. For the quality factor of the system, defined by the system's type and material, a 40% quality factor value is proposed. As far as the chosen degradation rate according to the type of the solar panels this was set to 0.5%.

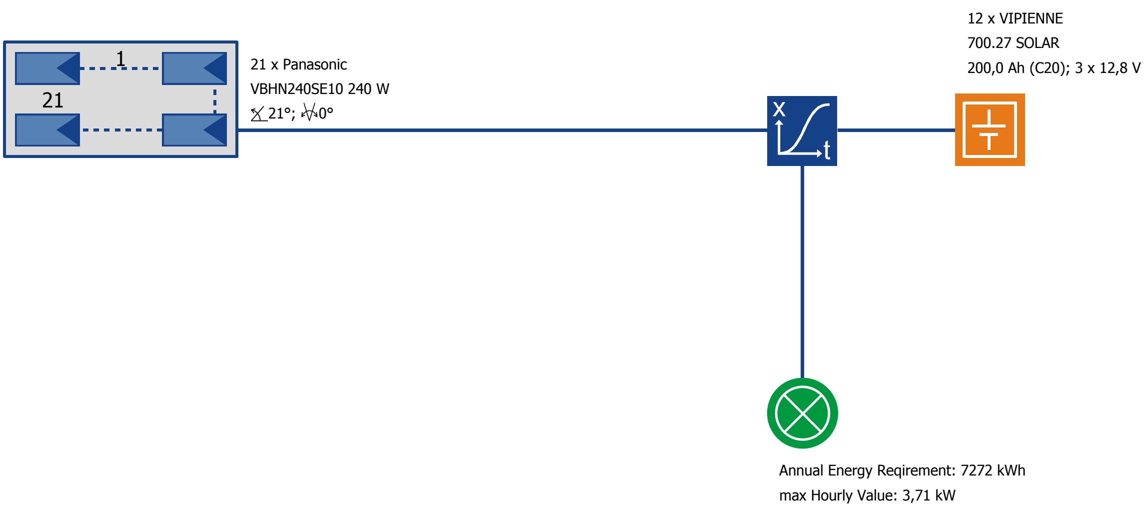


Figure 4-33. Photovoltaic power system scheme.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

SAC - PV system	PV solar array sub-system	
PV Module		
	Manufacturer	Panasonic
	Model	VBHN240SE10
	Nominal output	240 W
	Power rating deviation	0.0%
	Efficiency (STC)	19.0%
	Nominal Output	240 W
Array		
	Gross surface area	26.5 m²
	Active solar surface area	26.6 m²
	Number of Modules	21
	No. modules in series	1
	MPP Voltage (STC)	44V
	Orientation	0.0°
	Inclination	21.5°
	Mount	ventilation
	Shade	No
	Ground reflection	20.0%

Table 4-9. Photovoltaic sub-system – Design characteristics.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

The photovoltaic panel selection was based on highest performance and market availability. The chosen panel for this study was the Panasonic photovoltaic panel model VBHN240SE10, which was pointed out by NREL's latest performance test (see annex) as one of the most efficient ones available on the market up to date. Its specifications are shown in Table 4-9 below. The size also played an important decision factor since the roof had area limitations. In terms of pricing, that will be discussed in the Economic analysis later to follow.

The system peak power value has been calculated by using the equation:

$$P_{peak} = \frac{EI_{stc}}{GQ} \;;$$

Where

Ppeak=Power peak

E= Energy Yield

I_{stc}*=Irradiance under standard test conditions = 1000 W/m*^{2}

G= Global Radiation (kWh/m^2*/yr)*

Q= Quality Factor = 40

4.4.2 Storage sub-system

The battery system was sized for an eight hour backup period, as recommended by previous readings. Table 4-10 shows the back-up system characteristics.

SAC - PV system	Energy storage sub-system	
Battery		
	Manufacturer	VIPIENNE
	Model	700.27 SOLAR
	Nominal voltage	12.8V
	C20 capacity	200,0 Ah
	Self discharge	0.1% / Tag
	Mean charge efficiency	85.0%
	Mean discharge - efficiency	99.0%
	Charge controller	
	Lower battery discharge-threshold	30.0%

Table 4-10. Energy storage sub-system specifications

Source: By author, 2014. Information extracted from PV-SOL software simulation.

To determine the size of battery the following equation has been used:

$$B_c = \frac{E_1 N}{DOD\, \eta_b D} \;;$$

Where B_c *is the Battery capacity* , *N is the Number of no sun days the battery has to supply electricity*, E_1 *refers to the backed up energy -8 hrs- (kWh)*, while *DOD refers to the Depth of Discharge %* and η_b *to the Battery conversion factor %.*

4.4.3 **The load subsystem – Air conditioning equipment**

A vapor compression air conditioning system powered by the photovoltaic sub-system works with R134a refrigerant, under a variable compressor speed. The cooling size prediction of this PV stand-alone cooling system size is based on the actual array's energy production. Therefore the operational time of the compressor needs to match the PV average energy production. The compression load size then needs to be according to the housing unit cooling demand. The PV simulations results are then discussed in the following subchapter.

4.4.4 **Energy Yield.**

The following graphs show the simulation results obtained from the PV-SOL software. For the purposes of analyzing an equal energy consumption schedule that would match the cooling requirement as per the thermal load analysis made in subchapter 4.1, a daily nine hour period over a nine month period was allocated. The compressor based air conditioning equipment power requirement was set to 3.34 kW of power capacity, meaning that the cooling load would be capable enough to cover 5.58 kW of cooling demand with a standard CoP of 1.67. However, with newer equipment running up to 3.0 in CoP this would mean that the system would be able to carry a maximum load of up to 10.02 kW. Figure 4-34 shows the hourly energy yield and the disparity between the demand and supply. Here, during the summer design day, the equipment usage was set to start at 10:30 a.m. and end at 7:30 p.m. during the warmest period of the day. However the photovoltaic system started to produce energy early before 7:00 a.m. It is worth noting that the total daily energy yield is equals 28 kWh while the energy consumption requirement is not significantly higher, at 30 kWh of energy requirement. In relation to the non-consumption period Figure 4-35 shows the energy daily yield at 24 kWh during the winter equinox, with just 4 kWh of energy yield less compared to the summer design day.

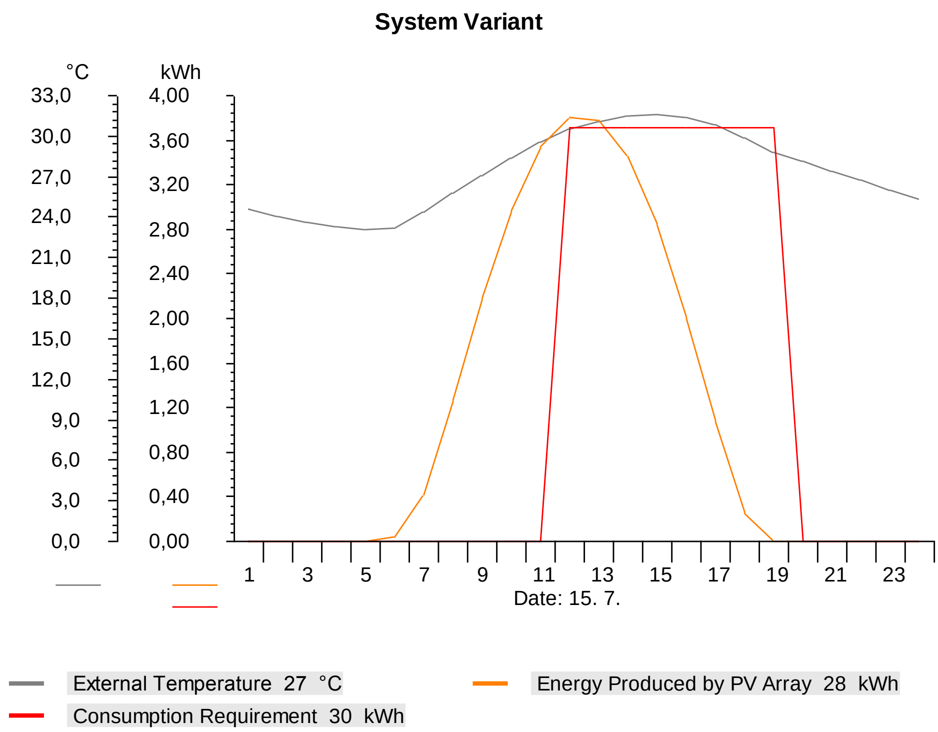


Figure 4-34. Photovoltaic sub-system. Hourly energy yield – Summer design day.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

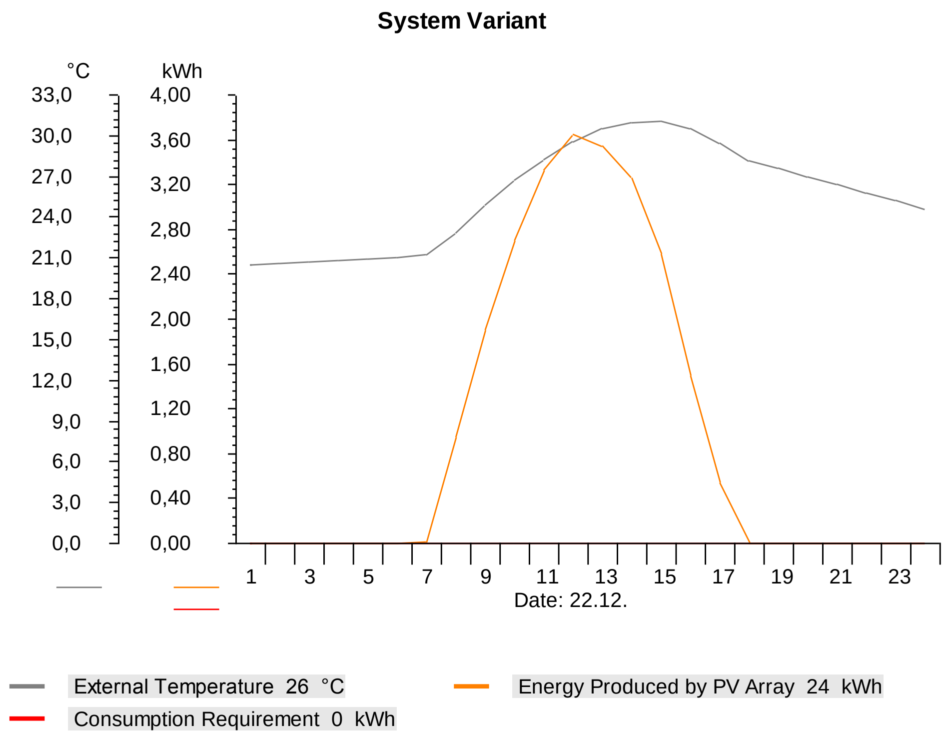


Figure 4-35. Photovoltaic sub-system. Hourly energy yield – Winter solstice.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

Figure 4-36 shows the weekly energy yield vs. the energy demand for the typical cooling design week. Here the energy demand comparison is accentuated, since the cooling requirement is equal to 208 kWh while the supplied energy yielded only 164 kWh. That is in fact due to the weather variation shown during Tuesday. It is worth noting that the simulation software uses a temperature average of the last 25 years to conclude this irradiance values. This outcome values could be regarded as negative, and get accentuated on a monthly perspective, as shown in Figure 4-37 and Figure 4-38. However, if a CoP of 3.0 is considered then one can assume that the effective cooling capacity could start at around 8:00 a.m. with a 1.42 kW of energy capacity and converting into a cooling capacity of approx. 4.25 kW. In the previous daily graphics this period lasts about eleven hours during the summer design day period, and 7 hours during the winter solstice period. Another factor to take into consideration is the fact that the high temperatures and humidity ratio in the area produce preclude the system to work into its maximum capacity, compared to other regions of the country. The large enough storage (battery) sub-system, on the other hand, is thus necessary to balance the time lapse when the photovoltaic sub-system energy yield is at its peak production and when the cooling system is required the most. The electricity required here is also not a simulation reading but rather the cooling design capacity, and therefore will also vary depending on the compressors' energy requirements.

