Open University of Cyprus

School of Engineering

Postgraduate course - *Sustainable Energy Systems*

Postgraduate Thesis

Energy performance and user's behavior for residential buildings

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Supervisor
Byron Ioannou

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Summary

Occupant or user behavior is known to be one of the main factors of uncertainty in the prediction of building energy use. Extended literature reviews linked the large performance gaps between residential buildings with the same properties and similar climate conditions to the way occupants interact with the building envelope and systems. Furthermore, in the last decades, more stringent energy codes have led to energy efficient design strategies with the aim of finally reaching the nearly-zero energy target. The success of these strategies is now heavily dependent on how the occupants interact with the building, or rather, on the energy-related lifestyles they undertake, the building location, the climate and the surrounding environment. All these factors affect residential energy performance and are analyzed leading to a further analysis of improvement methods. According to the analyzed factors and improvement, the project employs a building simulation and comparison of two buildings to demonstrate the potential impact of different user behavior lifestyles on the energy use of a Mediterranean residential building. The results are analyzed leading to the conclusion of how different much can different user behavior affect energy use with real world data. Improvement methods for this comparison are proposed as well as methods to implement them.

Contents

Acronyms and abbreviations

CO_2	Carbon Dioxide
EEA	European Environment Agency
EU	European Union
GHG	Green House Gases
HVAC	Heating Ventilation and Air conditioning
K	Degrees Kelvin
kW	Kilo Watt
kWh	Kilo Watt hour
LED	Light Emitting Diode
M	Meter
Pa	Pascal
UK	United Kingdom
US	United States
W	Watt
^oC	Degrees Celsius

Thesis aim and methodology

This master thesis aims at energy performance assessment and especially on how user behavior affects it in the case of residential buildings. User behavior is influenced by the user's educational and economic background, building characteristics, climate characteristics, surrounding environment and energy uses. Behavior is either a reflection of the user's inherited and developed personal characteristics or a reaction to the perception of the indoor comfort conditions created. The house's characteristics and surrounding environment affect user behavior in terms of their contribution to the indoor comfort conditions. Therefore, in order to understand the user behavior with respect to indoor comfort and energy performance of the house, these factors and their relations are going to be analyzed. In the available literature however there is little research that covers all the factors that affect residential building energy performance. Guerra Santin et al. conducted a research on the user behavior and heating energy consumption using OTB dataset (2010) and revealed that the determinants of heating energy consumption are household size, age of the respondent, ownership of the house and income, the number of heated bedrooms and thermostat settings. Caniggia et al (2001) distinguish different building types and architectural compositions, based on the community denomination, key design and intent of each residential building. Data from Wikipedia explain and analyze the definition and differences of climate and its zones. Sato et al (2019) define and analyze climate change, which affects energy performance. Regarding building location and its surrounding environment, there is decent amount of literature that covers many factors. Yasa et al (2017) focus on the distances between buildings and natural ventilation and with different studies and tests

support their claims. Energy uses, have a substantial amount of literature that covers them, with the United States Energy Administration (2015) providing data form surveys back in 2015 about lighting, heating, cooling, air condition, ventilation, air circulation, water heating and all the common electrical appliances with more data and analysis gathered by Atkinson et al (2009) , Kvols Heiselberg et al (2002) and Grondzik et al (2007). After the targets and goals are analyzed, with the main being those set by the European Council (2012) on energy. Other targets are also mentioned regarding emissions by Joeri Rogelj (2018). Continuing further, improvement methods are proposed by the author who is a qualified mechanical engineer, leading to a presentation and analysis of a maisonette building. A comparison is also fully analyzed between two different families with different behavior regarding energy use, living in two same maisonette buildings in Greece. After the comparison, the results are discussed, analyzed and improvement methods as well as their implementation are proposed.

Introduction

Climate change, energy performance and security are three of the most important issues for the current and next generations. Energy performance and consumption is a key way to achieve a more sustainable environment and development. Energy performance is affected by nonsustainable consumption which is an important factor for the climate change along with pollution from fossil fuel power generation and overexploitation of renewable energy resources. One of the simplest ways to improve sustainability, lower emissions, raise people's awareness and change their attitude towards the environment is through their behavior regarding energy consumption, especially in residential buildings. The simple reason is that people spend a large part of their day in their home buildings. Buildings consume a rather large quantity of energy that is estimated to be 30% of the total primary energy resources (Antonio Paone, 2018). While more and more renewable energy resources are introduced and installed, energy demand is still rising undoing in a sense all of the benefits that renewable energy sources offer. The modern lifestyle along with the rapid growth in the electronic devices market for consumers are the cause of that rising increase in building energy demand. Building energy efficiency is becoming a major factor in controlling that rising increase. Many recent studies indicate that user behavior regarding residential buildings can significantly increase the energy efficiency of the building through various strategies. In most cases these strategies utilize the quantification of energy savings and qualitative interpretation of user behavior in order to foster energy efficiency. Furthermore such strategies that influence the user's behavior include eco-feedback and social interaction. This master thesis presents a study that includes the energy performance and the impact that the user behavior in residential buildings has on energy efficiency and consumption, in order to provide improvement methods, solutions, suggestions and potential implementation methods. An energy-efficient behavior that also ensures comfort for the occupants is still a difficult task. Despite emerging technologies, strategies, developments and researches the impact of user behaviour is still difficult to quantify for methodological reasons. Factors that influence human behaviour are many and varied, with multi-dimensional and disciplinary approaches needed in order to gain new insights into the nature of user energy behaviour (Beerepoot, 2007).

Chapter 1

Factors that affect building energy performance

Diverse factors have caused an increase in energy use throughout the world. Globalization has spread the lifestyle of the most developed Western countries worldwide, changing the expectations about the quality of life in many societies to a point where sustainability is no longer possible on a large scale. One of the aspects of lifestyle that causes a high environmental burden in developed countries is the use of energy in buildings. While overall energy use associated with building characteristics is decreasing, because of the improved quality of thermal properties of buildings due to energy regulations, the role of the occupant is becoming more important now than ever. Occupant behavior affects building energy performance in a considerable amount, however building energy performance is affected by multiple factors that are interlinked with each other. Factors such as climate zone and geographical features can influence and affect other factors like building location, building typology, energy uses and occupant behavior as well. This part of the study will focus on the main factors that affect residential building energy performance, the way each factor affects energy performance, its importance and how they affect one another.

1.1 User behavior

It is in the nature of the human being to shape the physical environment around itself. However for every change that the human beings cause, the physical environment responds, especially when it starts to deform. This mutual interaction has started since humans appeared in this planet, but it is only recently that it led to environmental depletion and serious energy resource decay. (Guerra-Santin, 2012) Due to the importance of a good quality of the indoor environment and the problems caused by high energy consumption, governments have enacted a series of policies and regulations aimed at increasing the energy efficiency of dwellings and ensuring a good indoor environment. In order to reduce energy consumption, several measures are being proposed which are not easy to follow, because they also have to be viable and allow the occupant to have a decent and livable environment as close to his needs, desires and habits as possible. Although it is a rather difficult task to propose such measures, governments are slowly starting to introduce them while always trying to adapt them to what is acceptable and also viable. However user behavior is not the only factor that affects these measures, building typology and climatic zone are also key factors and are going to be analyzed further in this study. The aim of this section is to develop an understanding of the relation between occupant behavior and energy consumption in residential buildings.

Residential buildings consume energy directly in the form of fuels and electricity but also indirectly through the purchase of non-energy goods and services. Residential building consumption in developing countries introduces two significant issues for sustainable development. On the one side, increasing consumption of some basic goods and services through improved accessibility is important to sustainable development and also improving the quality of life for the poorest. On the other side, consumption causes energy and materials to transform, lowers their future usability and causes-increases pollution and that is why it imposes a large cost which makes it of outmost importance to discover methods of increasing the efficiency of use of these resources and diminishing as much as possible wasteful consumption. The different characteristics of residential buildings and the occupant’s lifestyles have a major impact on the type and volume of their consumption. At the aggregate global level, some of the lifestyle factors or key physical drivers other than income growth and urbanization, which play a major role into changing household energy use, include the change in the number of residential buildings (population growth and changes in the average size of buildings), area and character of residential areas, appliance penetration and utilization rates and changing patterns of fuel choice in households. Finding, using and combining information regarding such lifestyle changes at the level of an individual or household or for groups of similar households (lifestyle groups) with information regarding the structural and technical changes occurring in the economy as reflected by changes in energy efficiencies and intensities of producing sectors, makes it possible to trace through the energy implications of such changes. User behavior affects building energy performance and consumption through many variables. (Michael J. Brandemuehl, 2011)

The way human and specifically occupant behavior affects the energy consumption, efficiency and performance of a residential building is through their actions and choices. These choices can be routine or habit based, meaning that the user interacts with the house in a very similar manner every day and makes analyzing energy performance very easy. Choices can also be planned, meaning that the choice or action is not necessarily in the daily routine and is decided and preplanned to happen. Rational choices are also important to consider as rational choice theory suggests that the user uses rational calculations to make rational choices and achieve outcomes that are close to his self-interest and targets. (Ganti, 2019) On the opposite side irrational choices are the ones that happen without any common sense and usually because of psychological reasons against or counter to common logic. User behavior is multidimensional and is affected by many parameters. This happens because human life is complicated and every human is unique and different from one another, having different factors affecting every person in a different way. These factors also affect the way the house user lives and consumes energy. One factor that is very difficult to predict and to understand for every unique user is human psychology. Depending on the user’s mood, the way he or she operates can change dramatically. People often use lighting, heating and cooling more in order to feel better and more comfortable, while when they are in a good mood they might use electrical appliances more like television, radio or even the kitchen. Family is another important factor for energy consumption. A house where a family lives, has certain energy demands, such as hot water for the kids, higher heating and lower cooling set points for better living conditions for the children, much more lighting as the children often play in their own rooms, much more usage of electrical appliances like the dishwasher, the kitchen, television, vacuum cleaner or the washing machine. Apart from family in the same house it is possible for people of no blood relation to be living together, which also affects energy consumption as it is common for everyone to have different working hours and different comfort levels as well. The user's comfort level is a factor that can be very close but also very different from one user to the other. Each person has a different comfort level that can also differ each day depending on the stress, exhaustion, mood, health, clothing, activities and much more. This comfort level applies to lighting as some people might want more light than others, or no light in order to sleep, heating and cooling with different set points for both as some people need more warmth than others or more chill than others. The comfort level also affects natural ventilation and window opening, as some users might want more fresh air than others or less because of thermal losses. The occupant's work and especially the working hours is another factor that greatly affects the energy consumption. Working early in the morning and during daytime which are the most common working hours leads to a higher energy consumption as energy is needed for heated water in the morning and also energy demand for lighting and other uses at peak hours like evening and first night hours. Working outdoors can also affect energy performance as it is possible to change the user's comfort zone, as working on a cold environment leads to a need for more warmth and the other way round. Work can also take place at home, which increases energy consumption as well. Lifestyle is one more factor that affects energy consumption as clothing which is part of lifestyle can alter the user's comfort zone, elegant lighting and miscellaneous decorative devices increase energy consumption and in general modern lifestyle and consumer trends in electrical appliances lead to a much more energy dependent lifestyle. Education greatly affects the attitude and the perspective the user has about energy consumption, the environment and sustainability which are key elements in the relationship of the human kind and the environment. Education can greatly benefit the way the user operates within his home environment, by making him or her more sensible towards the environment so that he/her can consume electricity away from peak hours, or use high efficiency lighting and electrical appliances. On the opposite side a person that does not have the proper education in most cases proves to be consuming more energy. Even the perspective of a clean house by the user can affect energy consumption, as some people might clean the house often, using vacuum cleaners, water and opening windows that all together consume energy.