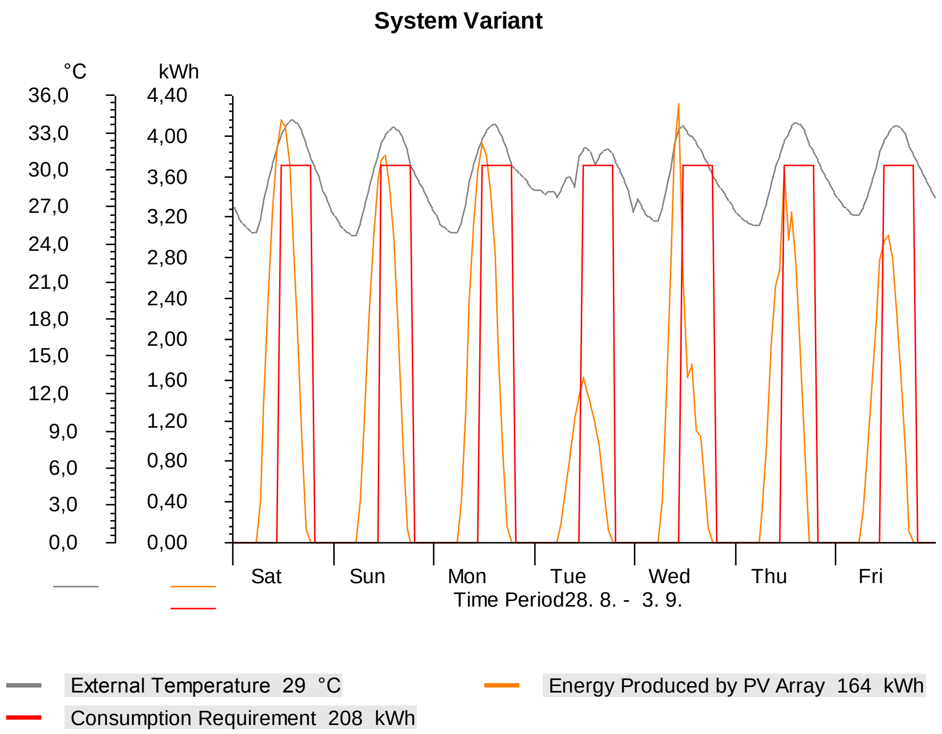


Figure 4-36. Photovoltaic sub-system. Daily energy yield – Summer design week.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

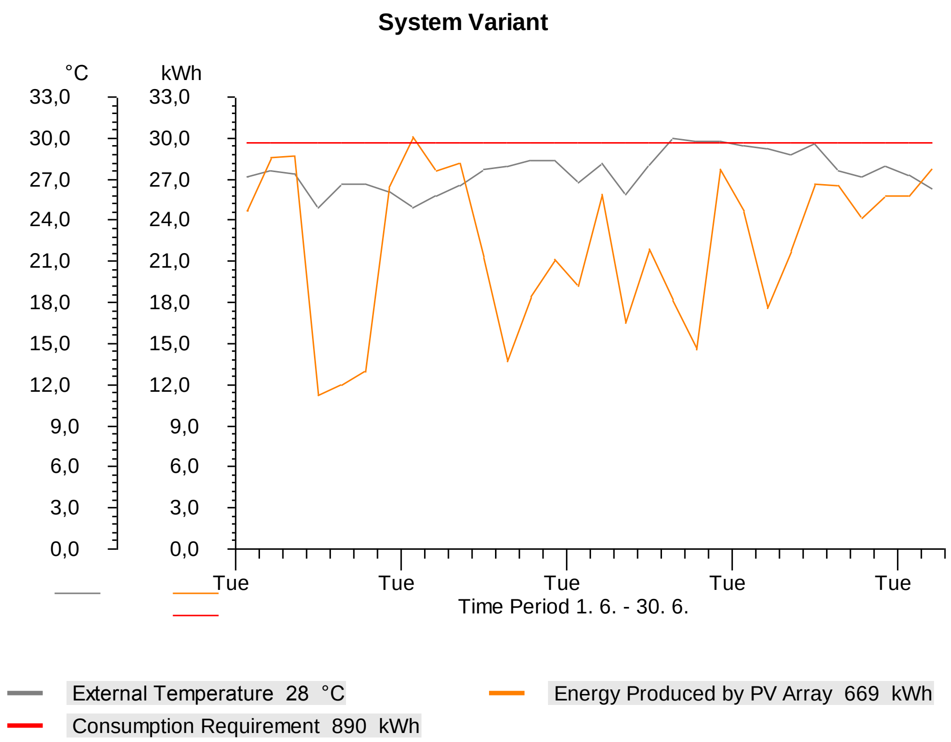


Figure 4-37. Photovoltaic sub-system. Weekly energy yield – June.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

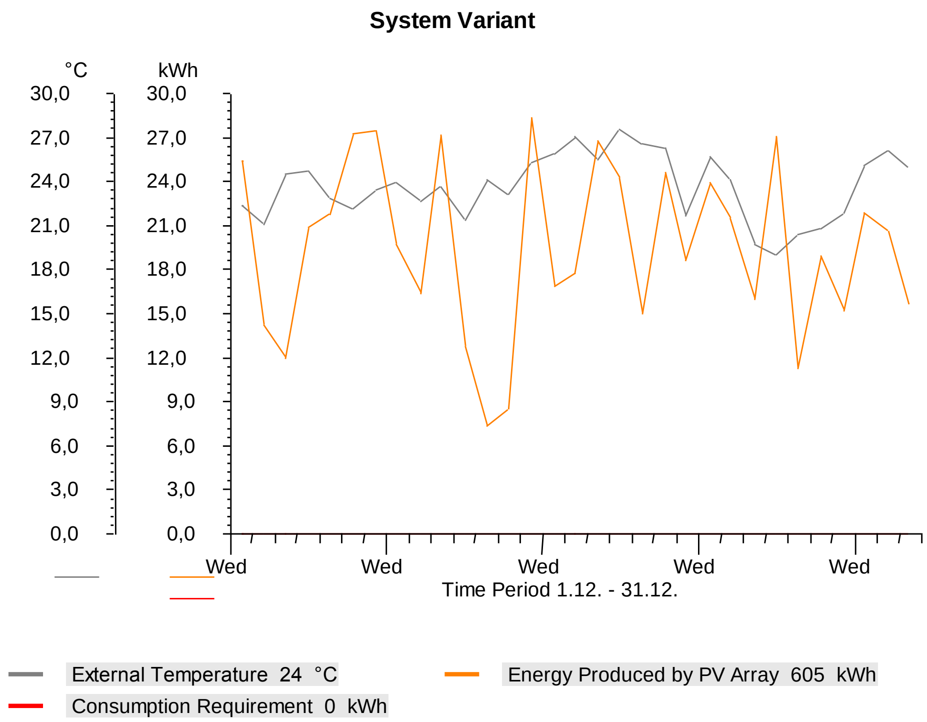


Figure 4-38. Photovoltaic sub-system. Weekly energy yield – December.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

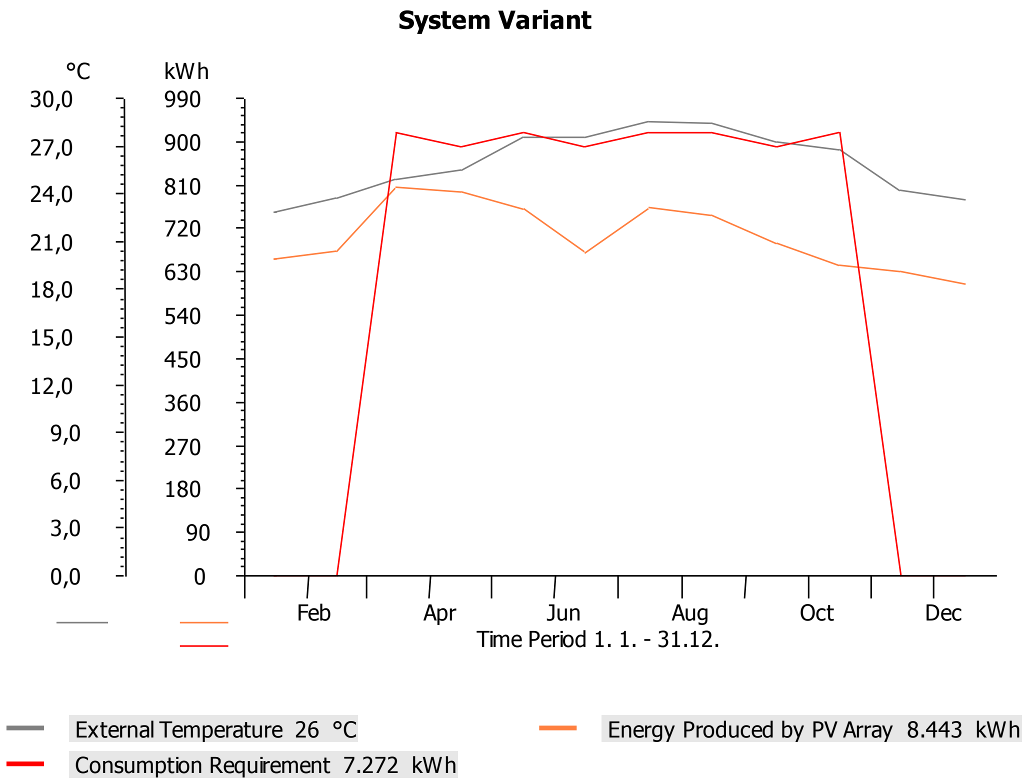


Figure 4-39. Photovoltaic sub-system. Monthly energy yield.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

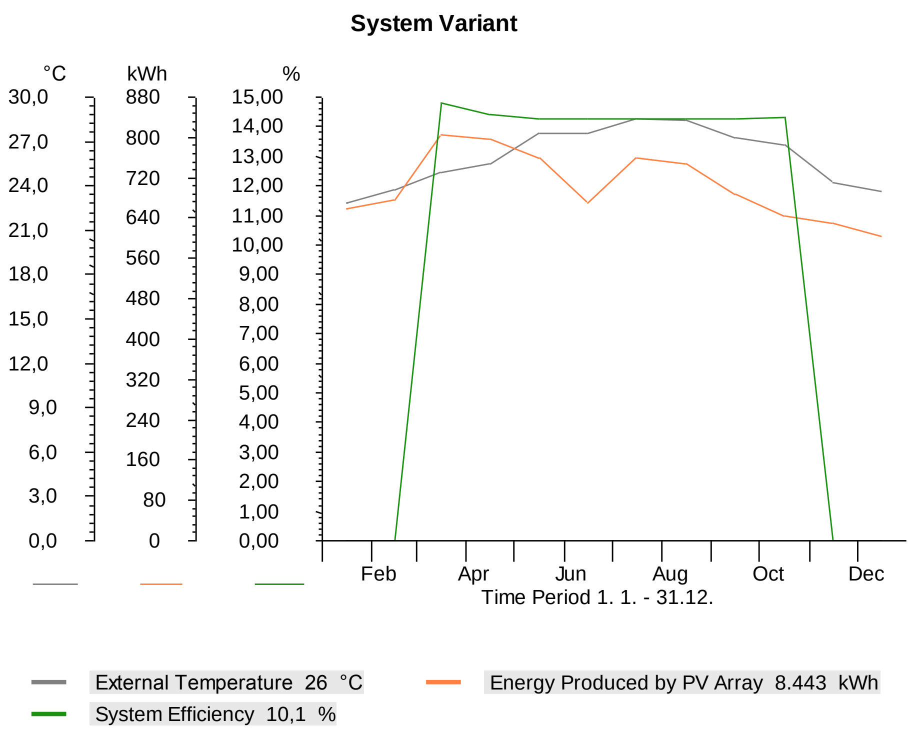


Figure 4-40. Photovoltaic sub-system. Monthly energy yield vs. efficiency curve.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

The annual energy yield is shown in Figure 4-39 and Figure 4-40. Figure 4-39 shows the air conditioning nine month usage period against the constant energy yield. While the system's capability to supply the energy load with enough capacity has been previously discussed, the left over energy yield during this non-usage period has not. Since this system layout does not include an inverter, provisions to this energy excess remains overlooked. Alternate current is often transformed into direct current in home appliances since small, low voltage devices do not need to operate at 120V alternate current. This may include computers, and many more appliances. Thus such a PV based solar cooling system may bring additional advantages over the solar thermal one. Figure 4-40 , on the other hand, addresses the efficiency range over the year, being March the month with the highest efficiency percentage.

SAC - PV system	Balance of energy	
Energy production		
	Irradiation onto horizontal	52,536 kWh
	PV array irradiation	54,484 kWh
	Irradiation minus Reflection	52,184 kWh
	Energy produced by PV array	8,443 kWh
Consumption		
	Consumption requirement	7,272 kWh
	Direct use of PV Energy	3,462 kWh
	Consumption not covered by system	1,771 kWh
	PV array surplus	2,550 kWh
	Consumption covered by solar - energy	5,501 kWh
	Battery discharge	2,039 kWh
	Battery efficiency	83.9%
	Battery charge	2,431 kWh
	Battery losses	392 kWh
	Charge condition at simulation start	100.0%
	Charge condition at simulation end	100.0%
Efficiency		
	Solar fraction	75.6%
	Performance ratio	53.3%
	Final yield	3.0 h/d
	Specific annual yield	1,091 kWh/kWp
	System efficiency	10.1%
	Ground reflection	15.5%

Table 4-11. Energy production results.

Source: By author, 2014. Information extracted from PV-SOL software simulation.

In conclusion, Table 4-11 shows the balance of energy. In an annual context the system's production to load ratio surpasses the 1.0 mark. This is due to the months that, it is speculated, the air conditioning system will not be used. On the other hand, however, from the air cooling system's 7,272 kWh needed only 3, 462 kWh are directly used by from the PV system. The remainder has been covered by the back-up system. The PV system's overall efficiency came up to 10.1% not taking into consideration the CoP factor. With this in mind, such an improvement could bring the system's production to load ratio surpassing well beyond the 3.0 mark.

4.5. **Comparative performance results and payback analysis.**

This subchapter briefly compares the performance of both thermal and photovoltaic systems with each other, in a daily and annual basis, while providing an insight to the cost implications vs. savings in energy consumption reduction. Solar active cooling systems will have a chance into the air conditioning market only if they arrive to save significantly more energy that their electricity grid-fed counterpart. A lowering of the running costs for the operator should also be considered. But the reduction of the primary non-renewable energy consumption is one of the main appeals. Should these three factors, energy saving and cost reduction, can be reconciled with one another, then an aperture to the market could be possible (DSG, 2005).