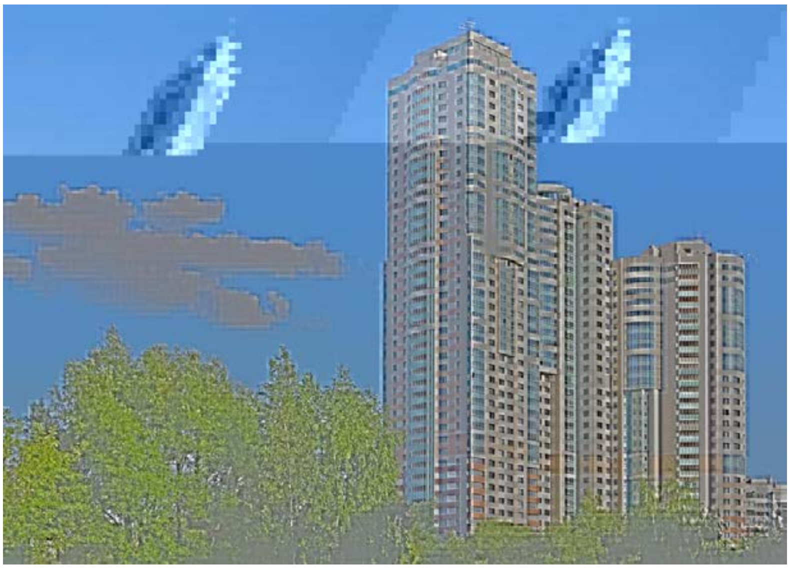
In the opposite side someone who does not clean the house so often might not use that much energy but it is unhealthy. Safety reasons can also increase energy consumption like keeping some of the lighting on at night or the television open in order to sleep, which happens in order to make the occupant feel more comfortable and safer. Another significant factor is how the occupant spends his free time, his hobbies and in general his daily routine. People that are more extroverted, spend their free time outside, are not consuming that much energy in house. People that have a more vibe social life might like gatherings and parties in their own place where usually a lot of energy is consumed. There are also people that like to stay inside in their free time and enjoy the latest technology offerings and trends like television, computers or console gaming. Vegetation or pets inside the house leads to more time with windows open thus more energy consumed for either heating or cooling.

1.2 Building typology

Building typology is the kind of typology that categorizes buildings by the similarity of their use first, in this case about residential only, and many other factors that define them (Caniggia, 2001). These factors will be analyzed further in this study. Residential buildings are what provide sleeping accommodation for their users with or without cooking and dining facilities. They are what the human evolution led to starting from caves and shacks until the modern houses. The modern house is where the human kind feels comfortable, safe and secure, where they take care of themselves and satisfy their primary needs the most. Thus they are of outmost importance to the lives of the human kind. Residential buildings can differ in many ways. First, depending on the year and place of construction around the world. Alongside human evolution, residential buildings are evolving as well, in design, style, comfort, security and ease of use. Houses also differ from country to country because of design, style, climatic zone, weather, altitude and legislation. Legislation is a very important factor in building typology because of earthquake activity for example, a house has to be very strong, unnecessarily strong for other parts of the world that do not have seismic activity. Another example is that a certain color, design and specific windows have to be installed in a house in order to keep the traditional style of the whole area like in Cyclades in Greece. Legislation in general defines almost every factor that characterizes and defines a building. Some of these characteristics are the building lot area ratio, the building volume, the minimum and maximum building height, roof slope, external surface area, capacity, total openings area, distance from plot limits and more. There are also different kinds of residential buildings. There are condominium known also as condos which are many houses within one building or buildings in one lot. They can be duplex, two stories or even triplex with three levels. (Caniggia, 2001)

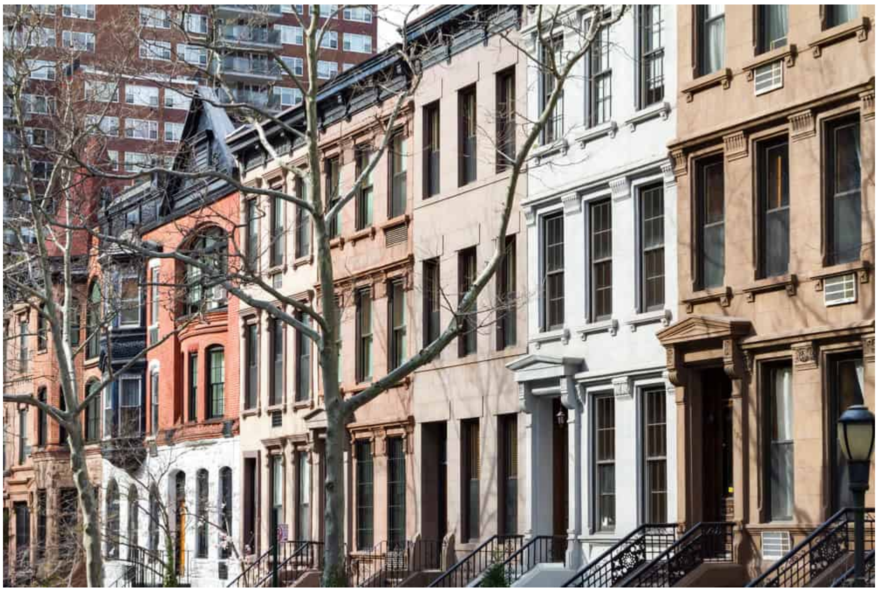
Picture 1: Condominium building

Then there is apartment which is part of a group of housing units in one building. The difference between condos and apartments is that in this case the building is owned by one entity that rents all the houses out to tenants.



Picture 2: Apartment building

A townhome is a house attached to other houses in a row sharing one or two walls. In most cases they are two or three stories and the owner owns both the interior and exterior of the house.



Picture 3: Townhome

There is also the bungalow, which is small, square-shaped, single story home with front porch. The floor is raised up; they usually have an attic with a window as well, keeping the design very simple and low cost.

Picture 4: Bungalow

A ranch style home is very much like the bungalow but instead of being square-shaped it is larger and more rectangular. The main characteristic is the large open space outside.

Picture 5: Ranch style house

Cottage is a small house with very few rooms and a roof that usually serves as a vacation home.

Picture 6: Cottage

A cabin is a more traditional cottage and is defined by being log-built.

Picture 7: Cabin

Chalet is mainly a winter vacation home, characterized by steep roof and long overhangs in order for the roof to handle large piles of snow. They are usually like cabins, also log-built but much larger in size.

Picture 8: Chalet

A multi-family house is basically a detached home and it contains two or even more housing units. The housing units can be separated by stories, by just walls or even a mix of both.

Picture 9: Multi-family house

A mobile house is a mobile structure as the name suggests, that can be easily transferred by being towed, but is not made for frequent transferring. These are built in big number in a factory and are transferred where the owner wants. They are inexpensive but not very big and with a very minimalistic design.

Picture 10: Mobile home

On the other hand a mansion is a large house that is defined by the word luxury. There is not an exact size because each one is different, built to the owners need and desires, but can be very large. Mansions are sometimes called villas depending on the style, ownership and country.

Picture 11: Mansion

Picture 12: Villa

Each type of house has different benefits and drawbacks. Houses that are directly connected to other buildings through a wall or roof, like apartments, townhomes, multi-family and condos benefit from less thermal losses and therefore less energy consumed for heating. But on the other hand they require more lighting as not every wall has an opening and also there is the noise from the families around the house. All the other type of houses have much more thermal losses and require more energy in order to reach the user's comfort zone. With proper design there is less of a need for lighting as natural light is sufficient during the day. Another factor is that activities or hobbies that create noise can be done at almost every time in these houses, thus targeting times that heating is not required or hours with discounted energy bill. Also in the case of buildings with many houses, the heating is not necessarily independent though there are certain times that the heating system is open. This leads to higher energy consumption because not every user's time schedule aligns and extra energy is consumed in order to cover everyone's needs. All these differences originate from the building characteristics of each type of house. Such residential buildings characteristics are:

- Insulation, or in this specific case thermal insulation is the use of materials in order to reduce rates of heat transfer in and out of the house and increase comfort and energy efficiency. There are many materials used for insulation, mostly based on polyurethane and polyisocyanurate. Insulation is usually placed on the outside of the wall in new constructions or on the inside of the wall in existing houses. Thermal insulation greatly reduces rates of heat transfer, meaning that it reduces thermal losses out from the house in winter and into the house in the summer. This greatly reduces energy consumption as the HVAC systems operate more efficiently and in the case of midseason like Autumn-Spring, heating or cooling is not even needed in some cases. It also helps in lowering humidity, which affects the comfort level of the occupant. All these reasons are why in almost every part of the world building insulation is demanded by the legislation.

- Roof. In this case roof type acts as some kind of insulation. Roofs can be flat, with a thick layer of concrete or they can be hip, in most cases a wooden construction with tiles. There are more roof styles like with a slight bend, or different types of hip but those are mostly for design and style with very few in order to cover high winds. A roof with tiles and in most cases an attic, acts as insulation because tiles are of ceramic origin and wood beneath them is insulation as well. In case there is an attic, it lowers rates of heat transfer even more because it acts like an antechamber where the heat or cold is trapped and cannot easily enter the house below. Hip roofs are more expensive and mostly noticed on detached houses. Therefore flat roofs are more common and cheaper also. A typical insulation as used on the outside walls is installed on the roof as well, but also a layer of insulation above the roof that stops solar irradiance. As with insulation a proper roof installment according to a specified mechanic and the legislation helps to increase energy efficiency.

- Openings can be a window, a door or a roof and basically what allows the passage of light, sound and sometimes air through a wall. Most of the openings in a house are windows. Windows are installed in order to give the occupant view of the outside for psychological reasons, to let light in and allow for better ventilation when opened. Windows in most cases are made of a frame from aluminum or wood that surrounds a glass surface with insulation between the two. There a few types of window panes. There are double panes or double glazing which are the most common and have two sheets of windows pane glasses that are separated by trapped gas (krypton or argon) in the middle. The gas makes a tight seal that holds the window more firmly, which prevents heat and energy loss inside the house. The pros of this type are that it prevents condensation, provide good insulation, they block outside noise and increase security and durability. The cons are that maintenance is costly and are not replaced. There are also triple pane windows which are an improved version of double pane, but are even more costly. The same follows for quadruple windows. Windows can be single hung where the bottom windows panel moves up and down, and the upper remains stationary or double hung where both and panels can move up and down. There are also arched windows that have rounded top in order to add an architectural design to the house. Awning windows are designed for climates with a lot of rainfall because the windows open from the bottom with hinges on the top. Hopper windows open the opposite way from awning and are usually placed in bathrooms and basements. Glass block windows are added just to increase light flow, they cannot be opened, like picture windows in which the glass is part of the wall providing better insulation than normal windows. There are also sliding windows that slide to opposite sides, even inside the wall in order to open but suffer from thermal losses. The most common of all are casement windows that open towards the outside, with hinges on the sides and seal when closed, providing less thermal losses. The window to area of the wall ratio and the orientation, affect the thermal heat transfer ratio of the house as well as ventilation and lighting. The windows in general have more thermal losses than an insulated wall but more thermal gains as well. Therefore proper placement is key. Depending on the hemisphere, window orientation is different. In the northern hemisphere for instance, a larger window surface area facing the south is preferred in order to have more thermal gains and smaller window surface facing north in order to avoid thermal losses. In case of the southern hemisphere it would have been the other way round. Windows must also be placed properly in order to let sunlight in and avoid the use of lighting and higher energy consumption.

- House layout and volume. How the house is laid out and its total volume are also important factors in energy use and consumption. First the total volume of the house is important which can be calculated by the sum of the total areas that house floor covers times the height of each floor. The total volume along with the thermal losses of the house will provide information on what HVAC system is ideal for every home, thus increasing energy efficiency. The house volume also helps to determine the window surface in order to achieve the best possible ventilation. Another factor is the house layout and floors if there are any. This can assist in determining certain zones in the house for heating or cooling. For example the house can be divided in zones by using the floors, each floor one zone, or even further by rooms. By dividing the house in zones, heating and cooling can be optimized only for the zones that the users use the most and therefore achieve better energy efficiency.

All the above mentioned factors are different for each type of residential buildings with different pros and cons. Some of these building types although they differ, they have many similar characteristics. Below follows a comparison between the residential building types with regard to the characteristics mentioned above.