Figure 4-41 shows the daily performance comparison between the thermal system and the PV one, in hourly values against kW of cooling load. The gray area represents the required cooling load throughout the day for the simulated housing unit (no. 6) with the reduced load. It can be assumed by looking at this graph that a compression based solar cooling system uses less cooling load than its thermal counterpart, this due to its high CoP value. On the other hand, the thermal system real efficiency needs to be adjusted in the graph by determining and discounting the amount of auxiliary energy needed to run the thermal system, such as pumps and auxiliary parts.

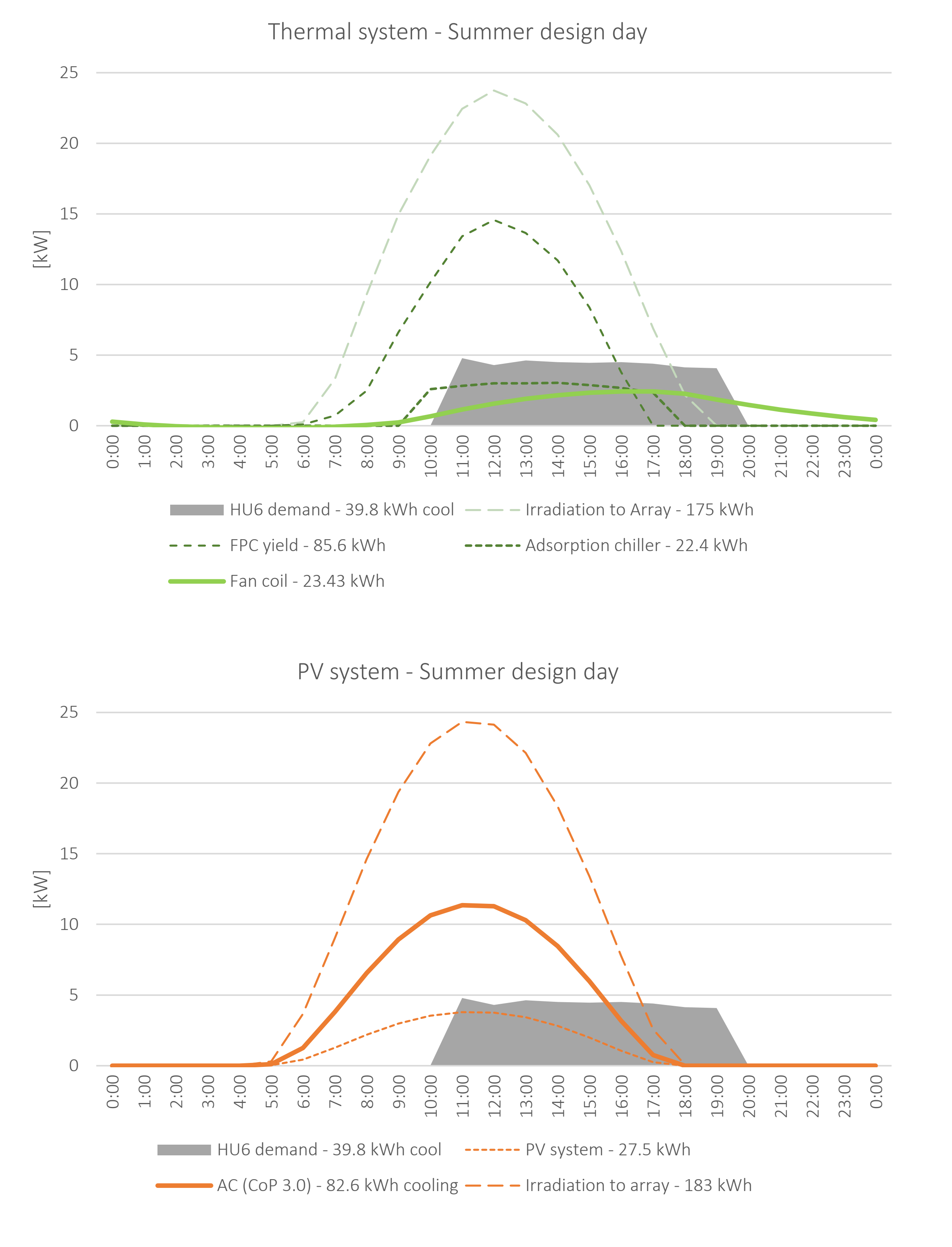


Figure 4-41. Comparative daily performance between thermal and PV system.

Source: By author. Data obtained from system simulations in Polysun and PVSol.

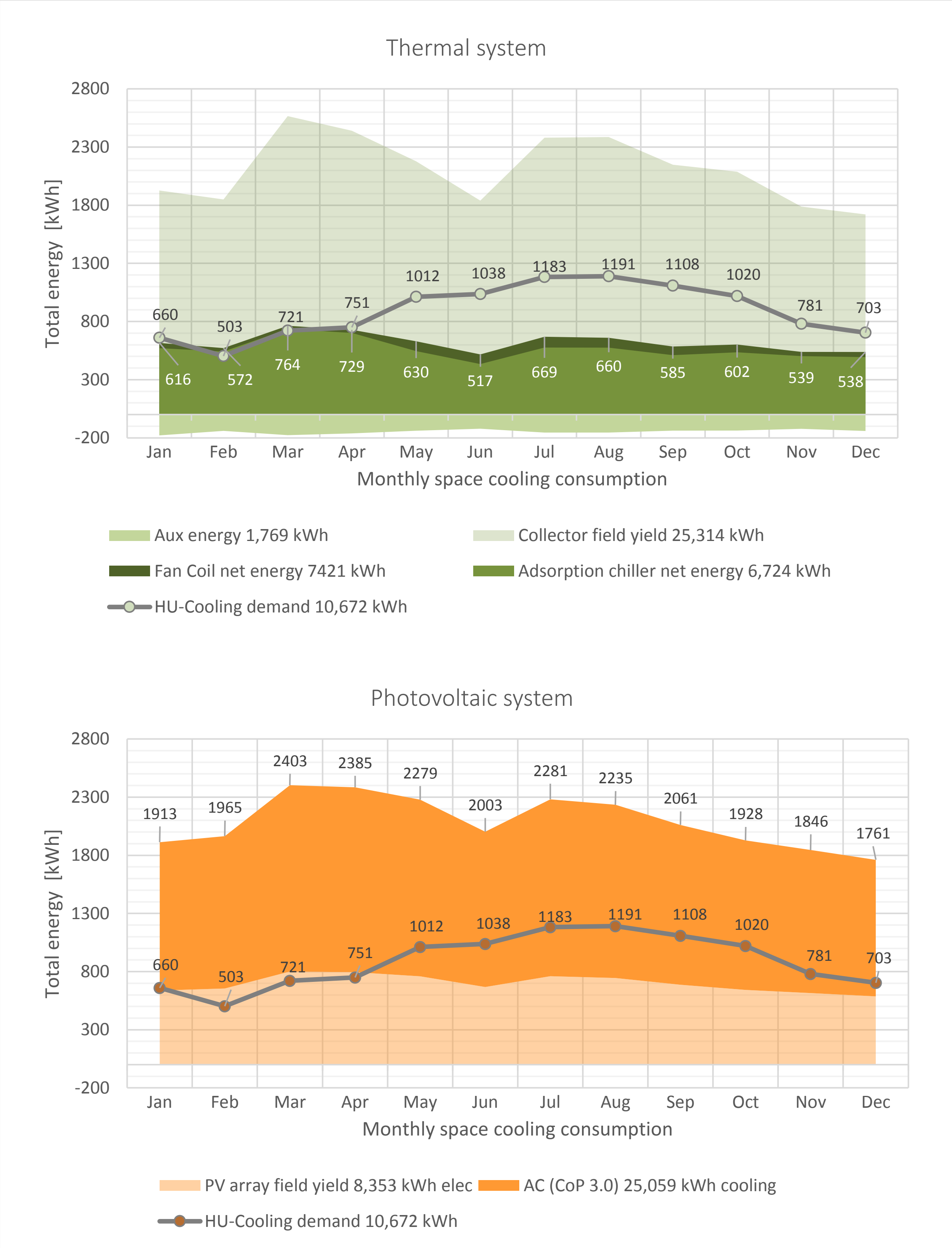


Figure 4-42. Comparative annual performance between thermal and PV system.

Source: Source: By author. Data obtained from system simulations in Polysun and PVSol.

Figure 4-42 shows a more dramatic contrast between both proposed systems. In the upper portion of the thermal system graph, the annual energy yield produced by the FPC array has 25,314 kWh of cooling, but it is only capable to transmit a third of that energy yield into the load distribution system. On the contrary, a PV system annual yield accounts for 8,353 kWh of electricity, just below the cooling demand, but the equipment CoP factor enables to surpass the load requirement more than twice.

Energy Balance & Economic assesment	Units	Scenarios					
System Description							
Housing unit no 6		Baseline	Proposed	Proposed		Proposed	
System type		Compression	Compression	ermal- Adsorption		PV- compression	
Cooling capacity required	kW	9.09	7.4	7.4		7.4	
Cooling capacity provided	kW	10.5	7.03	5.54		7.03	
CoP		2.63	2.63			3	
Supply & demand - Annual							
Cooling consumption	kWh	15,875	10,672	10,672		10,672	
Electric consumption	kWh	6,036	4,058	-1,769		8,353	
Cold production	kWh	15,875	10,672			25,059	
Cooling supply	kWh			7,421			
Surplus / Deficit	kWh	-	-	-3,251		14,387	
Daily coverage (10 hour cycle)		Full	Full	Partial		Full	
Primary energy - Annual							
PE conversion factor		2.70	2.70	1.00		1.00	
Primary energy consumptiom	kWh	16,298	10,956				
Primary energy production	kWh			7,421	th	8,353	elec
Economic Assessment							
Tariff type		HCT	HCT				
Electricity cost	USD/kWh	0.25	0.25				
Annual cost	USD	$1,509	$1,014				
Investment cost							
Equipment costs	USD	$960	$640	$30,000		$15,000	
Potential subsidies		-	-	$5,637		$5,637	
Initial investment		$960	$640	$24,363		$9,363	
Lifetime years	yrs	5	5	20		20	
20 year- simple return of investment comparative							
Cooling consumption	kWh	317,500	213,440				
Electric consumption	kWh	120,722	81,156	35,380			
Cooling production	kWh			148,412		501,174	
Electric production	kWh			91,810		81,156	
Electricity surplus						85,902	
Cost of electricity	USD	30,181	20,289	-22,953		-20,289	
Payback time	yrs			20+		6	

Table 4-12. Energy balance and economic evaluation.

Source: from author. Equipment cost information obtained from equipment manufacturer

The relevant question now answered related to energy load and energy yield. Based on the previous graphics, the PV system, proved itself technically feasible. Furthermore, it offers potential flexibility in terms of management and use of the electricity resources. In terms of the thermal system, silica/gel and zeolite adsorption systems with small capacities shall be look upon in the near future for efficiency, and a backup water heater may be included into the design equation for maintaining the high hot water temperature during the peak season.

Now, in terms of it being economically feasible, it is hard to provide a precise economic analysis during this part of the analysis, since it is of public domain that Mexico is going through an energy reform at this point in time. An example of a return of investment time lapse is given in Table 4-12 for both photovoltaic and thermal system. A housing subsidy available for new houses that incorporate sustainable practices and prove their reduction of energy consumption may be entitled to receive a substantial governmental aid, depending on the type of household to be purchased. However in terms of alternative energy incentives, at the current time there is no grants or subsidy mechanisms at a state and federal level that encourages. Another main aspects to take into consideration relate to the elimination of the electric residential tariff subsidy. It was inferred thought the household survey that the regular use of air conditioning system is cost prohibited for households in this area. But charging every household with a 25 cents per kWh for regular consumption as proposed the government would certainly increase the possibility for house owners to buy one of these systems, not just for cooling requirements but for all electrical appliance needs...

Other factors to consider are the further efficiency and price drop of the two types of systems here approached: the cost per watt for this high performance photovoltaic as well as solar panels is also in decreasing due to the competition among producers. In the long run, this could mean that tits expected efficacy within the country's energy sector could also be projected at a macro scale in the energy sector thus reducing the use of fossil fuels for electricity generation and thus the production of CO2 emissions as well.

But even before the integration of renewable energy technologies in the housing industry, the housing industry and its state regulators shall be conscious of the environmental impact that each planning decision may have. The process of housing construction and planning, which has been done today in Mexico at a massive scale over the last decades, has directly impacted not only human thermal comfort levels for better or worse, but also in a direct relationship, the energy consumption patterns.

CHAPTER 5. DISCUSSIONS AND CONCLUSIONS

5.1. Summary of findings

The selection of Playa del Carmen, in Mexico, for the implementation of this study proved ideal due to its drastic warm-humid climatic conditions. A household survey in the existing neighborhood chosen as the case study showed that depending on its orientation, a housing unit may confront adverse interior comfort conditions, even at night. Moreover, the electricity tariff limits, does not allow a continuous use of the mechanical air conditioning system.

A cluster building, with six units each, was then three-dimensionally modeled in Designbuilder software in order to perform a building thermal envelope simulation, and to obtain the cooling load required. This simulation proved that all units required high amounts of cooling requirement, specially the housing units located at the end wings. Thus a series of bioclimatic strategies were integrated into this model and the cooling load and projected energy consumption was then drastically reduced. From the five proposed improved conditions, the incorporation of an extra roofing surface over the building envelope (used for the incorporation of the panel array system) along with the use of a green wall in the extreme end wall, rendered as the most energy efficient measure. During the modeling process a big factor that altered the cooling load reduction was the incorporation of the ground temperature. This prevented window shading devices from reducing only 1% the cooling load.

Polysun software was then used to evaluate the performance of a thermal solar cooling system. The system configuration proved that, although a significant portion of cooling load was generated during the peak load hours, this did not equal the cooling requirements of the housing unit. During the two simulation samples, one in January and the other one in July, the heat production system was not able to provide a water temperature higher than 85°C, needed for an ideal performance of the adsorption chiller. In contrast, simulation results performed with PVSol software for a photovoltaic array system feeding a DC current heat pump system provided with a significant surplus of energy at daily and yearly periods beyond the required amount, and with the actual load conditions covered during the peak load hours.

The current efficiency of a DC air conditioning system feed by a photovoltaic array renders a positive energy balance with a potential medium range cost of investment, especially since providing space cooling through ordinary means is cost prohibited. However, financial government mechanisms still need to be established so that this alternative is feasible to an ample portion of the society.

5.2. **Conclusions**

The findings of this thesis show that through bioclimatic strategies, a significant reduction of the cooling load for a household in Playa del Carmen, Mexico, chosen as the case study, was accomplished. A cooling energy performance simulation of a stand-alone thermal solar active cooling system for this typical household, however, only partially covered the household requirements, and this only during the daylight period. On the contrary, a simulation of a photovoltaic system outperformed the cooling demand load. In a warm-humid location, such as Playa del Carmen, where mechanical air conditioning it is most needed, it is not economically feasible to integrate this type of systems without a considerable high investment.

5.3. **Recommendations**

In relation to the self-assessment of this study, several different criteria are suggested below to refine the results in the implementation of solar cooling technology in the Mexican household. This, in order to define more accurately the current stand between the acquisition of technology, its current performance, and the energy and economic savings they may incur in. Note that these recommendations are not just specific for warm-humid locations.

-It is recommended, that, to further define the energy consumption at a small household scale, an earlier study may be executed where the potential primary energy savings at regional scale is incorporated into the energy balance. This, in order to broaden the understanding of the household's energy consumption, at a micro and macro-scale.

-Assess the convenience of this study in a housing setting with a condominium regime or in lease agreement terms, where the energy balance may be beneficial to third party users.

--A well-defined target group shall be selected, through the use or consulting of previous socio-economical study. This may derive in the expansion and potential implementation in different areas: Examples of these are academic institutions (classroom settings) where building occupancy is more frequent at daylight times and systems would be constantly on, and therefore would be an ideal setting. Another option would be hotel rooms, where the majority of time the system is on and at a higher performance values.

-Simulate a building model that further incorporates site variables such as other buildings in the vicinity, wind flow and material site components.

-Utilize a software capable of modeling in a time dependent simulation all the systems with the same climatic information in order to obtain an integral result.

-It is recommended to broaden the spectrum of housing energy analysis regarding the use of thermal systems to further weight the performance compared to photovoltaic systems. This to compare the surplus exceeding energy (photovoltaic and thermal) can be coupled with other needs such as domestic hot water and electric consumption, respectively.

In the case of the thermal system, simulate recent efficient applied strategies such as a backup heating system in the heat production side, and thermal mass cooling in the load distribution.

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ANNEX

Annex 3-A. Playa del Carmen-Mundo Habitatt, Air conditioning and electricity consumption survey format.

Annex 3-B. Mexico climatic region map – Map by INEGI.

Annex 3-C. Mexico solar global irradiation map, annual – Map by Instituto de Investigaciones electricas, Mexico.

Annex 4-A. Benito Juarez – Cancun – Quintana Roo MX, climatic statistics – Meteonorm software report.

Annex 4-B. Thermal comfort analysis results, ASHRAE adaptive method – CBE Berkeley website tool report.

Annex 4-C. Thermal comfort analysis results, ASHRAE PVM method – CBE Berkeley website tool report.

Annex 4-D. Housing unit no. 6 building envelope annual thermal load analysis results – DesignBuilder software graphic report.

Annex 4-E. Housing unit no. 6 summer design day graphic results, without use of air conditioner – DesignBuilder software graphic report.

Annex 4-F. Housing unit no. 6 summer design day graphic results, with use of air conditioner – DesignBuilder software graphic report.

Annex 4-G. Solar cooling thermal system performance results – Polysun software report

Annex 4-H. Photovoltaic array simulation performance results – PV-Sol software report.

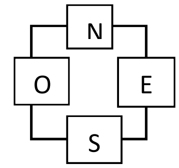
Universidad Autónoma de San Luis Potosí

Posgrado Multidisciplinario en Ciencias Ambientales

ANNEX 3-A

Encuesta de gasto energético residencial y uso de aire acondicionado

Playa del Carmen



Ubicación Domicilio: ____________________________________

Orientación de Fachada: ________________________________

Cuántas unidades de aire acondicionado usan: ______________

¿Cuál es la capacidad de las unidades?___________________________________

¿Las unidades tienen algún etiquetado de eficiencia?________________________

¿Qué otros electrodomésticos de alto consumo energético usan?

____

Periodo Bimestral de Luz -Historial

1er Bimestre_____________ kWh 2do Bimestre___________ kWh

3er Bimestre____________ kWh 4to Bimestre____________ kWh

5to Bimestre____________ kWh 6to Bimestre____________ kWh

Número de Personas en Domicilio: ____Cuantos Adultos: ___Cuantos niños: _____

Horas de Salida a trabajar: ____

Hora de llegada del trabajo: ____

¿Trabajan fines de semana?____

Hora de salida de la escuela: ____

¿Durante cuánto tiempo al día las usa?____________________________________

____

¿Usan aire acondicionado los niños cuando llegan de la escuela?_______________

¿Cuantas veces al día/semana/ por cuantas horas?___________________________

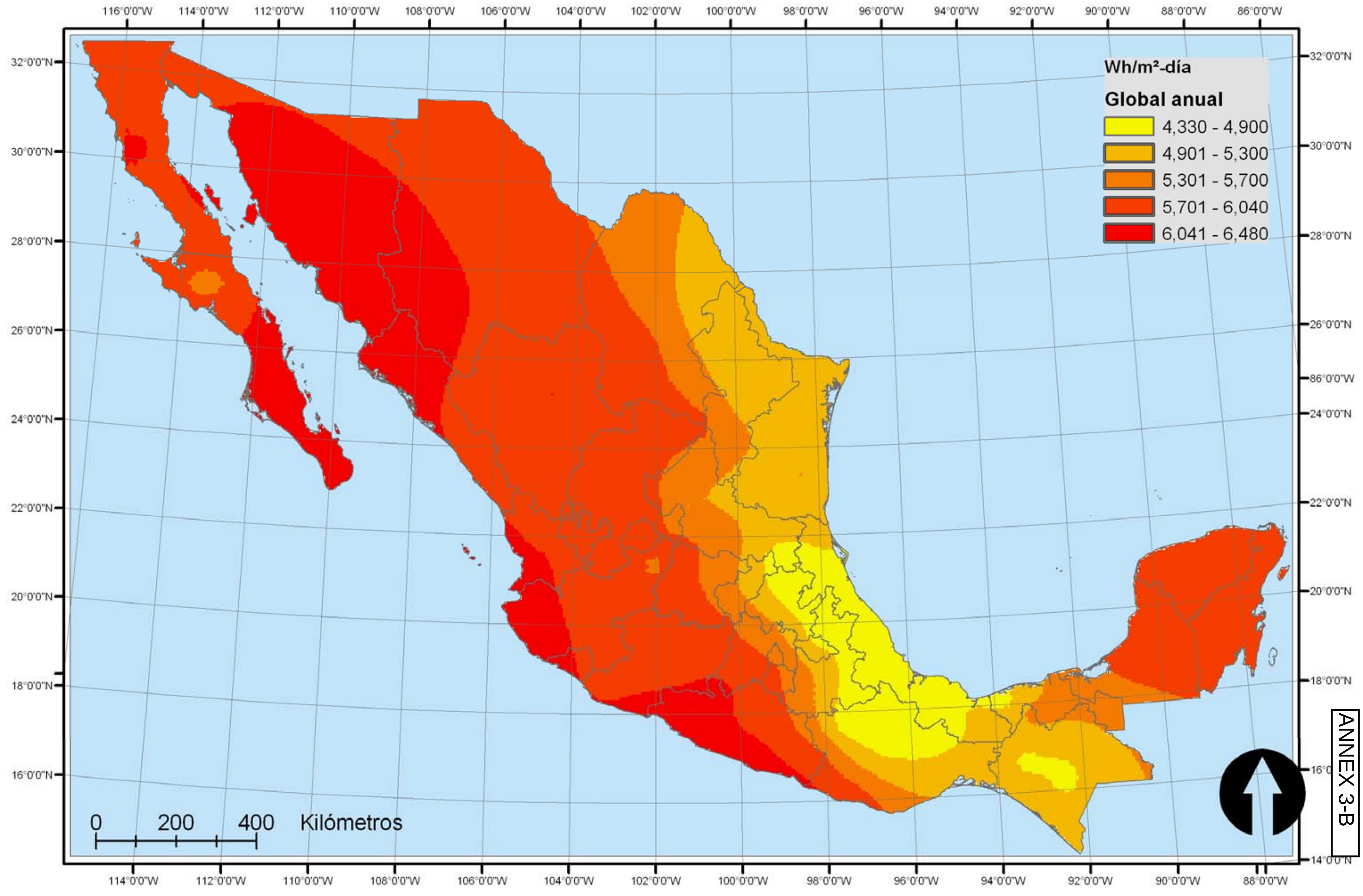
____

¿Cuál es el tiempo de la hipoteca de su casa?_________________________

¿Estaría dispuesto a compartir un sistema de aire acondicionado solar eficiente entre vecinos?____

¿Estaría dispuesto a pagar una cuota diferida en su recibo de Luz a cambio de un sistema de aire acondicionado con mantenimiento incluido?_______________

Irradiación Solar Global Anual



ANNEX 3-B

ESTADOS UNIDOS MEXICANOS

ANNEX 4-A

Benito Juarez-Cancun-Q.Roo MX

Location name

21.17
Latitude [°N]

-86.83
Longitude [°E]

0
Altitude [m a.s.l.]

V, 3
Climate region

Standard
Radiation model

Standard
Temperature model

Perez
Tilt radiation model

2000–2009
Temperature period

1986–2005
Radiation period

Custom
Horizon

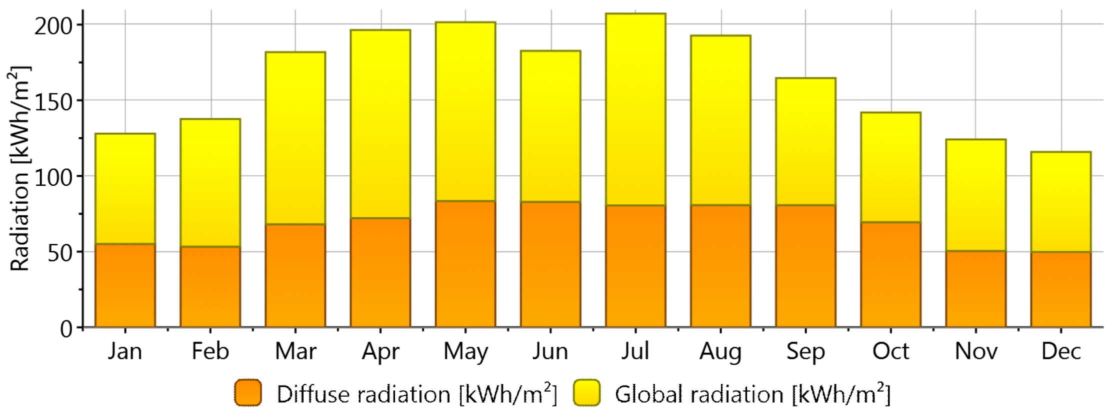
Additional information

Uncertainty of yearly values: Gh = 3%, Bn = 6%, Ta = 0.5 °C
Trend of Gh / decade: -
Variability of Gh / year: 3.2%
Radiation interpolation locations: Cancun (11 km), COZUMEL (CIV/MIL) (72 km), Rio Lagartos (145 km), Sian Kaan (133 km), Merida (293 km), Tantaquin (263 km)
Temperature interpolation locations: CANCUN INTL AIRPORT (16 km), COZUMEL (CIV/MIL) (72 km), Merida (293 km), Campeche/Ignacio (414 km), Chetumal (334 km), HAVANA/JOSE MARTI (499 km)