Building type	
Apartments, condominium buildings, multi-family houses	**Pros:** • Modern construction and design • Good insulation (Low U-values) • Openings of modern technology • Low thermal losses • Better HVAC coverage (because of more than 1 floors-zones) **Cons:** • Noise from adjacent houses • May require ventilation
Townhome	**Pros:** • Low thermal losses (towards adjacent townhomes) • Better HVAC coverage (because of more than 1 floors-zones) • Can utilize any roof design **Cons:** • Usually of older construction date • Insufficient insulation • Need for more HVAC usage • Noise from adjacent houses
Bungalow and Ranch style house	**Pros:** • Modern construction • Good insulation • Openings of modern technology **Cons:** • More thermal losses because of no directly adjacent buildings • Need for more HVAC usage

Cottage	**Pros:** • Good insulation • Openings of modern technology • Can utilize any roof design **Cons:** • Construction date can differ • More thermal losses because of no directly adjacent buildings • Need for more HVAC usage
Cabin and Chalet	**Pros:** • Good insulation (thick layer of wood) • Lower HVAC usage because of low house volume **Cons:** • More thermal losses because of no directly adjacent buildings • Older type of openings (in order to match the design)
Mobile home	**Pros:** • Modern construction and design • Good insulation • Openings of modern technology • Lower HVAC usage because of low house volume **Cons:** • More thermal losses because of no directly adjacent buildings
Mansions and villas	**Pros:** • Good insulation • Can utilize any roof design **Cons:** • Construction date can differ • High HVAC usage because of large house volume • More thermal losses because of no directly adjacent buildings

1.3 Climate

Climate is defined as the long-term average of weather, usually over a standard period of 30 years (Planton, 2016). Climate zones are areas with distinct climates that can be classified using different climatic and meteorological characteristics. The main climate zones are:

- The Tropical zone (0° - 23.5°), which is in the areas between the equator and the tropics, where the solar radiation reaches the ground nearly vertically at noon practically the whole year round. Thus these regions are very warm, with high temperatures, moist air and high water evaporation. All these result in dense cloud cover that halts solar radiation.

- Subtropics (23.5° - 40°), are the regions that have the most solar radiation during the summer, as the Sun's angle is almost vertical to the Earth with very little cloud cover. These regions are also characterized by less moisture which also increases the solar radiation effect that explains why most of the deserts are located in this zone. During the winter radiation drops and makes the region cooler and moister.

- Temperate zone (40° - 60°), are the areas that solar radiation reaches at a smaller angle with temperatures being much cooler than subtropics. Each season and day length changes substantially during the year. This zone does not have that much extremes and has a more regular distribution of precipitation over the year and a longer vegetation period.

- Cold zone (60° - 90°), are the polar areas that receive less solar radiation and therefore less heat because of the very flat angle of the Sun towards the ground. Because Earth's axis angle to the Sun changes, the length of the day varies the most in this zone. The life conditions in these regions are very harsh.

There are also local climates that are defined by local topography and characteristics. The local climate can be considerably different than the general area climate. Such examples are glaciers, areas with high mountains and littoral areas which are all influenced by rapid temperature change and local atmospheric currents. Climate is most commonly measured with some parameters which are temperature, humidity, atmospheric pressure, wind and precipitation. Some other parameters that affect climate are latitude, terrain, altitude, sea level and water bodies along with their currents. All these parameters have an impact on energy use. Depending on the climate and considering the parameter temperature, a house has to be designed accordingly or it will have high energy consumption. In the case of high temperatures, the house should have proper shading, insulation, openings for natural ventilation and not for thermal gains but for cooling. If not designed correctly energy for cooling alone would be substantial. In the case of low temperature climates, in order to avoid high energy consumption, a house should have proper insulation, openings for thermal gains and proper heating. In a situation where winters are cold and summers are very hot, like in the Mediterranean a compromise between the two above scenarios has to be adopted. Humidity is a parameter that, when in higher percentages can affect the occupants negatively. In order for the user to alleviate the problem, air conditioning is used which leads to increased energy use. Wind can also affect energy use as it can raise or drop the temperature of the house, leading to the need of HVAC use. In fewer cases high winds, demand for the user to close every opening for safety and turn on the lighting. Precipitation leads to an increase in humidity with all its negative effects.

Another important factor that affects residential building energy use is climate change and the effects of global warming. Global warming is the long term increase in the Earth's climate system average temperature. Climate change and global warming are linked but they are not the same. Global warming is caused by humans and it refers to the increase in Earth's surface temperature while climate change includes that increase and also changes in precipitation, wind currents and more (Sato, 2019). Human caused global warming reached approximately 1 ^{o}C above pre-industrial levels in 2017 (Myles R. Allen (UK)). All these are working alongside with the greenhouse effect. The greenhouse effect is the procedure where radiation from a planet's atmosphere warms the planet's surface to a higher temperature than it should normally be. Greenhouse gas, which are radioactively in Earth's atmosphere radiate energy towards all directions. Some of this energy is radiated towards Earth's surface, raising its temperature. How intense this radiation is, depends on the atmosphere's temperature and the total amount of GHG it contains. All these factors contribute to an increase in global average temperature and change in user's living conditions. This affects the house user by requiring increased use of HVAC systems in areas with high temperatures and also the need for dehumidifier in other areas because of higher percentage of moist in the air. The global increase in temperature also lowers the efficiency of HVAC systems. In areas with high temperatures, the residents prefer to stay indoors with air conditioning than go out, thus increasing the energy use even more. A warmer climate may reduce the efficiency of power production for many existing fossil fuel and nuclear power plants because these plants use water for cooling. The colder the water is, the more efficient the generator. Thus, higher air and water temperatures could reduce the efficiency with which these plants convert fuel into electricity.

1.4 Building location and surrounding environment

Another important factor that affects residential building energy performance, is building location and its surrounding environment. Although building typology and how it affects energy use has already been mentioned, there are still some parameters that are interlinked with location and surrounding environment and will be further analyzed. The location and surrounding environment of the user is very important because in a way it defines his daily routine, his daily routes, his timeline. In most cases people choose their home based on proximity to their workplace, markets and amenities in general. But, having close proximity to the workplace as a first priority is not always the best option as workplaces can be located in an industrial area where living conditions are not ideal. Therefore a compromise in most cases has to be made in order for the user to have the most comforting living conditions (Tettey, 2017). Another very important factor for the user to consider when choosing a home is the energy consumption of the house depending on its location and its surrounding environment, which both have extra parameters that affect energy use. However although everyone would like to choose their residence in the best possible area, that is not easily achieved because of social and economic reasons. In most cases, especially in big towns, the areas where the rich live tend to be newer, less crowded with higher building to plot ratios and usually detached houses. While areas for the middle economic group and lower, are filled with blocks of flats and generally older buildings, while being more crowded as well. Building location and surrounding environment have some further parameters that affect energy use and consumption. Distance between buildings is proven to affect energy use, by affecting wind velocity and volume, shading and sunlight radiation. It is observed that with increased distance between two buildings, the amount of air flow increases as well. The speed of the air though, as distance increased, it decreased. However because houses don't need that much air velocity for natural ventilation, a larger distance between buildings is preferred. If the building though is not in direct contact with other buildings, it will have higher thermal losses in the winter. The distance between buildings also affects the sunlight radiation the surrounding buildings allow to reach the user's house and define the amount of shade they provide. Depending on the location around the world and the climate, as mentioned before, this can have both positive and negative results. (Yasa, 2017) The orientation of the building can also affect energy performance. Building orientation is mostly focusing in certain aspects of the surrounding environment such as street appeal, capturing a scenic view or for drainage considerations and more. However it is becoming of outmost importance to capture the free energy that the sun provides. Proper building orientation can maximize thermal gains, increase natural lighting and minimize thermal losses as much as possible. As mentioned before depending on the hemisphere and location of the building the proper orientation can be completely different for every case. One more factor is if the building is located on a slope and how steep that slope is. In case the house in question is based on a slope and also depending on the steepness of the slope the air circulation from the bottom to the top of the hill and vice versa can change. Another factor for consideration is the building shape, its geometrical variables, length, width, height and depth. The building shape can dictate how the building manages the wind and sun light. Shapes can differ dramatically to please the user aesthetically and also to cover certain needs, like block undesirable winds or sunlight. The building's dimensions are also a key factor, especially height because if the building is higher than others it will be exposed to wind and sunlight more. However if a whole building also covers a large area, that means that the center of the buildings will suffer from low natural lighting and that is going to increase energy consumption (Simone Ferrari, 2016). The building town district is another important factor. First as mentioned before the age of the buildings plays a very important role as older building consume much more energy than new ones. Another factor is the affordability and availability of electricity and energy in each district. In high-end districts buildings are more spaced out, thus much less people than medium to low end districts, which enables energy to be delivered much easier and with many more options like natural gas for example. Medium to low-end districts suffer from power outages and higher prices due to the demand and density. A denser urban environment also suffers from heat which is drawn from the sun light and eventually released out at night, raising the temperature of the surrounding environment and requiring the use of HVAC systems for cooling. Also traffic jams and automobiles in general assist that effect because they release heat and GHG that trap the heat. Here is where a well-designed district comes in to play, where the inhabitants use public transport or environmental friendly transportation, like the bicycle, to lower GHG and traffic jams. The surrounding environment of a building is also another very important factor. Nature is so vast and different, with each place around the world being different, with different characteristics. Thus there are many parameters with which the surrounding environment affects a residential building. Environment close or near the sea, usually includes a lot of humidity that also causes rust. Mountainous environments with dense vegetation and rivers also have a lot of humidity. Desolate environments are very drought, with water shortages. Depending also on the local topography, the microclimate of the area can be affected. In all cases which are outside of normal values of temperature, wind velocity and volume, humidity and air pressure, energy consumption is increased because there is an increased need for HVAC or other systems in order to reach comforting living conditions (John Littler, 2003).

Picture 13: Examples of rural, suburban and urban environments (Quotev)

1.5 Energy load of home appliances

Residential energy uses, how the user uses energy, is one for the key factors that make his/hers home feel comforting and secure. Energy use can vary from household, both in quantity, how much total energy is used, and in specific use. When electricity flows through a circuit, there are points on the circuit, called loads, where energy is drawn away. Loads, in essence, are objects that use electricity such as light bulbs. There is a variety of classification systems, but one way you can divide loads is into resistive, capacitive, and inductive or a combination of these types. There are also different types of electrical loads, resistive loads, inductive loads and capacitive loads. Resistive loads consist of any load that includes heating like lights, toasters, space heaters, coffee makers and more. This load draws current in a sinusoidal waxing-waning pattern in concert with a sinusoidal variation in voltage, that is maximum, minimum and zero points of the voltage and current values over time line up, a purely resistive one and includes no other elements. Inductive loads are those that power electrical motors. In a household these are devices with moving parts like fans, vacuum cleaners, dishwashers, washing machines refrigerators and air conditioners. In this case current follows a sinusoidal pattern that peaks after the voltage sine wave peaks, so the maximum, minimum and zero points are out of phase. Capacitive loads are loads that are not seen in households and in engineering they do not exist in a stand-alone format. These loads are mostly used in large circuits in controlling power use (Sean Barker). Although the type of energy use can differ dramatically from house to house, the uses are common but with different frequency and cover the user’s needs. The main energy uses in residential buildings are:

- Lighting. Lighting is used in nearly every home around the world and its one of the primary needs that the user has. Lighting offers a safer more comfortable environment for the user during the night or in times or places with low natural light. It is of outmost importance for the house user, because it offers comfortable living conditions and gives the user the option to be turned on/off or even be dimmed. Lighting can also help the user with other energy uses or activities like cooking, cleaning, reading and more. In 2015, in the United States lighting covered approximately 10% of the total residential energy consumed. (Administration, 2015)

- Heating, cooling, air conditioning. Since the ancient times, starting from fires in caves, the human kind needed a temperature that made their living conditions, comfortable. Nowadays with the innovation in technology and modern HVAC systems heating, cooling and air conditioning in general is easier to access than ever. Traditional heating systems like diesel or wood burner are proven to be very bad for the environment, which led to a sudden shift to environmental friendlier systems like, air conditioners and heat pumps. These systems use electrical energy in order to provide heating or cooling but combined with renewable energy systems they are considered environmental friendly. Depending on the location of the house and the climate, the use of such systems differs. These systems are vital for the home user especially in areas with very high or low temperatures, like close to the poles or close to the equator. They are used of course and in more mild climates, but can be avoided in the change of seasons due to mild conditions. In 2015 in the United States energy use for heating, cooling and air conditioning covered approximately 40-50% of the total residential energy consumed. (Administration, 2015)