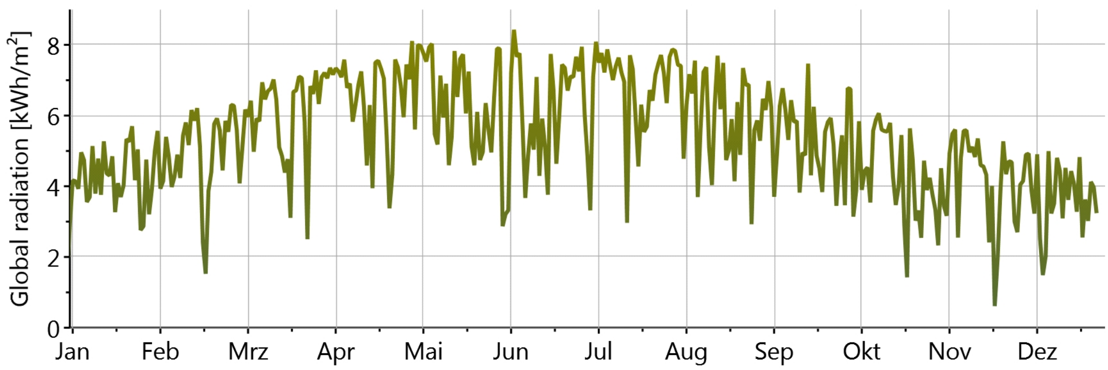
Month	**H_Gh**	**H_Dh**	**H_Bn**	**Ta**
	[kWh/m2]	[kWh/m2]	[kWh/m2]	[C]
January	128	55	131	22.8
February	138	53	134	23.8
March	182	68	165	24.8
April	196	72	176	25.8
May	202	83	164	27.5
June	183	83	136	28.0
July	207	81	173	28.5
August	193	81	159	28.4
September	165	81	121	27.7
October	142	70	117	26.8
November	124	50	133	24.6
December	116	50	125	23.7
Year	1974	827	1735	26.0

H_Gh: Irradiation of global radiation horizontal
H_Dh: Irradiation of diffuse radiation horizontal
H_Bn: Irradiation of beam
Ta: Air temperature

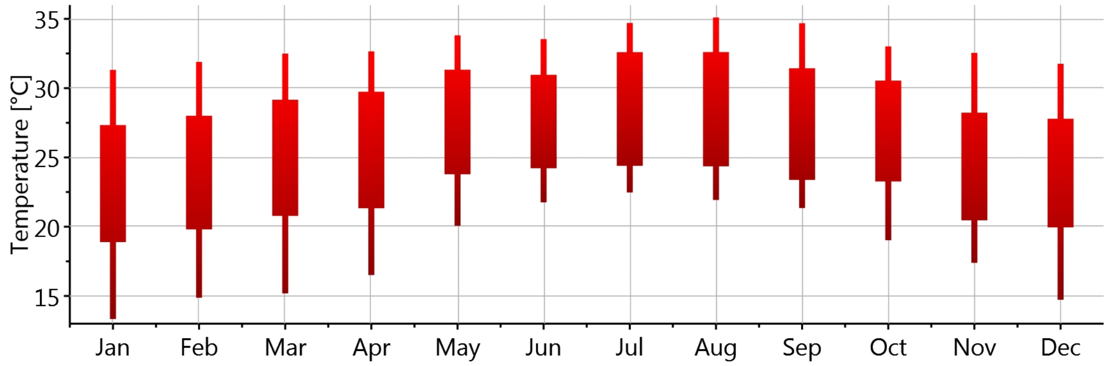
Monthly radiation



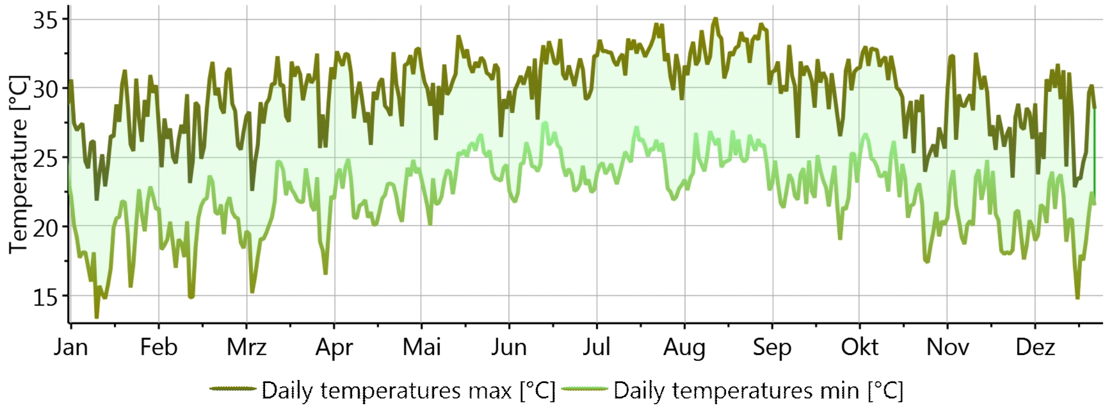
Daily global radiation



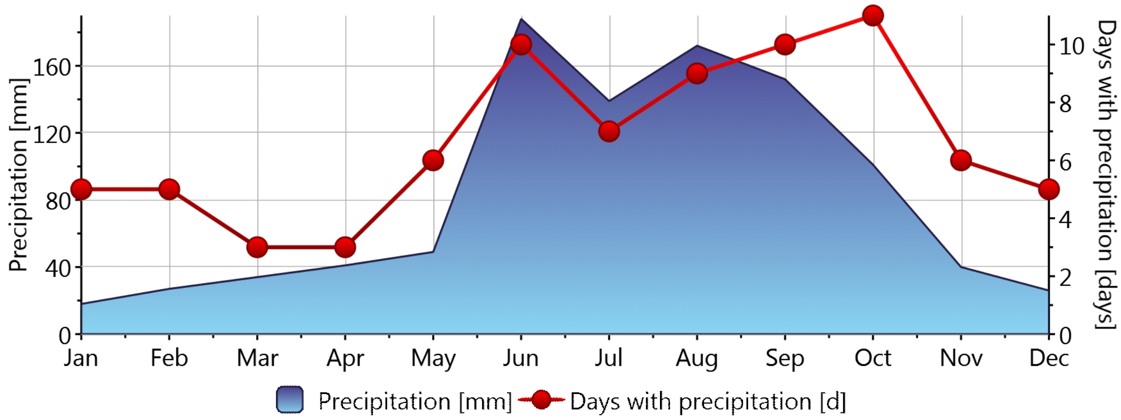
Monthly temperature



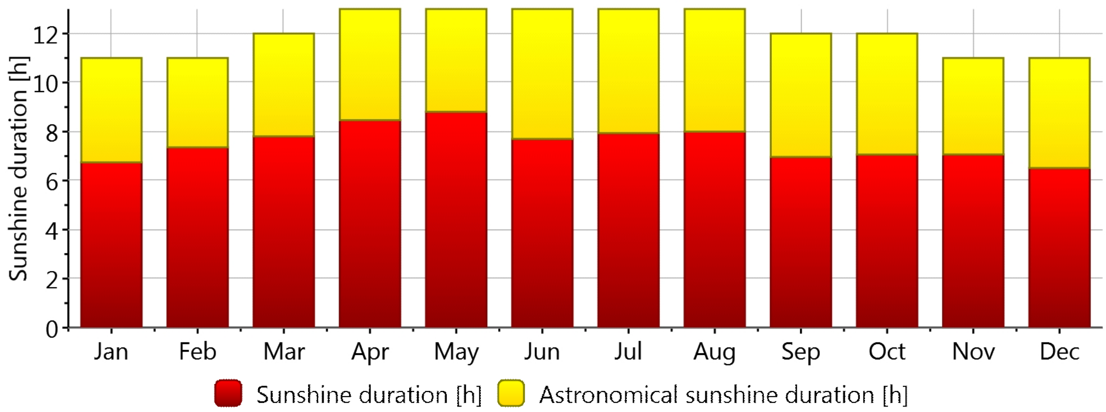
Daily temperature



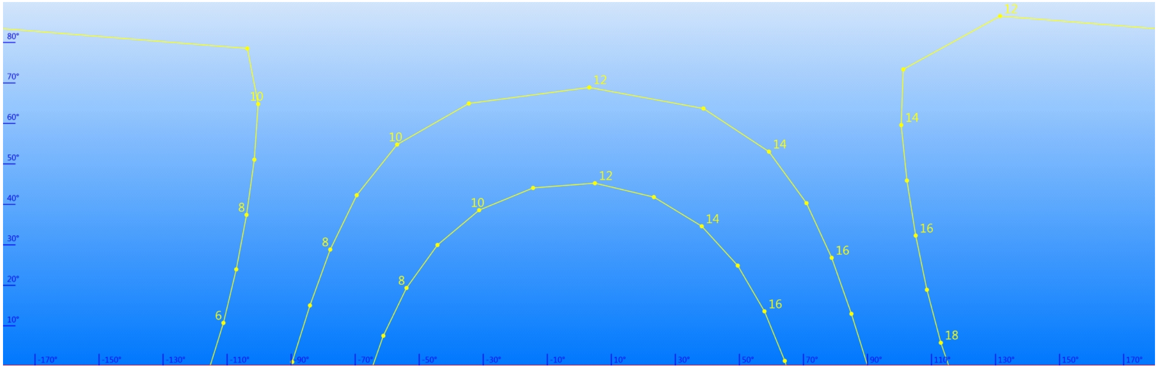
Precipitation



Sunshine duration



Horizon



ANNEX 4-B

CBE Thermal Comfort Tool

ASHRAE-55 | Compare | Ranges

Select method: Adaptive method

Operative temperature
29.26 °C
Use operative temperature

Prevailing mean outdoor temperature
29.43 °C

Air speed
0.3 m/s (59 fpm)

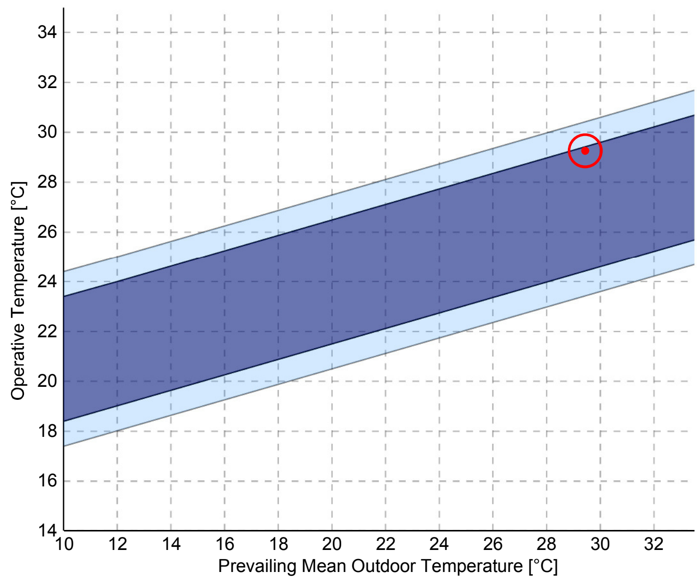
LEED documentation

Globe temp | SolarCal | Specify pressure | SI IP | Local discomfort | ? Help

✔ Complies with ASHRAE Standard 55-2010

80% acceptability limits	Operative temperature: 23.4 to 30.4°C
↳ Status	Comfortable
90% acceptability limits	Operative temperature: 24.4 to 29.4°C
↳ Status	Comfortable

Adaptive chart



NOTE: Method is applicable only for occupant-controlled naturally conditioned spaces that meet all of the following criteria: (a) There is no mechanical cooling system installed. No heating system is in operation; (b) Metabolic rates ranging from 1.0 to 1.3 met; and (c) Occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5-1.0 clo.

To cite this webpage:
Hoyt Tyler, Schiavon Stefano, Piccioli Alberto, Moon Dustin, and Steinfeld Kyle, 2013, CBE Thermal Comfort Tool.
Center for the Built Environment, University of California Berkeley,
http://cbe.berkeley.edu/comforttool/

 Developed by: Tyler Hoyt, Stefano Schiavon, Alberto Piccioli, Dustin Moon and Kyle Steinfeld. Based on work at Center for the Built Environment. **Note:** Internet Explorer is not fully supported. Some features (e.g. LEED documentation) do not function in latest versions of IE, and older versions of IE may not work at all. We recommend using Chrome, Firefox, or Safari.

ANNEX 4-C

CBE Thermal Comfort Tool

ASHRAE-55 | Compare | Ranges

Select method: PMV method

Operative temperature
29.26 °C — Use operative temperature

Air speed
3 m/s — Local air speed control

Humidity
84 % — Relative humidity

Metabolic rate
1.2 met — Standing, relaxed: 1.2

Clothing level
0.5 clo — Typical summer indoor

Create custom ensemble

Dynamic predictive clothing

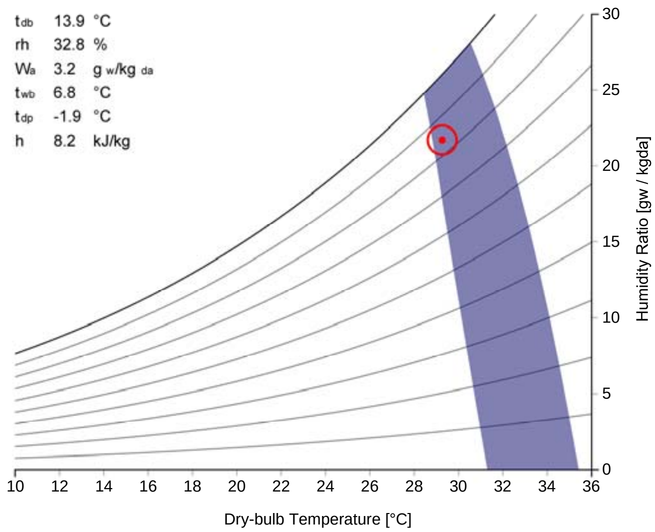
LEED documentation

Globe temp | SolarCal | Specify pressure | SI IP | Local discomfort | ? Help

✘ Does not comply with ASHRAE Standard 55-2010
↳ Maximum air speed has been limited due to no occupant control

PMV with elevated air speed	-0.32
PPD with elevated air speed	7%
Sensation	Neutral
SET	24.2°C
Drybulb temperature at still air	22.4°C
Cooling effect	6.9°C

Psychrometric chart (air temperature)



NOTE: In this psychrometric chart the abscissa is the dry-bulb temperature, and the mean radiant temperature (MRT) is fixed, controlled by the inputbox. Each point on the chart has the same MRT, which defines the comfort zone boundary. In this way you can see how changes in MRT affect thermal comfort. You can also still use the operative temperature button, yet each point will have the same MRT.