- Ventilation and air circulation. Ventilation moves outdoor air into a building or a room, and distributes the air within the building or room. The general purpose of ventilation in residential buildings is to provide healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it (Atkinson J, 2009). Residential building ventilation has three basic parameters that is defined by. Ventilation rate which is the amount and quality of the outdoor air provided into the space. Airflow direction, which is the airflow direction in a building and should be directed from clean zones to dirty ones. Air distribution or airflow pattern which is the external air that should be provided to each part of the space in an efficient way, with airborne pollutants that are generated in each part of the space been removed in an efficient way as well. There are three types of ventilation in residential buildings, natural, mechanical and hybrid or mixed. Natural ventilation is all the natural forces, winds and thermal buoyancy force that happen due to differences in air density, that drive air through purpose-built building envelope openings. These openings include windows, doors, solar chimneys, wind towers and trickle ventilators. Natural ventilation is affected by climate, building design and user behavior. Mechanical ventilation is where mechanical fans are installed in windows, walls or in air ducts to supply air in or out of a room. The type of mechanical ventilation used depends on climate. For example, in warm and humid climates, infiltration may need to be minimized or prevented to reduce interstitial condensation (which occurs when warm, moist air from inside a building penetrates a wall, roof or floor and meets a cold surface). In these cases, a positive pressure mechanical ventilation system is often used. Conversely, in cold climates, exfiltration needs to be prevented to reduce interstitial condensation, and negative pressure ventilation is used. For a room with locally generated pollutants, such as a bathroom, toilet or kitchen, the negative pressure system is often used. In a positive pressure system, the room is in positive pressure and the room air is leaked out through envelope leakages or other openings. In a negative pressure system, the room is in negative pressure, and the room air is compensated by "sucking" air from outside. A balanced mechanical ventilation system refers to the system where air supply and exhaust have been tested and adjusted to meet design specifications. The room pressure may be maintained at either slightly positive or negative pressure, which is achieved by using slightly unequal supply or exhaust ventilation rates. For example, a slight negative room pressure is achieved by exhausting 10% more air than the supply in a cold climate to minimize the possibility of interstitial condensation. In an airborne precaution room for infection control, a minimum negative pressure of 2.5 Pa is often maintained relative to the corridor. Hybrid or mixed mode ventilation relies on natural driving forces to provide the desired flow rate. It uses mechanical ventilation when the natural ventilation flow rate is too low. When natural ventilation alone is not suitable, exhaust fans can be installed to increase ventilation rates in rooms housing patients with airborne infection. However, this simple type of hybrid or mixed-mode ventilation needs to be used with care. The fans should be installed where room air can be exhausted directly to the outdoor environment through either a wall or the roof. The size and number of exhaust fans depends on the targeted ventilation rate, and must be measured and tested before use. Problems associated with the use of exhaust fans include installation difficulties, noise, increased or decreased temperature in the room and the requirement for non-stop electricity supply. If the environment in the room causes thermal discomfort spot cooling or heating systems and ceiling fans may be added. Another possibility is the installation of whirlybirds that do not require electricity and provide a roof-exhaust system increasing airflow in a building (Kvols Heiselberg, 2002). The use of outdoor air for natural ventilation, combined with natural cooling techniques and the use of daylight have been essential elements of architecture since ancient times and up to the first part of the 20th century. In recent times, natural ventilation has been largely replaced by mechanical ventilation systems in high and middle income countries. At first, full mechanical heating, ventilation and air-conditioning systems appeared to be able to solve all the practical problems of natural ventilation for year-round control of indoor environmental conditions (Grondzik, 2007). In 2015 in the United States energy use for ventilation and air circulation covered approximately 4% of the total residential energy consumed (Administration, 2015).

- Water heating. Water heating is a heat transfer process that uses some kind of energy source, in order to heat water. The most common devices that provide heated water are water heaters, hot water heaters, hot water tanks, boilers, heat exchanges and calorifiers. All these devices can be named differently depending on the area and by whether they heat portable or non-portable water in residential use. Fossil fuels or solid fuels are commonly used for heating water. These may be consumed directly or may produce electricity that, in turn, heats water. Electricity to heat water may also come from any other electrical source, such as nuclear power or renewable energy. Alternative energy such as solar energy, heat pumps, hot water heat recycling, and geothermal heating can also heat water, often in combination with backup systems powered by fossil fuels or electricity (Encyclopedia, 2017). The main types of water heaters used in residential buildings are:

    - Conventional storage water heaters, that offer a ready storage tank of hot water
    - Tankless or demand-type water heaters that heat water directly without the use of a storage tank.
    - Heat pump water heaters that move heat from one place to another instead of generating heat directly for providing hot water.
    - Solar water heaters which use the sun’s heat to provide hot water.
    - Tankless coil and indirect water heaters which use a home’s space heating system to heat water.

And from these the ideal are selected using the following criteria:

- Fuel type, availability and cost. The fuel type or energy source you use for water heating will not only affect the water heater's annual operation costs but also its size and energy efficiency.

- Size. To provide the household with enough hot water and to maximize efficiency, a properly sized water heater is needed.
- Energy efficiency. To maximize energy and cost savings, how energy efficient a water heater is must be first defined.
- Costs. Before the purchase of a water heater, it's also a good idea to estimate its annual operating costs and compare those costs with other less or more energy-efficient models (Energy).
- Appliances used for different purposes in a residential building.

One of the larger users of electricity on average in a residential building is electrical appliances, which when aggregated account for approximately 30% of the electricity used in the residential building sector. Appliances can be classified based on their use to those that are for washing, cleaning, for entertainment, training, cooking, air conditioning, air circulation and for refrigeration. A list of the most common home appliances follows below:

Air conditioner	Convection oven	Hob	Radiator
Air ionizer	Deep fryer	Home server	Radio receiver
Air purifier	Dehumidifier	Humidifier	Refrigerator
Appliance plug	Digital camera	HVAC	Rotisserie
Aroma lamp	Dish drying cabinet	Icebox	Sewing machine
Attic fan	Dishwasher	Juicer	Sink
Bachelor griller	Drawer dishwasher	Karaoke set	Slow cooker
Bedside lamp	DVD player	Kimchi refrigerator	Snowblower
Back boiler	Edger	Lawn mower	Space heater
Beverage opener	Electric cooker	Leaf blower	Steam mop
Blender	Electric razor	Light fixture	Stereo
Box fan	Electric toothbrush	Mangle	Stove
Box mangle	Electric water boiler	Meat grinder	Sump pump
Calculator	Evaporative cooler	Megaphone	Telephone
Camcorder	Exhaust hood	Micathermic heater	Table lamp
Can opener	Fan heater	Microwave oven	Television set
Cassette player	Desk fan	Mixer	Tie press
Ceiling fan	Flame supervision device	Mogul lamp	Toaster
Central vacuum cleaner	Food processor	Mousetrap	Toaster oven
Clock	Forced-air	Nightlight	Trash compactor
Clothes dryer	Freezer	Oil heater	Trouser press
Clothes iron	Futon dryer	Oven	Vacuum cleaner
Coffee grinder	Garbage disposal uni	Panini press	Waffle iron
Coffee maker	Gas appliance	Pasta maker	Washing machine
Coffee percolator	Gramaphone	Patio heater	Water cooker
Cold-pressed juicer	Go-to-bed matchbox	Paper shredder	Water purifier
Cooler	Hair dryer	Pencil sharpener	Water heater
Combo washer dryer	Hair iron	Popcorn maker	Weed eater
Computer	Hearing aid	Pressure-cooker	Window fan

Table 1: Common home appliances

(Wikipedia, List of home appliances)

Electricity consumption in United States for residential buildings was measured in 2015 by the U.S. Energy Information Administration. The three larger categories and their respective shares of residential electricity consumption in 2015 were:
Air conditioning with 17%, space heating with 15% and water heating with 14%.

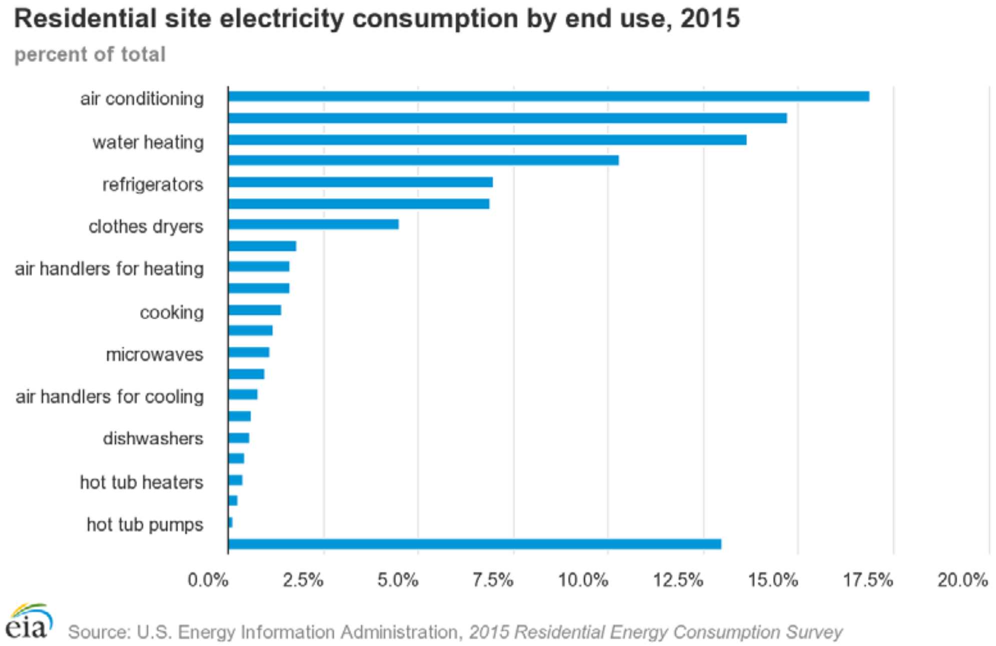
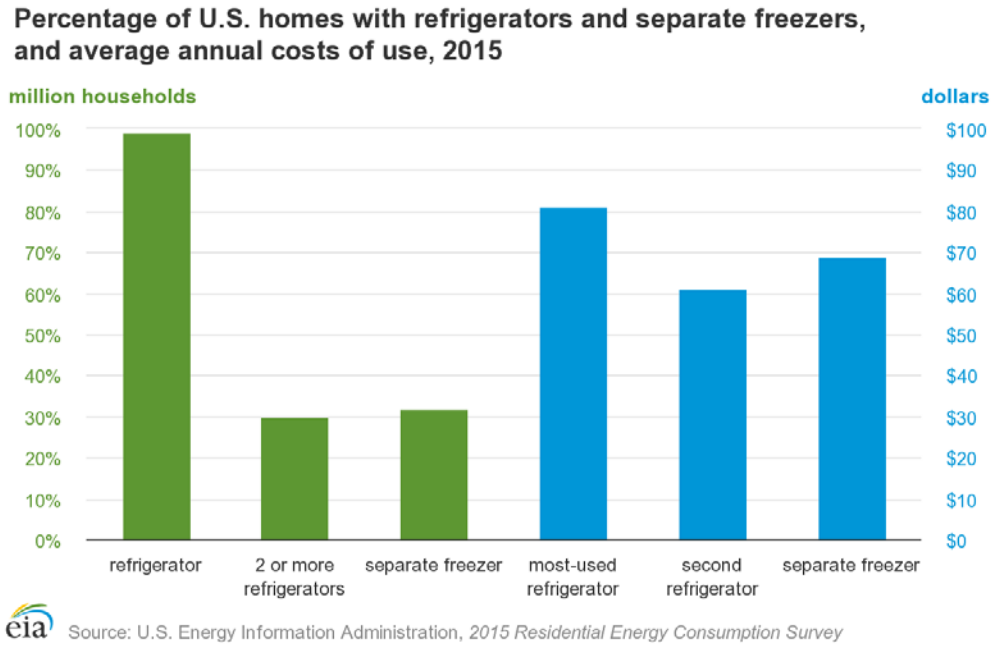


Table 2: Residential site electricity consumption be end use, 2015

Nearly all homes, almost 99%, have a refrigerator, and 30% have two or more. Second refrigerators and separate freezers are most common in Midwest homes, where, in 2015, 34% of homes had a second refrigerator and 39% had a separate freezer compared with 30% and 32%, respectively, for all U.S. homes. The most-used refrigerator in a home costs $81 per year to operate on average, while the second refrigerator has an average annual operating cost of $61. Second refrigerators are often smaller than the home's most-used refrigerator, and they may not be in use the entire year—17% of homes with a second refrigerator reported that it was in use six months or less in 2015. Separate freezers cost $69 per year to operate on average.



Source: U.S. Energy Information Administration, *2015 Residential Energy Consumption Survey*

Table 3: Percentage of U.S. homes with refrigerators and separate freezers and average annual costs of use for 2015

Below follows a table with energy consumption for the most common electrical appliances found in households today. The data regarding consumption are pretty close to the actual real data. The cost data can differ significantly depending on the location and time of reading.

Appliance type	Capacity	Length of use	Consumption/year	Cost
Heat pump tumble dryer	A+++	100 cycles/year	200 kWh	50 €
Evacuation tumble dryer with heat pump	C	100 cycles/year	500 kWh	125 €
Powerful washing machine	A+++	200 cycles/year	180 kWh	45 €
Conventional washing machine	A	200 cycles/year	270 kWh	67,50 €
Iron	750 to 1100W	48 weeks-5h/week	260 kWh	65 €
Steam iron	2000 W	1,5 h/week	750 kWh	18,75 €
Vacuum cleaner	800 W	48 weeks-2h/week	80 kWh	20 €
Kitchen boiler 5 liters	2500 W	10 l/day	200 kWh	50 €
Computer	250 W	4 h/day	90 kWh	75 €
Computer	250 W	Continuously	70 kWh	17,50 €
Portable computer	75 W	4 h/day	90 kWh	22,50 €
Portable computer	75 W	Continuously	20 kWh	5 €
Wifi router		Continuously	85 kWh	21,25 €
Desk LED lamp	8 W	4 h/day	10 kWh	2,50 €
Television	82 W	4 h/day	150 kWh	37,50 €
Television	82 W	Continuously	14 kWh	3,50 €
Radio alarm	10 W	365 days-Continuously	87 kWh	21,75 €
Electric toothbrush	8 to 12 W	355 days – 5min./day	0,3 kWh	0,075 €
Back-up heating appliance	2000 W	2h/150 days	600 kWh	150 €
Hairdryer	300 to 600 W	48 weeks-30 min./day	11 kWh	2,75 €
Boiler 100 liters	2200 W	80 l/day	1700 kWh	425 €

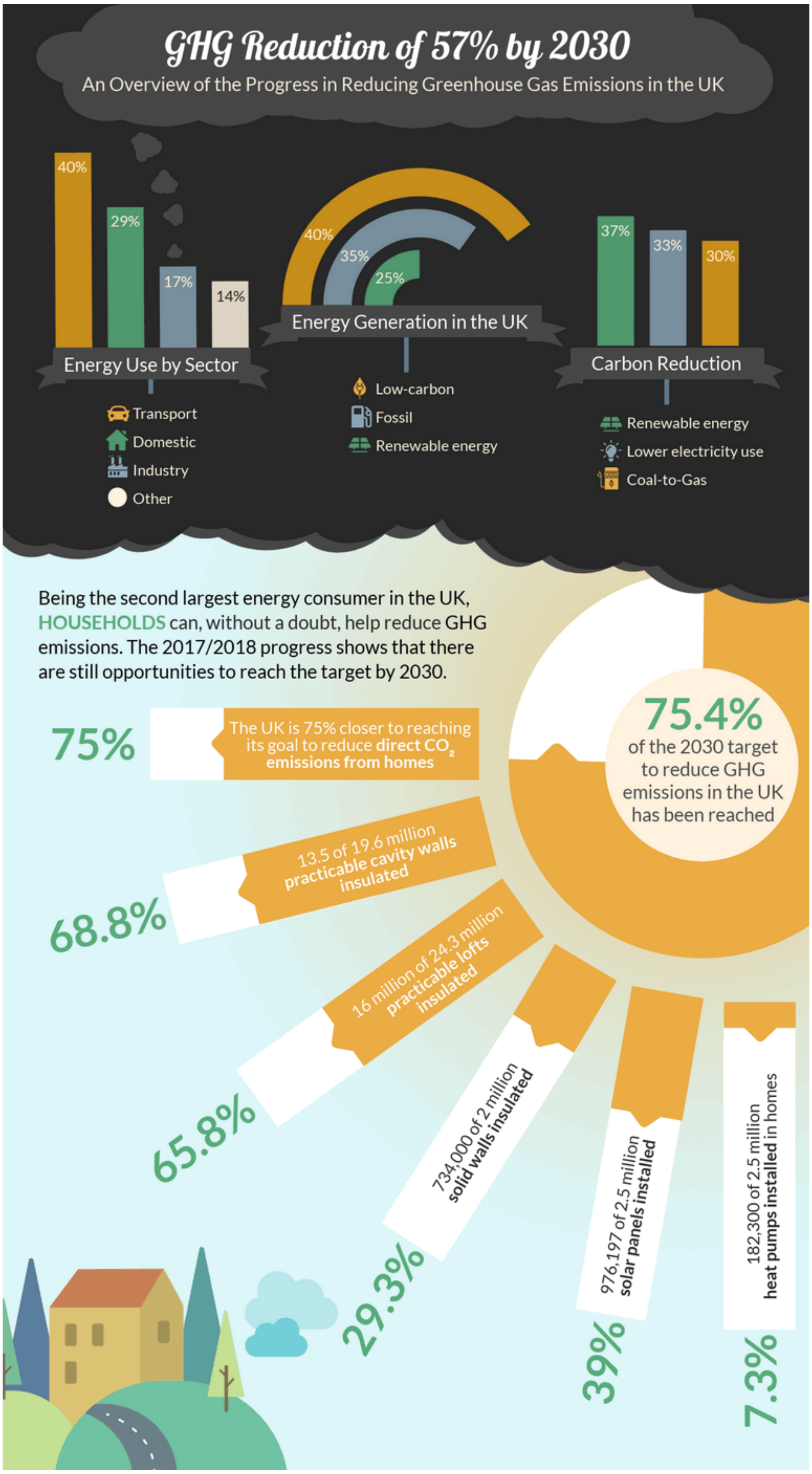
Table 4: Energy consumption per house electrical appliance (Energuide, 2019)

It turns out that the energy load of home electrical appliances can differ significantly from house to house. Which electrical appliances/loads and for how long the occupant uses them define his/hers energy consumption pattern. Low energy loads, like lighting, don’t affect energy consumption significantly, except if used excessively. Energy loads for ventilation and air circulation, have very similar patterns of use and energy consumption. However HVAC and water heating energy loads can have a major difference in energy consumption from house to house depending on all the factors mentioned before that affect energy performance. All these lead to the conclusion that the user’s comfort zone, habits, patterns along with building characteristics, location, climate and generally his behavior can affect energy use performance substantially.

Chapter 2
Goals, targets and the potential

After identifying and analyzing all the important factors that can affect residential energy use and performance, it is important to also have certain goals and targets set in order to try and to finally achieve them. Goals and targets define the pattern by which energy performance is increased. They also provide a never-ending improvement standard. Most of the goals and targets are set by the government with respect to the environment first, the national economy, the location and the needs of the users. Goals and targets proved to have a great result, as they force governments and users to achieve them, through financial incentives and fines in case of disobedience. They also create new job opportunities, widen the market, reshape the economy and provide energy security and better energy availability.

Most commentators expect improved energy efficiency and reduced energy demand to provide the dominant contribution to tackling global climate change. But at the global level, the correlation between increased wealth and increased energy consumption is very strong and the impact of policies to reduce energy demand is both limited and contested. But although it is difficult, improving energy efficiency and reducing energy demand are widely considered as the most promising, fastest, cheapest and most safe means to mitigate climate change. Many opportunities appear to be cost-effective at current energy prices and can deliver additional benefits such as improved energy security, reduced fuel poverty and increased economic productivity (E.Shove, 2014). The main targets that are set to be accomplished through optimizing residential energy patterns and behavior are increasing energy efficiency, lowering emissions, lower energy demand, increasing people's awareness and mitigating climate change. Energy is a rather mysterious property that cannot be crafted or destroyed but only transfer from one system to another or be converted from one form to another. Energy in general is of outmost importance because nothing in the environment can function without the use of some kind of energy. Human societies rely upon different kinds of networks for distributing energy, water, food and other materials which are all in fact energy flows. The large increase in human population and wealth has led to a significant increase in energy demand. As mentioning above improving energy efficiency and energy demand through user behavior is a very efficient, cost-effective and immediate method for achieving these targets. The European Commission which can be considered as the prime mover regarding sustainability has put energy efficiency as the main and key objective. The EU has set binding targets of reducing energy consumption through improvements in energy efficiency by 2030 by at least 32.5 %. The energy efficiency directive places recommendations that these address the practical implementation of the energy savings obligation for the period 1 January 2021 to 31 December 2030, the revised metering and billing provisions for thermal energy and efficiency in heating and cooling (Council, 2018). How each member state interpreters can differ as far as the targets are accomplished. Here is where user behavior can have a significant impact on the national economy and future without the need for drastic and costly methods by the government. The only goal set for energy demand is to shut down existing coal-fired power plants and divert to natural gas fired and renewable energy systems. A specific goal for energy demand cannot realistically be set because of how multidimensional the energy consumer market is and it is a rather challenging and demanding task to set priorities regarding energy uses. Also technology and economy are uncontrollable and are factors of major significance that affect energy demand. Increased awareness on environmental sustainability in individuals on the level of householders is a never ending goal that can largely contribute to sustainable living. Sustainable living requires a change in behavior in the way household devices are used. In order to change their behavior, people first have to become aware of their energy consumption. The main goal is for the majority of people, through education, seminars and special promotion to raise their awareness regarding energy consumption and the environment as much as possible. Starting from very young ages to as old as the oldest energy consumer. Another important goal is the mitigation of climate change. However this is a very difficult target to set, because it is multidimensional and affected by many unpredictable parameters. Mitigating climate change is about reducing the release of greenhouse gas emissions that are warming up the planet (Valerie Masson-Delmotte). Limiting global warming to 1.5 ^{o}C depends on GHG emissions over the next decades but lower predicted GHG emissions in 2030 lead to a higher chance of keeping peak warming to 1.5 ^{o}C. Although there is no official statement, scientists believe that a target to be set for 2030 is a reduction of at least 0.5 ^{o}C. However such a target can prove rather difficult to accomplish because although there is a shift to more sustainable energy generation, the energy demand is still rising and the energy trends, demand as well as the future weather and climate are unpredictable. In order to ensure that there will be a mitigation of climate change, new policies are being devised that will aim to put a higher price on emissions therefore making them of outmost importance for governments and industries to improve on (Joeri Rogelj, 2018). One more goal that is vital for the mitigation of climate change is the reduction of GHG emissions. The effort sharing target is the EU's commitment of reducing all greenhouse gas emissions at least by 40 % from 1990 to 2030. This is the wider goal regarding all sectors that emit GHG. Heating and cooling in residential and commercial buildings delivered about half of the reductions in Effort Sharing emissions from 2005 to 2018. Measures addressing energy use for heating and cooling in the building sector helped deliver the largest contribution to overall reductions in Effort Sharing emissions between 2005 and 2018 (50 %). Such measures were in particular improvements in energy efficiency and the switch to less carbon intensive fuels for heating and cooling, including renewable energy sources. Improving energy efficiency and switching to cleaner heating and cooling fuels, including renewable energy sources, helped make these cuts, the EEA briefing states. Emission reductions in this sector are expected to continue (Agency). Heating and cooling activities of residential and commercial buildings are responsible for a quarter of greenhouse gas emissions in the Effort Sharing sectors, the second biggest source after transport. Fluctuations in weather conditions from one year to another (i.e. warmer or colder winters) are an important cause of annual variations in this sector's emissions. However, emissions over the period 2005-2018 show a clearly decreasing trend. This can be linked to several policy-driven factors, in particular the increasing energy efficiency of buildings and the switch to less carbon intensive fuels, including renewable energy sources for heating and cooling. The UK government has released emission data from 2017, which reveals that direct CO_2 emissions from homes in the UK have decreased by 18% since 1990. This is in a part thanks to UK households having a total of 182,300 heat pumps, and 976,197 solar panels, installed by the end of 2017. UK houses mainly have cavity walls and lofts practicable for insulation. The majority of these houses already had been insulated by 2017. However, the target for 2030 is to have all of these cavity walls and lofts in the UK insulated, so there is still some work left to do. Moreover, the Committee on Climate Change has set a target for solid walls too. So far, only 734,000 solid walls have been insulated in the UK, whereas the target for 2030 is set at two million insulations.