To cite this webpage:
Hoyt Tyler, Schiavon Stefano, Piccioli Alberto, Moon Dustin, and Steinfeld Kyle, 2013, CBE Thermal Comfort Tool.
Center for the Built Environment, University of California Berkeley,
http://cbe.berkeley.edu/comforttool/

 Developed by: Tyler Hoyt, Stefano Schiavon, Alberto Piccioli, Dustin Moon and Kyle Steinfeld. Based on work at Center for the Built Environment. **Note:** Internet Explorer is not fully supported. Some features (e.g. LEED documentation) do not function in latest versions of IE, and older versions of IE may not work at all. We recommend using Chrome, Firefox, or Safari.

Program Version:**EnergyPlusDLL-32 8.1.0.008, 10/2/2014 2:10 AM**

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ANNEX 4-D

Tabular Output Report in Format: **HTML**

Building: **Building**

Environment: **PROPOSED CASE ** Benito Juarez-Cancun- MX - MN6 WMO#=302**

Simulation Timestamp: **2014-10-02 02:14:36**

Table of Contents

Report: **Climatic Data Summary**

Table of Contents

For: **Entire Facility**

Timestamp: **2014-10-02 02:14:36**

SizingPeriod:DesignDay

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
SUMMER DESIGN DAY IN PROPOSED CASE	33.90	8.00	26.70	Wetbulb [C]	0.00	0.00
WINTER DESIGN DAY IN PROPOSED CASE	13.20	0.00	13.20	Wetbulb [C]	15.10	0.00

Weather Statistics File

	Value
None	

Report: **HVAC Sizing Summary**

Table of Contents

For: **Entire Facility**

Timestamp: **2014-10-02 02:14:36**

Zone Cooling

	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]	Design Day Name	Date/Time Of Peak	Thermostat Setpoint Temperature at Peak Load [C]	T
HU62NDFLOOR:HU6BATHROOM	279.95	321.94	65.04	0.020	0.023	SUMMER DESIGN DAY IN	7/15 12:00:00	0.00	

						PROPOSED CASE			
HU62NDFLOOR:HU6BEDROOM% BACK	558.74	642.56	66.41	0.040	0.046	SUMMER DESIGN DAY IN PROPOSED CASE	7/15 12:00:00	0.00	
HU62NDFLOOR:HU6BEDROOM% FRONT	565.42	650.23	54.11	0.040	0.046	SUMMER DESIGN DAY IN PROPOSED CASE	7/15 12:00:00	0.00	
HU61STFLOOR:HU6DINNING	519.13	597.00	61.71	0.037	0.042	SUMMER DESIGN DAY IN PROPOSED CASE	7/15 12:00:00	0.00	
HU61STFLOOR:HU6KITCHEN	236.55	272.03	83.38	0.017	0.019	SUMMER DESIGN DAY IN PROPOSED CASE	7/15 12:00:00	0.00	
HU61STFLOOR:HU6LIVING	982.47	1129.84	59.67	0.070	0.080	SUMMER DESIGN DAY IN PROPOSED CASE	7/15 12:00:00	0.00	
HU61STFLOOR:HU6RESTROOM	126.41	145.37	78.71	0.009	0.010	SUMMER DESIGN DAY IN PROPOSED CASE	7/15 12:00:00	0.00	

Zone Heating

	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]	Design Day Name	Date/Time Of Peak	Thermostat Setpoint Temperature at Peak Load [C]	Te
HU62NDFLOOR:HU6BATHROOM	0.00	0.00	0.00	0.000	0.001	WINTER DESIGN DAY IN PROPOSED CASE		0.00	
HU62NDFLOOR:HU6BEDROOM% BACK	0.00	0.00	0.00	0.000	0.002	WINTER DESIGN DAY IN PROPOSED CASE		0.00	
HU62NDFLOOR:HU6BEDROOM% FRONT	0.00	0.00	0.00	0.000	0.003	WINTER DESIGN DAY IN PROPOSED CASE		0.00	
						WINTER DESIGN			

HU61STFLOOR:HU6DINNING	0.00	0.00	0.00	0.000	0.002	DAY IN PROPOSED CASE		0.00	
HU61STFLOOR:HU6KITCHEN	0.00	0.00	0.00	0.000	0.001	WINTER DESIGN DAY IN PROPOSED CASE		0.00	
HU61STFLOOR:HU6LIVING	0.00	0.00	0.00	0.000	0.003	WINTER DESIGN DAY IN PROPOSED CASE		0.00	
HU61STFLOOR:HU6RESTROOM	0.00	0.00	0.00	0.000	0.001	WINTER DESIGN DAY IN PROPOSED CASE		0.00	

System Design Air Flow Rates

	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]
None				

Report: **System Summary** Table of Contents

For: **Entire Facility**

Timestamp: **2014-10-02 02:14:36**

Economizer

	High Limit Shutoff Control	Minimum Outdoor Air [m3/s]	Maximum Outdoor Air [m3/s]	Return Air Temp Limit	Return Air Enthalpy Limit	Outdoor Air Temperature Limit [C]	Outdoor Air Enthalpy Limit [C]
None							

Demand Controlled Ventilation using Controller:MechanicalVentilation

	Controller:MechanicalVentilation Name	Outdoor Air Per Person [m3/s-person]	Outdoor Air Per Area [m3/s-m2]	Air Distribution Effectiveness in Cooling Mode	Air Distribution Effectiveness in Heating Mode	Air Distribution Effectiveness Schedule
None						

Time Not Comfortable Based on Simple ASHRAE 55-2004

	Winter Clothes [hr]	Summer Clothes [hr]	Summer or Winter Clothes [hr]
HU62NDFLOOR:HU6BATHROOM	2406.00	2060.50	2006.00
HU62NDFLOOR:HU6BEDROOM%BACK	3874.50	3926.50	3813.00
HU62NDFLOOR:HU6BEDROOM%FRONT	3912.50	3878.50	3809.50
HU61STFLOOR:HU6DINNING	2730.00	2051.00	1992.00

HU61STFLOOR:HU6KITCHEN	2439.50	2001.00	1982.00
HU61STFLOOR:HU6LIVING	2280.50	971.50	942.50
HU61STFLOOR:HU6RESTROOM	2652.50	2053.50	2010.50
Facility	6241.50	4991.50	4819.50

Aggregated over the RunPeriods for Weather

Time Setpoint Not Met

	During Heating [hr]	During Cooling [hr]	During Occupied Heating [hr]	During Occupied Cooling [hr]
HU62NDFLOOR:HU6BATHROOM	0.00	303.50	0.00	0.00
HU62NDFLOOR:HU6BEDROOM% BACK	0.00	331.50	0.00	0.00
HU62NDFLOOR:HU6BEDROOM% FRONT	0.00	392.50	0.00	0.00
HU61STFLOOR:HU6DINNING	0.00	360.50	0.00	0.50
HU61STFLOOR:HU6KITCHEN	0.00	375.00	0.00	1.00
HU61STFLOOR:HU6LIVING	0.00	456.00	0.00	38.50
HU61STFLOOR:HU6RESTROOM	0.00	358.50	0.00	3.50
Facility	0.00	491.50	0.00	38.50

Aggregated over the RunPeriods for Weather

Report: **EnergyConsumptionDistrictHeatingCoolingMonthly** Table of Contents

For: **Meter**

Timestamp: **2014-10-02 02:14:36**

Custom Monthly Report

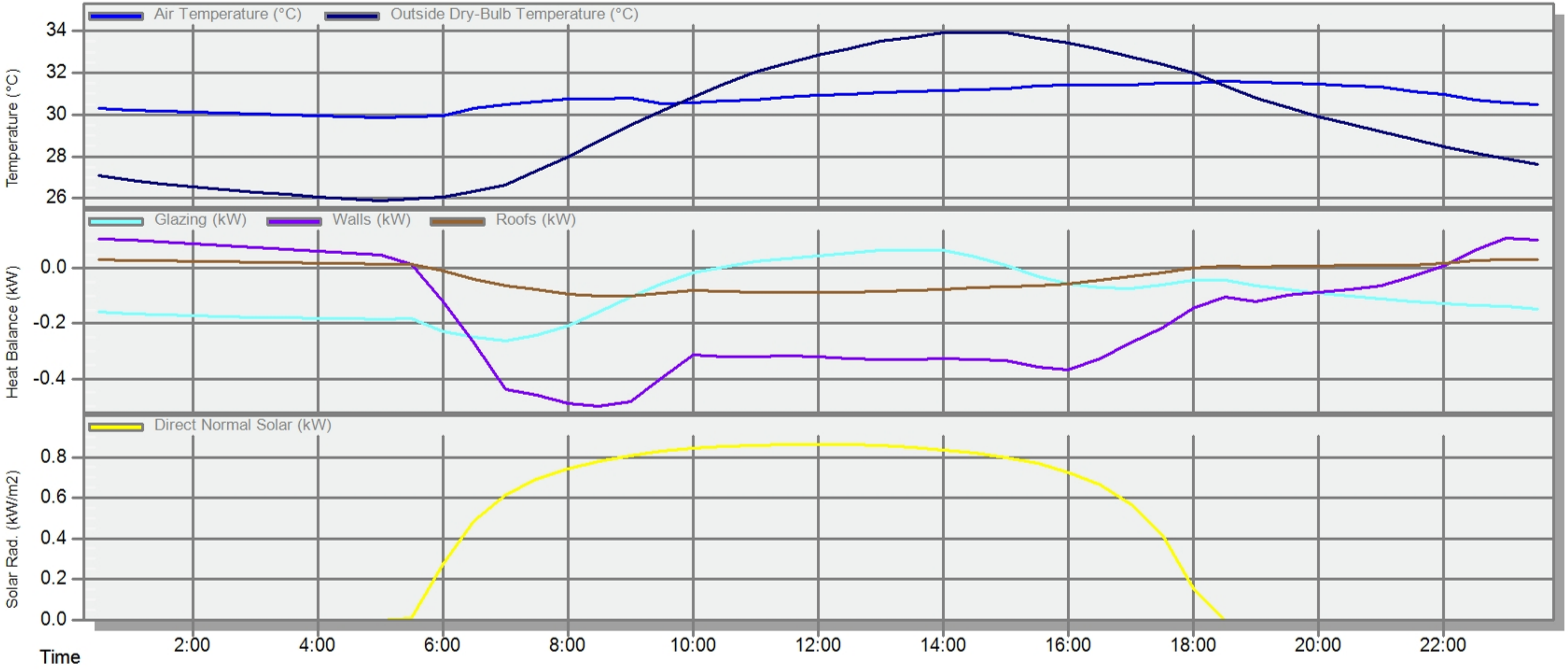
	DISTRICTCOOLING:FACILITY [kWh]	DISTRICTCOOLING:FACILITY {Maximum}[W]	DISTRICTCOOLING:FACILITY {TIMESTAMP}	DISTRICT
January	659.57	5024.97	31-JAN-12:30	
February	503.45	4988.48	02-FEB-11:00	
March	721.44	5024.97	23-MAR-11:00	
April	750.62	5024.97	10-APR-12:30	
May	1012.43	5024.97	03-MAY-10:00	
June	1037.54	5024.97	04-JUN-10:00	
July	1183.39	5024.97	12-JUL-11:30	
August	1190.55	5024.97	13-AUG-11:30	
September	1108.17	5024.97	01-SEP-13:30	
October	1019.86	5024.97	11-OCT-13:00	
November	781.05	5024.97	11-NOV-11:30	
December	703.46	5024.97	19-DEC-11:00	
Annual Sum or Average	10671.52			
Minimum of Months	503.45	4988.48		