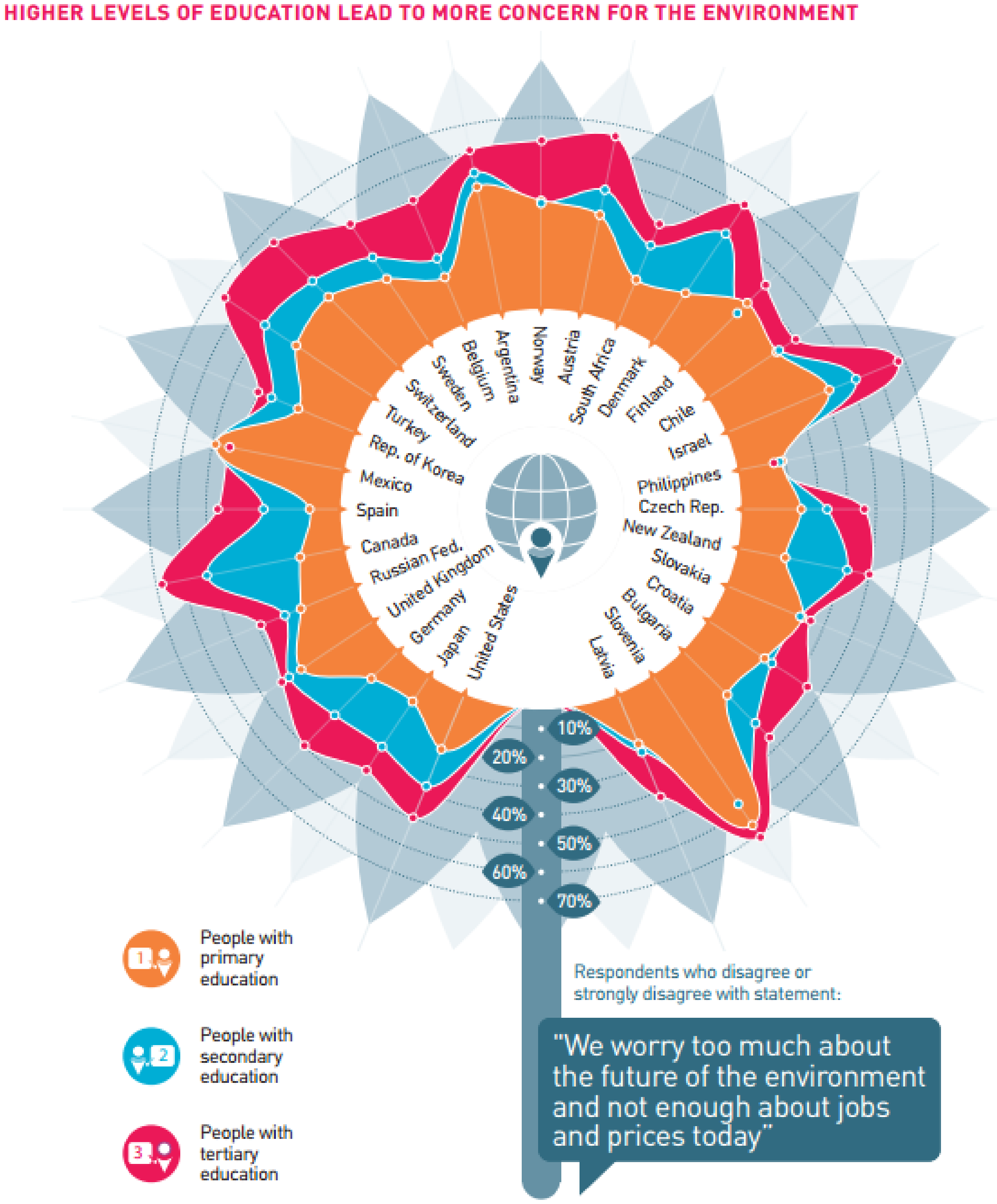
Being the second largest energy consumer in the UK, HOUSEHOLDS can, without a doubt, help reduce GHG emissions. The 2017/2018 progress shows that there are still opportunities to reach the target by 2030.

Picture 14: GHG reduction by 2030 for the United Kingdom (GreenMatch, 2019)

Chapter 3

Improvement methods – Decision making

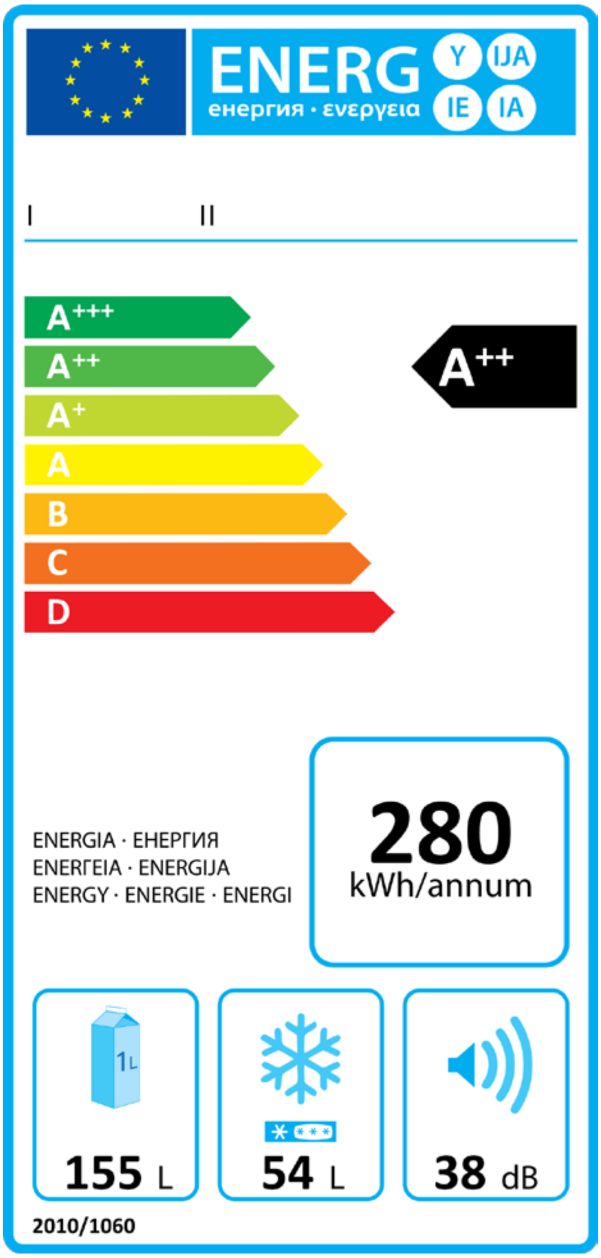
Setting goals and targets, as mentioned before, is proven to provide great results. But, in order to reach these goals and targets there have to be some areas that need improvement. This chapter focuses on possible improvement methods for residential energy use and performance. The main improvement methods are analyzed, regarding how the user reacts and consumes energy, but also how the energy consumed can be lowered and more become more efficient. Also, methods that assist energy production and use are mentioned. All these improvements can be adapted by the user with regard to his/hers needs, financial status and the final result they provide. Improvement methods are many and varied and in order to suit each user's needs and achieve the goals and targets that are set. During the last decades, one of the most concerning problems for our society is the efficient use of energy resources that draws more and more resources for its resolution (Barbu A.D., 2013). In the wider strategy of the EU in achieving a 20% reduction in emissions by 2020, there is a sector that has a significant impact, household energy consumption. In 2015, this sector alone consumed 33% of the total energy (Gynther L., 2015). The EU identified this issue and determined that with simple methods that encourage the change of user behavior, the energy consumption could drop around 1.8% annually. Such a method is through education. Classes that aim to educate children on how to conserve energy and use it more efficiently can significantly make a change in their behavior. By instructing people from a young age, energy saving is going to happen subconsciously. Seminars are also a great way to instruct and inform people of older ages about energy use and conservation. These methods are perhaps the most important because they raise people's awareness and their attitude towards the environment, which is possibly the most desired outcome.


HIGHER LEVELS OF EDUCATION LEAD TO MORE CONCERN FOR THE ENVIRONMENT

Source: National Centre for Social Research [2013], based on the 2010 International Social Survey Programme data.

Picture 15: Education levels throughout the world (Reports, 2015)

However while these methods are very good and effective they are not followed by everyone, therefore proper legislation must be introduced in order for every house to follow. The legislation must be very clear and must take into consideration many parameters such as the condition of the house, year of construction, energy classification, financial status of the owner, the location and its environmental footprint.

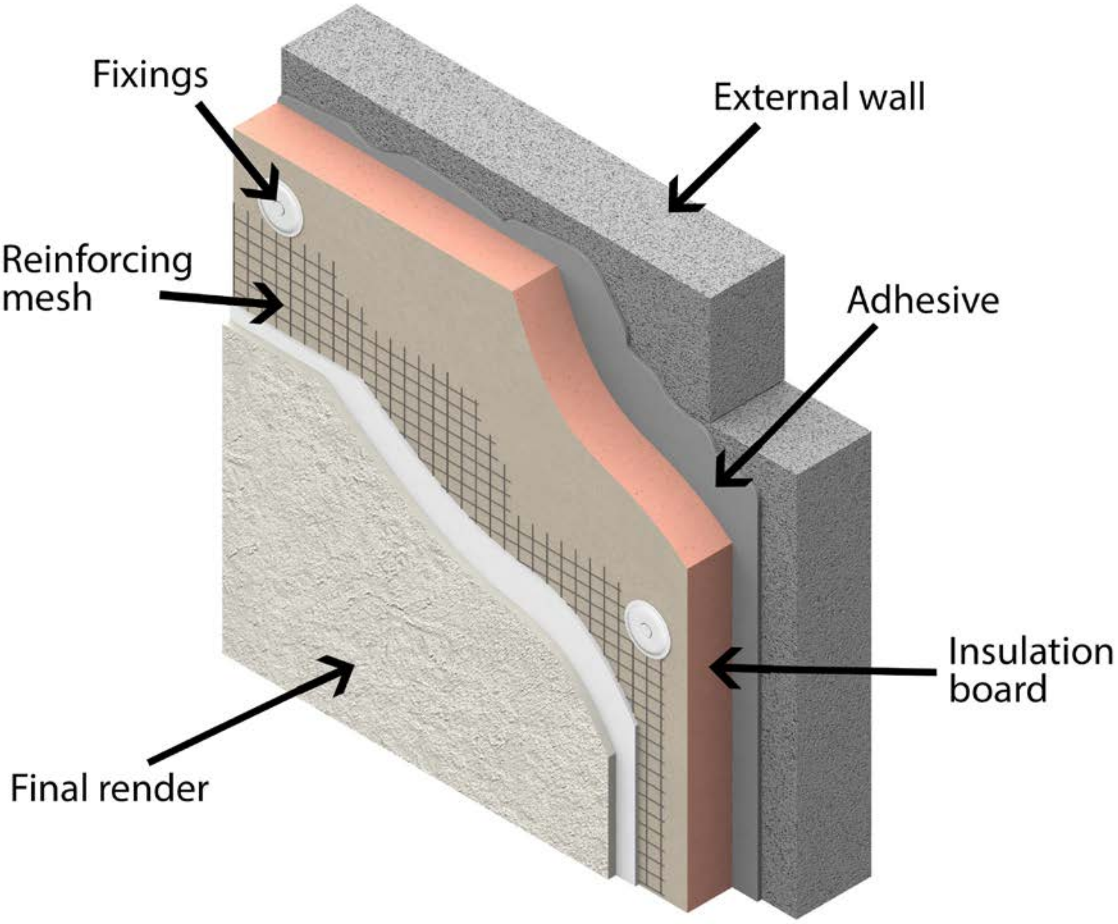


Picture 16: Energy classification indicator forced by EU legislation for every electrical appliance (AMDEA, 2011)

Another way that the government can assist is with a subsidy in order to raise the house's energy classification again taking into consideration the parameters mentioned above. This is a great way to improve the energy classification of houses and it is done in Greece with much success. While these methods assist the energy conservation by changing the user's behavior, there are many more direct methods to increase energy efficiency. First of all the use of renewable energy technologies with solar panels and/or wind turbines to assist or even fully cover the energy needs of a house. These kinds of systems produce energy with no emissions and a very small carbon footprint during their construction mostly.

Picture 17: Solar panels installed in the roof of houses in UK (Gallucci, 2019)

Another very important method is with proper insulation. Nowadays insulation is forced to be installed in houses by the legislation; however there are houses of much older date of construction that still lack. Insulation greatly increases energy efficiency as it minimizes thermal gains in summer, greatly lowers thermal losses in winter and lowers humidity levels as well resulting in much less energy needs for heating and cooling. It also negates the use of such systems for the more mild times of the year.



Picture 18: External wall typical insulation (Superstore, 2019)

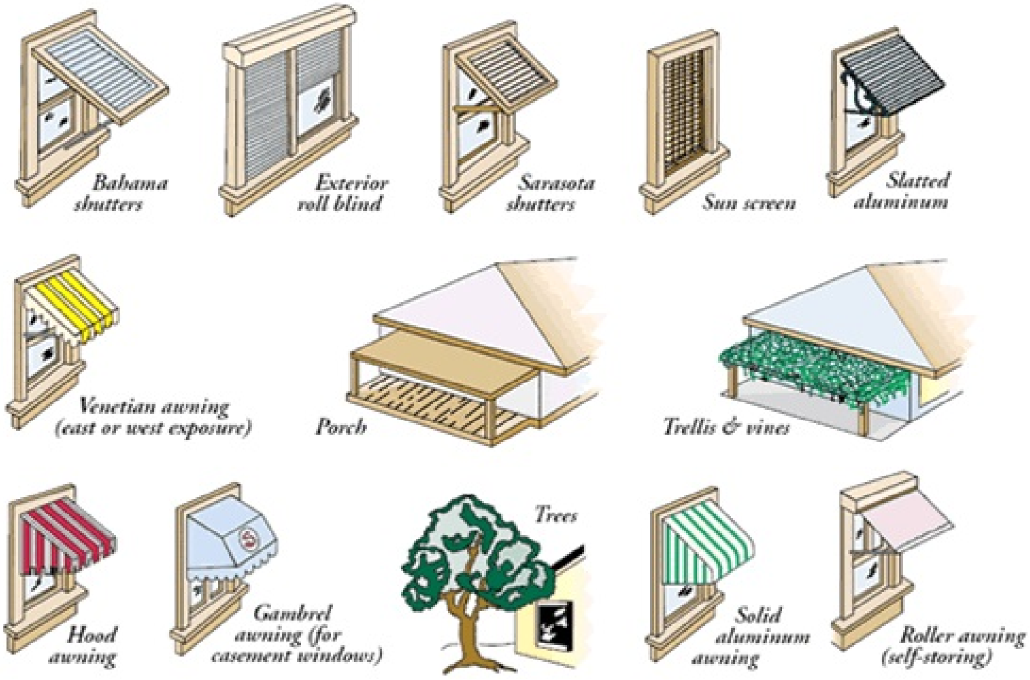
The replacement of common windows with double glazing is also another very important method. Double glazing windows consists of two or even more glass windows panes that are separated by air in most cases or some other insulating gas, in order to reduce heat transfer across a part of the building envelope (Jester, 2014).

Picture 19: Double glazing windows (Cinta, 1996)

Another very effective method is solar water heating. Solar water heating is very efficient, especially in areas with a lot of sunlight and substitutes the need for electric water heating which is demanding a lot of energy for operation. It is also an energy free way of producing heated water.

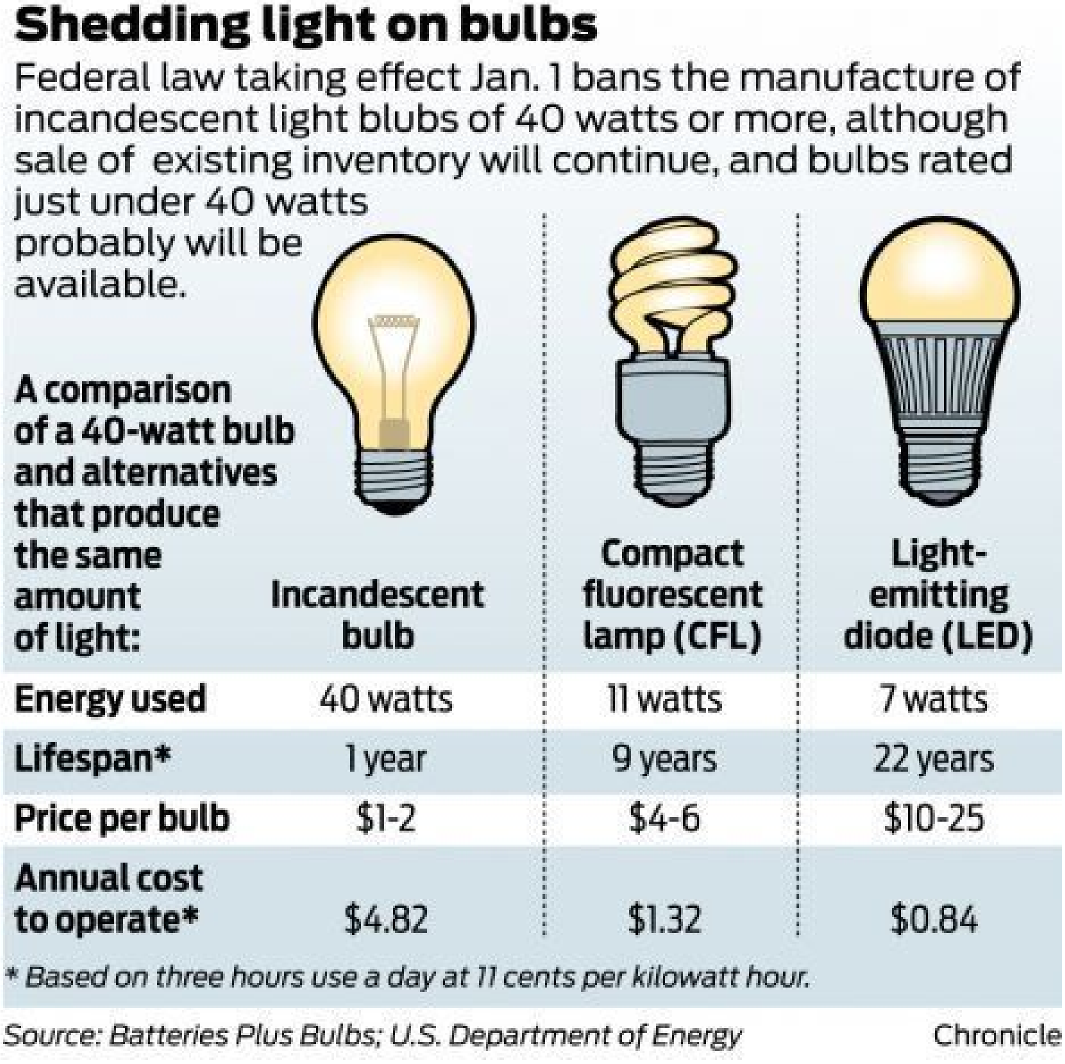
Picture 20: Solar water heating (West, 2020)

Shading is one more method to lower thermal gains in summer, by blocking the sunlight. There are many methods of shading, fixed shading like eaves, awnings, pergolas and louvres as well as adjustable shading like sliding screens, louvre screens, shutters, retractable awnings, adjustable external blinds or even season vegetation.



Picture 21: Different shading options ((FSEC), 2014)

Low-flow shower head is another cheap option that can reduce the amount of water used during showers. In a case of a four member family that uses on average 50 liters of hot water per day with a common shower head, the low-flow can decrease that by even 30%, leading from 200 liters per day to approximately 150 liters. Another method is the replacement of all common lamps in a house with LED lamps which have many benefits. They are much more energy efficient, they have a much longer life span, less environmental issues, have improved controllability, they are much smaller with small fixtures and more manageable.



Shedding light on bulbs

Federal law taking effect Jan. 1 bans the manufacture of incandescent light blubs of 40 watts or more, although sale of existing inventory will continue, and bulbs rated just under 40 watts probably will be available.

A comparison of a 40-watt bulb and alternatives that produce the same amount of light:	Incandescent bulb	Compact fluorescent lamp (CFL)	Light-emitting diode (LED)
Energy used	40 watts	11 watts	7 watts
Lifespan*	1 year	9 years	22 years
Price per bulb	$1-2	$4-6	$10-25
Annual cost to operate*	$4.82	$1.32	$0.84

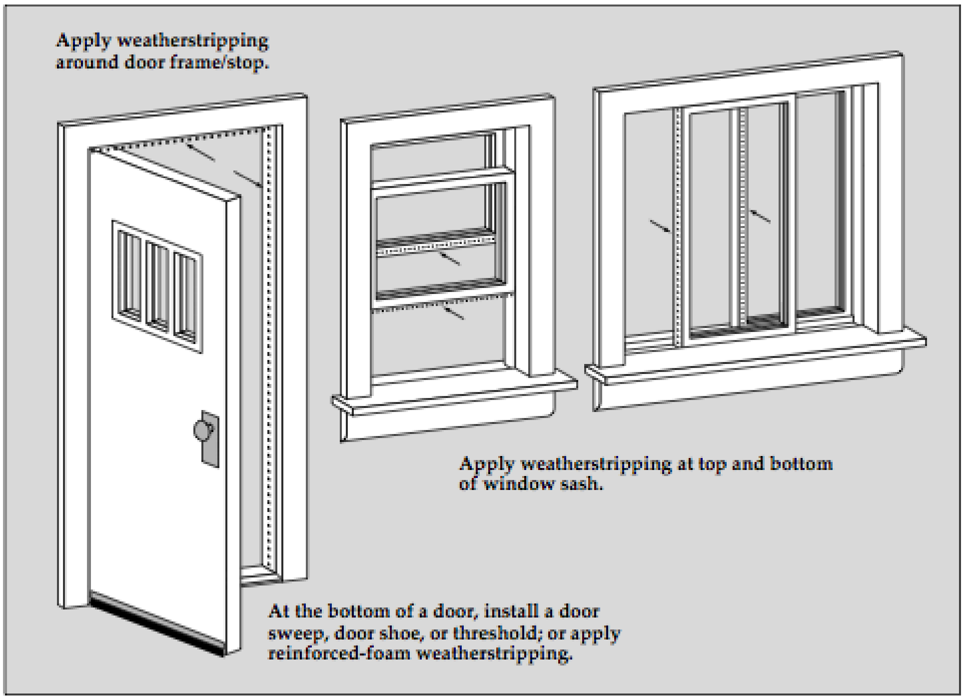
** Based on three hours use a day at 11 cents per kilowatt hour.*