ANNEX 4-E

EnergyPlus Output — Licensed

Temperature and Heat Gains - Proposed case, Building 6

15 Jul, Sub-hourly



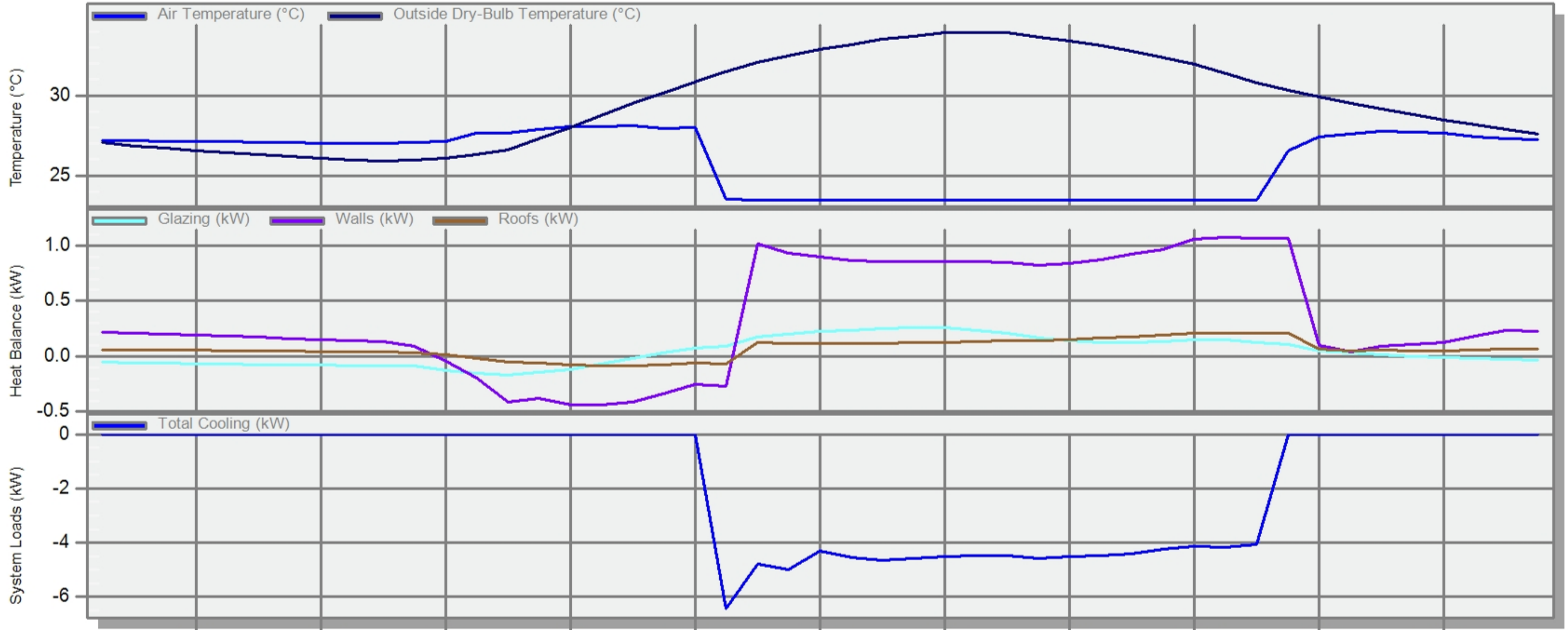
Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Air Temperature (°C)	30.13	29.93	29.93	30.74	30.57	30.92	31.17	31.42	31.51	31.47	30.98
Outside Dry-Bulb Temperature (°C)	26.54	26.06	26.06	27.98	30.86	32.86	33.90	33.42	31.98	29.90	28.46
Glazing (kW)	-0.17	-0.18	-0.23	-0.21	-0.02	0.05	0.07	-0.06	-0.04	-0.09	-0.13
Walls (kW)	0.09	0.06	-0.12	-0.49	-0.31	-0.32	-0.33	-0.37	-0.14	-0.09	0.01
Roofs (kW)	0.03	0.02	-0.01	-0.09	-0.08	-0.09	-0.08	-0.06	0.00	0.01	0.02
Direct Normal Solar (kW)	0.00	0.00	0.27	0.74	0.84	0.86	0.84	0.73	0.15	0.00	0.00

EnergyPlus Output

Temperature and Heat Gains - Proposed case, Building 6

15 Jul, Sub-hourly

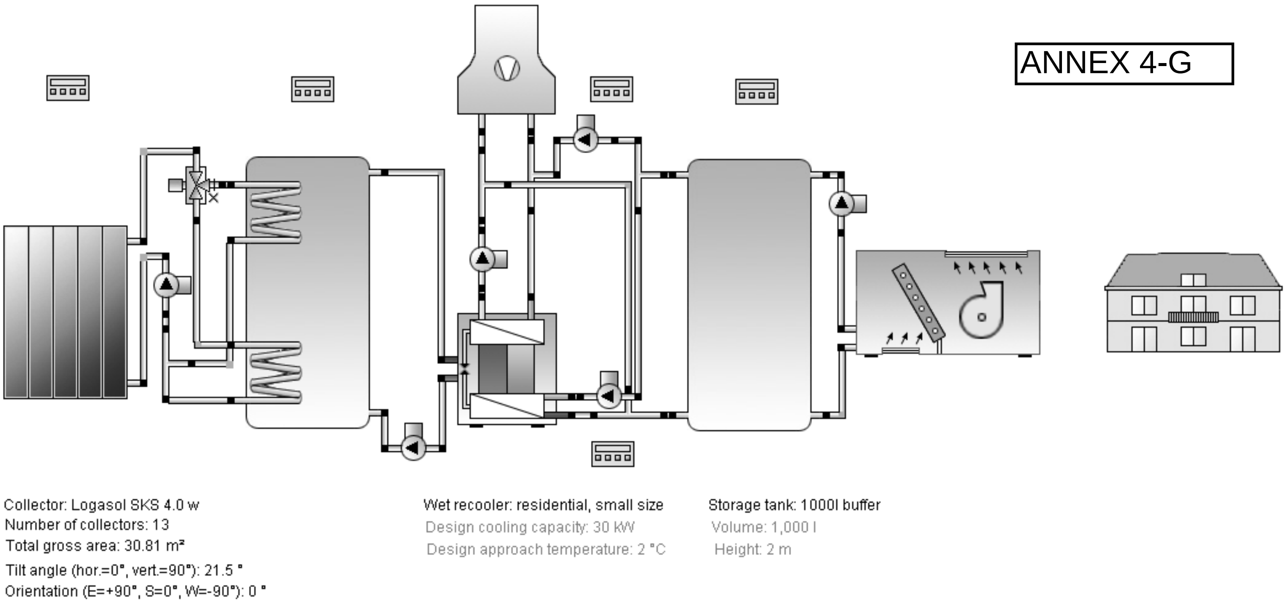
Licensed



Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Air Temperature (°C)	27.13	27.04	27.16	28.04	28.00	23.50	23.50	23.50	23.50	27.39	27.66
Outside Dry-Bulb Temperature (°C)	26.54	26.06	26.06	27.98	30.86	32.86	33.90	33.42	31.98	29.90	28.46
Glazing (kW)	-0.07	-0.08	-0.13	-0.12	0.07	0.22	0.26	0.14	0.15	0.05	-0.01
Walls (kW)	0.19	0.15	-0.04	-0.43	-0.25	0.89	0.85	0.84	1.05	0.10	0.13
Roofs (kW)	0.05	0.04	0.01	-0.08	-0.06	0.12	0.13	0.15	0.21	0.06	0.05
Total Cooling (kW)	0.00	0.00	0.00	0.00	0.00	-4.30	-4.51	-4.51	-4.14	0.00	0.00

ANNEX 4-F

Professional Report



Location of the system

Mexico
Benito Juarez-Cancun-Q.Roo
Longitude: -86.83°
Latitude: 21.17°
Elevation: 0 m

This report has been created by:

Claudio Leon
Betzdorfer Straße 2
50679 Köln

System overview (annual values)

Total fuel and/or electricity consumption of the system [Etot]	1,769.2 kWh
Total energy consumption [Quse]	7,674.8 kWh
System performance [(Quse+Einv) / (Eaux+Epar)]	4.34
Comfort demand	Energy demand of the building not met

Professional Report

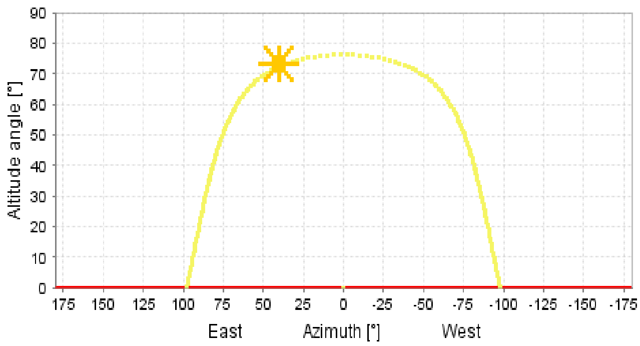
Overview solar thermal energy (annual values)

Collector area	30.8 m²
Solar fraction total	100%
Total annual field yield	25,314.3 kWh
Collector field yield relating to gross area	821.6 kWh/m²/Year
Collector field yield relating to aperture area	931.7 kWh/m²/Year
Max. energy savings	-
Max. reduction in CO2 emissions	-

Overview heat driven chiller (annual values)

Seasonal performance factor - Cooling	0.33
Total cooling energy yield	6,723.8 kWh
Heat supplied in generator	20,631.96 kWh

Horizon line



Meteorological data-Overview

Average outdoor temperature	26.1 °C
Global irradiation, annual sum	1,923.8 kWh/m²
Diffuse irradiation, annual sum	802.5 kWh/m²

Component overview (annual values)

Adsorption chiller	**ACS08**	
Seasonal performance factor - Cooling [ ]		0.33
Cooling energy yield	kWh	6,723.8
Heat supplied in generator	kWh	20,632

Professional Report

Collector		Logasol SKS 4.0 w
Data Source		ISE
Number of collectors		13
Number of arrays		2
Total gross area	m²	30.81
Total aperture area	m²	27.17
Total absorber area	m²	27.17
Tilt angle (hor.=0°, vert.=90°)	°	21.5
Orientation (E=+90°, S=0°, W=-90°)	°	0
Collector field yield [Qsol]	kWh	25,314.3
Irradiation onto collector area [Esol]	kWh	54,557.8
Collector efficiency [Qsol / Esol]	%	46.4
Direct irradiation after IAM	kWh	30,976.3
Diffuse irradiation after IAM	kWh	20,689.9
Wet recooler	**residential, small size**	
Rejected heat	kWh	26,093.3
Thermal efficiency [ ]	%	24.58

Building	Proposed case housing unit	
Heated/air-conditioned living area	m²	64
Cooling setpoint temperature	°C	40
Total energy losses	kWh	25,000

Fan coil	Four-pipe system size 1	
Number of fan coils	-	4
Nominal cooling power	W	1,100
Nominal cooling water inlet temperature	°C	6
Nominal cooling water return temperature	°C	12
Net energy from/to heating/cooling modules	kWh	-7,420.7

Pump Rückkühlung	Wilo-Stratos 30/1-12	
Circuit pressure drop	bar	0.164
Flow rate	l/h	3,800
Fuel and electricity consumption [Epar]	kWh	33.8

Pump Verdampfer	Wilo-Stratos 30/1-12	
Circuit pressure drop	bar	0.098
Flow rate	l/h	2,850
Fuel and electricity consumption [Epar]	kWh	33.8

Pump SR	Wilo-Stratos 25/1-8	
Circuit pressure drop	bar	0.028
Flow rate	l/h	1,550
Fuel and electricity consumption [Epar]	kWh	78.8

Professional Report

Pump Solar loop	Eco, medium	
Circuit pressure drop	bar	0.028
Flow rate	l/h	533.7
Fuel and electricity consumption [Epar]	kWh	61.5

Pump Generator	Wilo-Stratos 25/1-8	
Circuit pressure drop	bar	0.027
Flow rate	l/h	1,800
Fuel and electricity consumption [Epar]	kWh	19

Pump RK	Wilo-Stratos 30/1-12	
Circuit pressure drop	bar	0.166
Flow rate	l/h	3,500
Fuel and electricity consumption [Epar]	kWh	4

Storage tank KSP	1000l buffer	
Volume	l	1,000
Height	m	2
Material		Steel
Insulation		Rigid PU foam
Thickness of insulation	mm	80
Heat loss	kWh	86.5

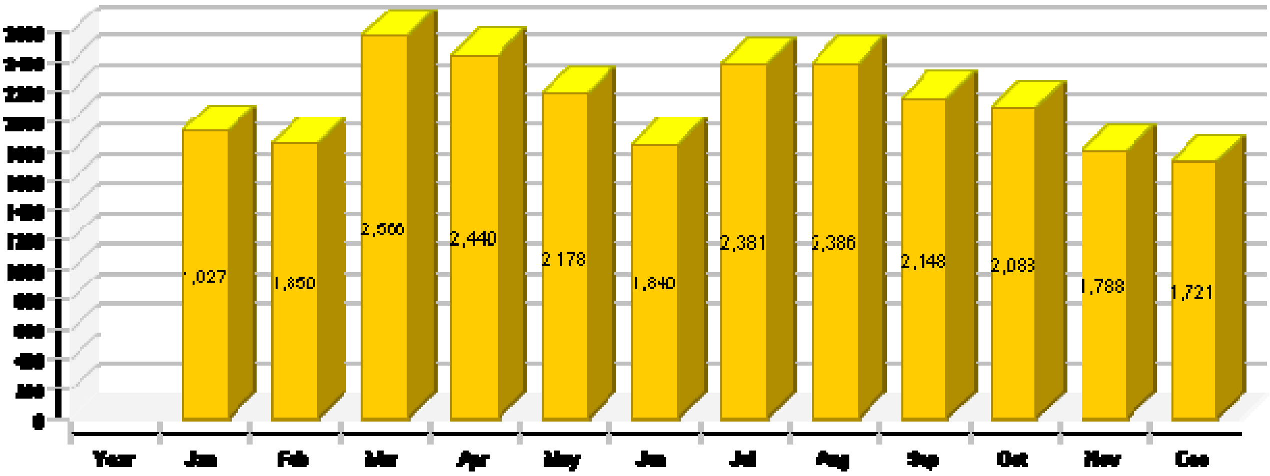
Storage tank 4	1000 l	
Volume	l	1,000
Height	m	2
Material		Stainless steel
Insulation		Rigid PU foam
Thickness of insulation	mm	120
Heat loss	kWh	621.8
Connection losses	kWh	486

Loop

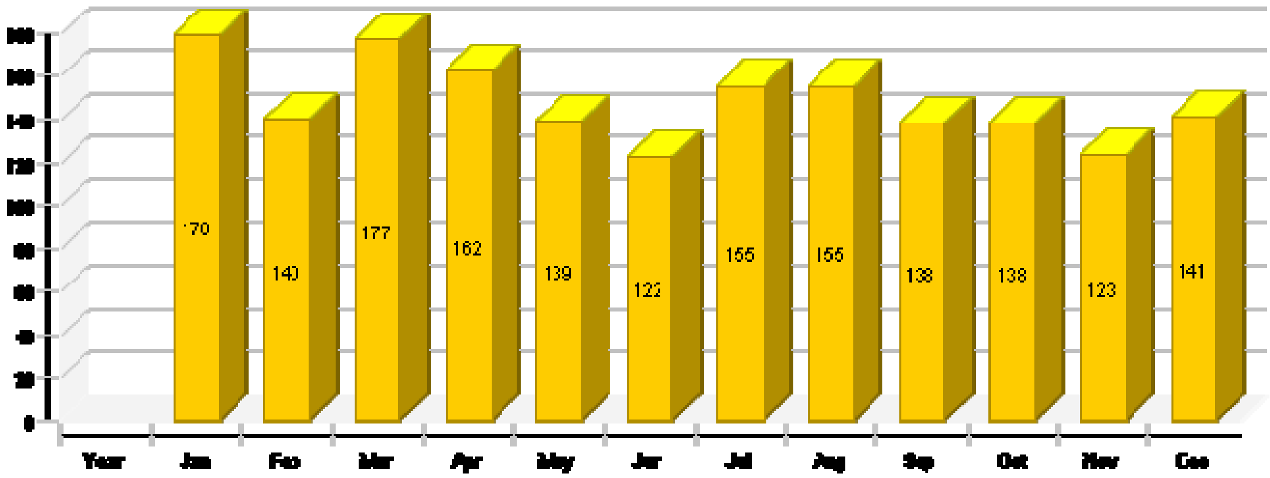
Solar loop		
Fluid mixture		Propylene mixture
Fluid concentration	%	33.3
Fluid domains volume	l	115.8
Pressure on top of the circuit	bar	4

Professional Report

Solar thermal energy to the system [Qsol] kWh



Total fuel and/or electricity consumption of the system [Etot] kWh



	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar thermal energy to the system [Qsol]													
kWh	25314	1927	1850	2566	2440	2178	1840	2381	2386	2148	2088	1788	1721
Heat generator fuel and electricity consumption [Eaux]													
kWh	1538	160	123	156	141	120	104	134	134	119	119	105	124
Total fuel and/or electricity consumption of the system [Etot]													
kWh	1769	179	140	177	162	139	122	155	155	138	138	123	141
Irradiation onto collector area [Esol]													
kWh	54558	4349	4086	5261	5070	4678	4276	4972	4948	4488	4434	4035	3963
Electricity consumption of pumps [Epar]													
kWh	231	19.5	17.6	21.2	20.7	19.4	18.3	20.8	20.7	18.9	18.8	17.4	17.7
Total energy consumption [Quse]													
kWh	7675	639	597	779	748	647	537	685	681	604	623	563	572

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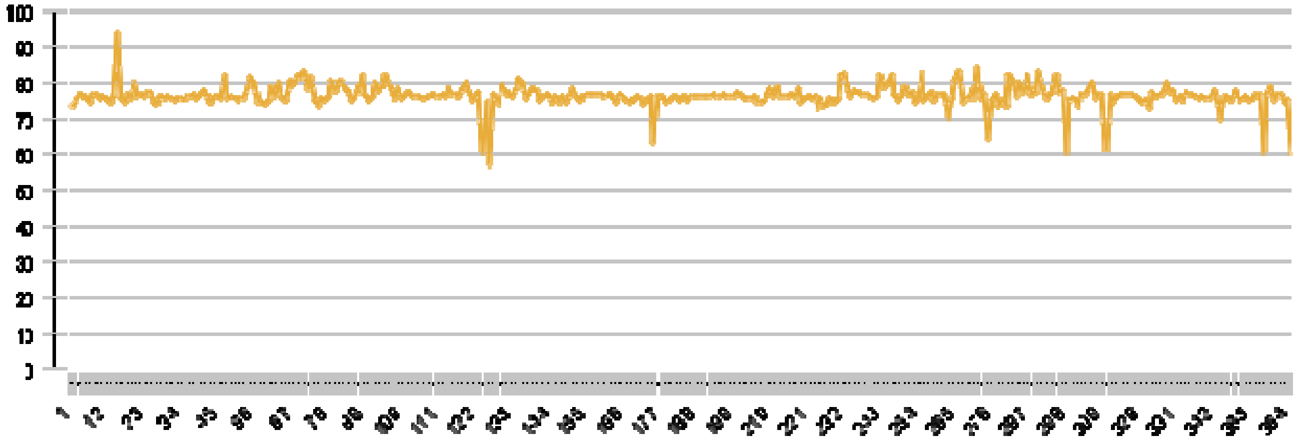
Professional Report

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heat loss to indoor room (including heat generator losses) [Qint]													
kWh	6728	487	469	571	574	600	583	650	647	594	577	501	475

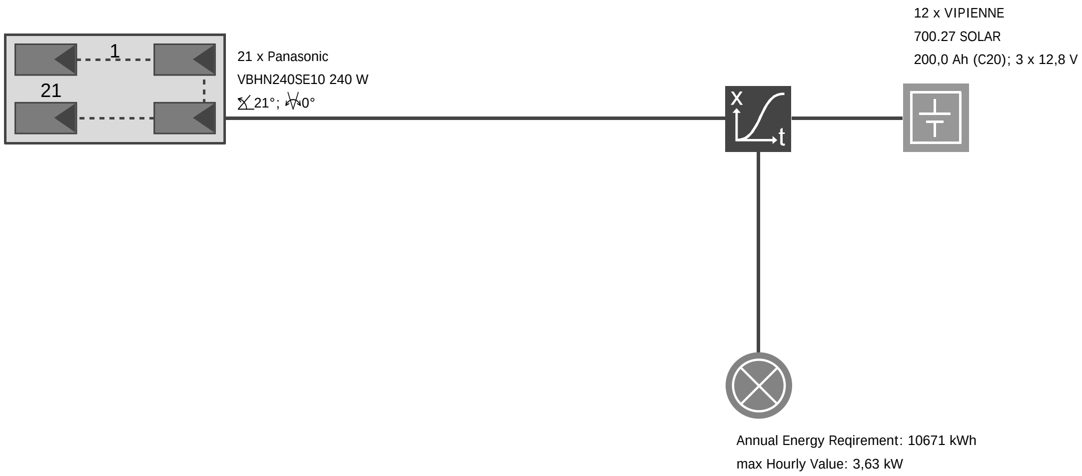
Collector

Daily maximum temperature [°C]



ANNEX 4-H

Project Name: Integration of solar space cooling technology in M 26.09.2014
Variant Reference: System Variant



Location:	Benito Juarez-Cancun-Q.Roo MX	
Climate Data Record:	Benito Juarez-Cancun-Q.Roo MX	
PV Output:	5,04	kWp
Gross/Active PV Surface Area:	26,48 / 26,61	m²

PV Array Irradiation:	54.484	kWh
Energy Produced by PV Array:	8.352,9	kWh
Consumption Requirement:	10.671	kWh
Consumption Covered by Solar Energy:	7.981,0	kWh
Consumption Not Covered by System:	2.690,3	kWh

Solar Fraction:	74,8	%
Performance Ratio:	77,3	%
Specific Annual Yield:	1.583,5	kWh/kWp
CO2 Emissions Avoided:	4.903	kg/a
System Efficiency:	14,6	%
PV Array Efficiency:	15,3	%

The results are determined by a mathematical model calculation. The actual yields of the photovoltaic system can deviate from these values due to fluctuations in the weather, the efficiency of modules and inverters, and other factors. The System Diagram above does not represent and cannot replace a full technical drawing of the solar system.

Project Name:	Integration of solar space cooling technology in M	26.09.2014
Variant Reference:	System Variant	

System in Stand-Alone Operation

Location:	Benito Juarez-Cancun-Q.Roo MX	PV Output:	5,04 kWp
Climate Data Record:	Benito Juarez-Cancun-Q.Roo MX	Gross/Active PV Surface Area:	26,5 m² / 26,6 m²
Number of Arrays:	1		

Array 1: Typical house unit array

Output:	5,04 kW	Ground Reflection:	20,0 %
Gross/Active Solar Surface Area:	26,5 m² / 26,6 m²	Output Losses due to...	
PV Module	21 x	deviation from AM 1.5:	1,0 %
Manufacturer:	Panasonic	deviation from Manufacturer's Specification:	2,0 %
Model:	VBHN240SE10	in Diodes:	0,5 %
Nominal Output:	240 W	due to Soiling:	0,0 %
Power Rating Deviation:	0 %		
Efficiency (STC):	19,0 %		
No. of Modules in Series:	1		
MPP Voltage (STC):	44 V		
Orientation:	0,0 °		
Inclination:	21,5 °		
Mount:	with Ventilation		
Shade:	No		

Battery

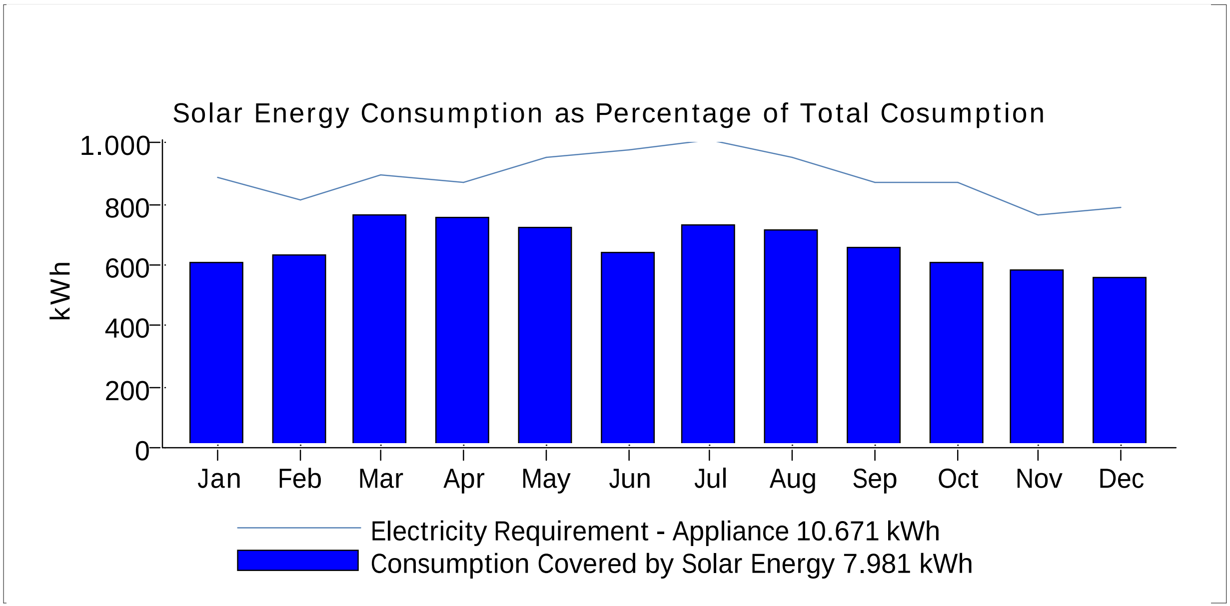
Manufacturer:	VIPIENNE	Mean Charge Efficiency:	85,0 %
Model:	700.27 SOLAR	Mean Discharge Efficiency:	99,0 %
Nominal Voltage:	12,8 V	Charge Controller	
C20 Capacity:	200,0 Ah	Lower Battery Discharge Threshold:	30,0 %
Self Discharge:	0,1 %/Tag		

Individual Appliances Total Consumption: 10.671 kWh

Air conditioning		Model: User-Dependent Appl.	10.671 kWh

Simulation Results for Total System

Irradiation onto Horizontal:	52.536 kWh	Battery Charge:	2.322 kWh
PV Array Irradiation:	54.484 kWh	Battery Losses:	372 kWh
Irradiation minus Reflection:	52.184 kWh	Charge Condition at Simulattion Start:	30,0 %
Energy Produced by PV Array:	8.353 kWh	Charge Condition at Simulattion End:	30,0 %
Consumption Requirement:	10.671 kWh	Solar Fraction:	74,8 %
Direct Use of PV Energy:	6.031 kWh	Performance Ratio:	77,3 %
Consumption Not Covered by System:	2.690 kWh	Final Yield:	4,3 h/d
PV Array Surplus:	0 kWh	Specific Annual Yield:	1.584 kWh/kWp
Consumption Covered by Solar Energy:	7.981 kWh	System Efficiency:	14,6 %
Battery Discharge:	1.950 kWh	Array Efficiency:	15,3 %
Battery Efficiency:	84,0 %		


Solar Energy Consumption as Percentage of Total Cosumption
kWh
1.000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Electricity Requirement - Appliance 10.671 kWh
Consumption Covered by Solar Energy 7.981 kWh