Source: Batteries Plus Bulbs; U.S. Department of Energy Chronicle

Picture 22: Different types of light bulbs comparison

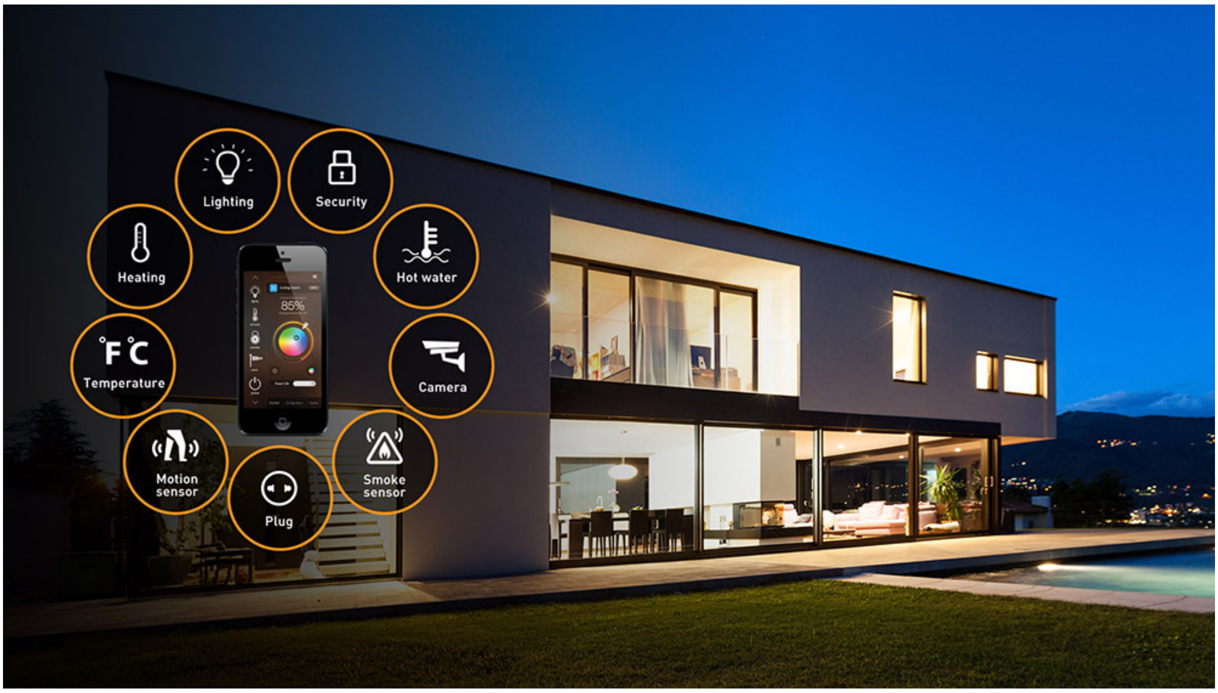
Energy saving ceiling fans is also a great way to conserve energy. While they do not cool a room, they create a wind chill effect that can make it seem cooler and also lower humidity levels which makes the room more comfortable without lowering the temperature. These operate with 1/30 of the power that a HVAC system draws.

Reducing the amount of air that leaks in and out of the house is a cost-effective way to cut heating and cooling costs, improve durability, increase comfort, and create a healthier indoor environment. Caulking and weather stripping are two simple and effective air-sealing techniques that offer quick returns on investment, often one year or less. Caulk is generally used for cracks and openings between stationary house components such as around door and window frames, and weather stripping is used to seal components that move, such as doors and operable windows.



Picture 23: Sealing and weather-stripping (Darling, 2007)

The replacement of home appliances with energy efficient models is another method for energy conservation, but requires initial investment that takes some time to pay back. Replacing common heating and cooling systems with modern energy efficient ones is also another method that can significantly assist the energy conservation and lower energy consumption as heating and cooling systems are energy demanding in general. Hot water circulation is another not very common but great method to conserve hot water and in turn energy. With this option, an additional pipe that is designated for hot water is installed in the house's plumbing. This system creates a loop from the water heater to the faucet and back again. The unused hot water is drawn back through this loop by the pump, so when the hot water is turned on, hot water comes quickly. Water is not left in the pipes to get cold and less water is. Simpler methods are, setting the computers and all capable electrical devices to sleep or hibernate mode, cleaning the air ducts and filters and air drying clothes and dishes to conserve energy. One more very modern way of improving energy efficiency and conserving energy is with smart home systems. Smart home is an expression that is used for houses that utilize technologies which enable proper scrutiny of residents while promoting autonomy (Jackie). These technologies are many, varied and can assist in many different ways. A programmable thermostat can offer flexibility and the power to control the climate of the house efficiently. It also offers the ability to program the set points to different temperature levels during set times throughout the week to follow the user's exact schedule. Automatic timers are used to turn on holiday or porch lights after the sun goes down or at bedtime. Motion sensors automatically turn the lights off or on depending on what they detect, and can cut lighting costs by as much as 50 %. Light dimmers offer the flexibility to preset brightness levels to match the user's need at every moment. Energy efficient light bulbs can save money and energy just by swapping old existing incandescent bulbs for compact fluorescent lights or LEDs, which use up to 70 % less energy and last 10 times longer. Real energy management though requires an energy monitoring system, which means knowing how much energy the user is using. If the amount and time of energy of a certain home are known, one can better respond to the usage and manage of the house energy costs. The modern smart homes technologies use the house's existing power lines to monitor energy usage in real time. The electricity monitoring system uses measuring devices that clamp onto the main conductors inside the breaker panel. These devices then send the data that are measured over the house power lines. These data are received then by a receiving unit that plugs into an outlet of the house. The system can take more data, inputs from the user such as occupancy-time schedule that ensures that the house operates according to occupancy levels. Zoning is another cost-effective way to save energy but giving data about areas with different occupancy patterns.



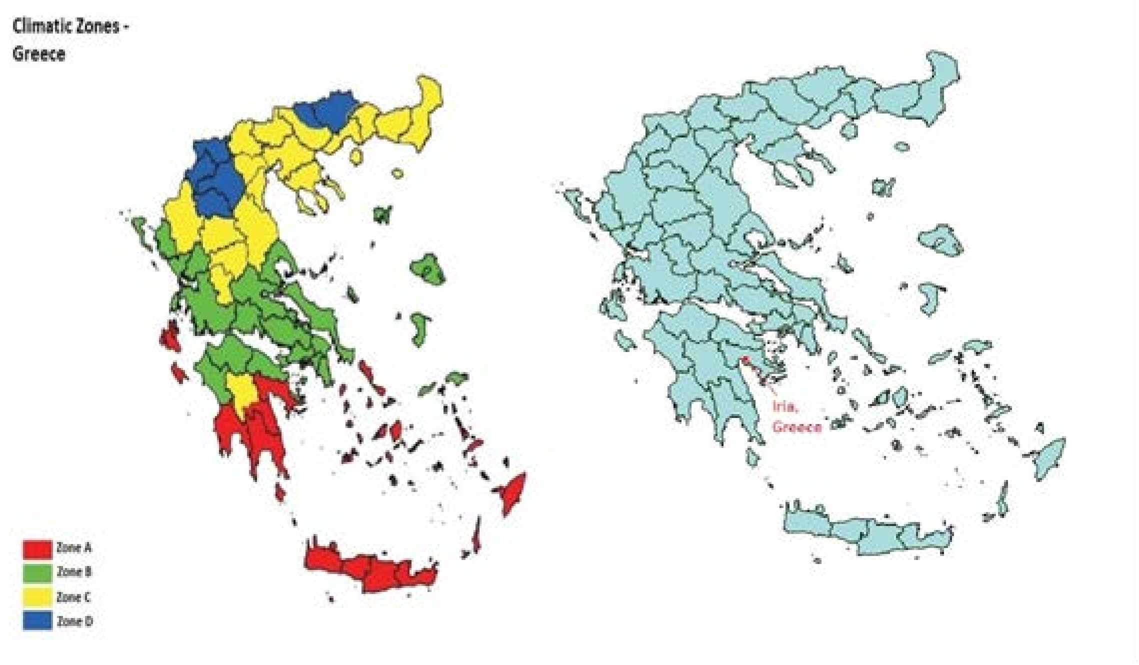
Picture 24: Smart home features (Zarifopoulos, 2016)

Chapter 4
Analysis of two buildings with different user behavior

Identifying the factors that can affect residential energy use assists in recognizing the potential energy problems in each household. The analysis of improvement methods can help each user's approach towards more efficient energy use, be closer to his/hers individual needs. However in order for the user to identify that there must be an improvement, an energy audit must first take place. An energy audit is basically an analysis of energy flows for energy conservation in a building. This chapter presents an analysis of a selected house followed by a comparison between two different families living in two identical houses. The comparison aims to show the difference that user behavior can have between two households.

4.1 House description

The house of the analysis is located in Iria village outside of the town Nafplio, in Greece. It is 157 kilometers from the city of Athens. The building is a maisonette, a two story flat basically with the front door on the lower ground and inside stairs that connect the upper floor to the lower. The building is only adjacent to one on the north-west side. The building shape is considered common, with its main openings and balconies facing south-east, in order to utilize maximum thermal gains in winter and also for the view. On the ground floor there is a balcony and inside the living room along with the kitchen, one bedroom and one bathroom. Moving on the upper floor there is another bathroom, three more bedrooms and two more balconies one facing south to south east and the other east to south east. The exterior construction consists of load-bearing cavity walls 0.3 m thick. All the exterior walls have insulation. The building was structured after the introduction of the thermal insulation regulation (TIR) in Greece. The building was constructed in 2007.



Picture 25: Climatic zones in Greece and location of village Iria

Location	Heating degree days for 18 °C	Cooling degree days for 25 °C	Design cooling DB	Conditions °C WB
Heraklion (zone A)	782	225	32.5	24
Athens (zone B)	1100	245	34.5	25
Thessaloniki (zone C)	1725	169	34.5	24

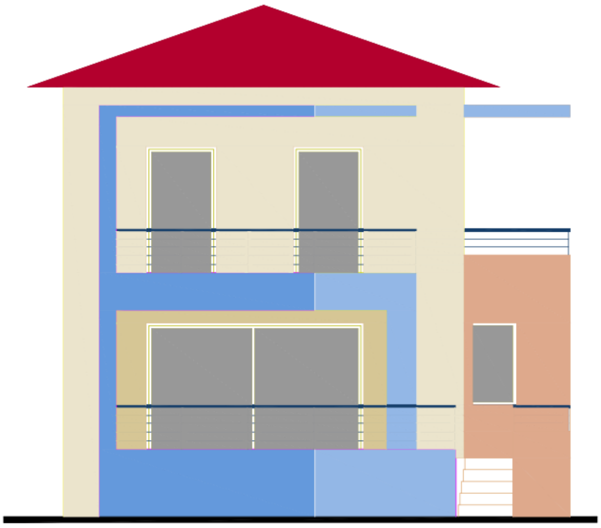
Table 5: Examples of climatic zones in Greece

Village Iria belongs in climatic zone A. It is considered as the hottest zone in Greece. Below follow some drawings and schematics of the house showing its layout.

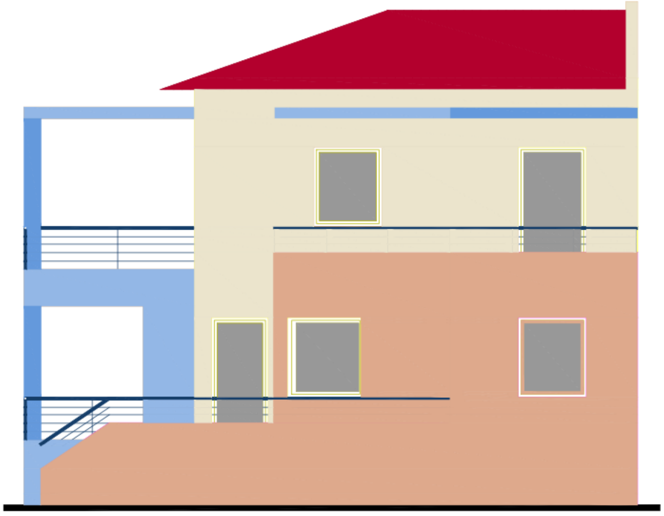
Picture 26: Building location

Picture 27: Building outside look

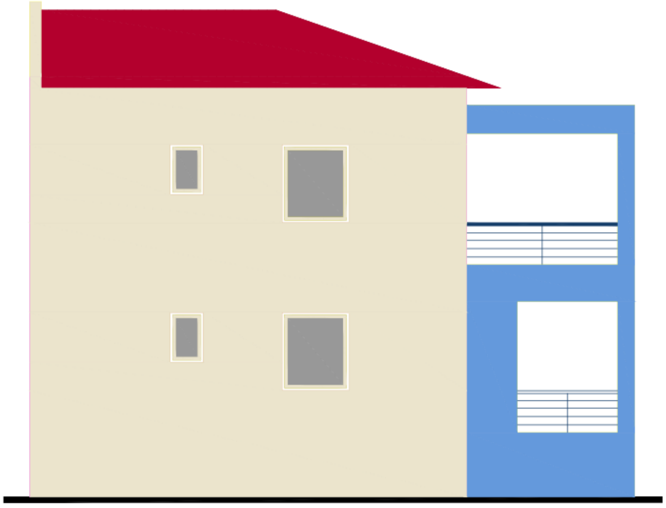
SOUTHWEST SIDE



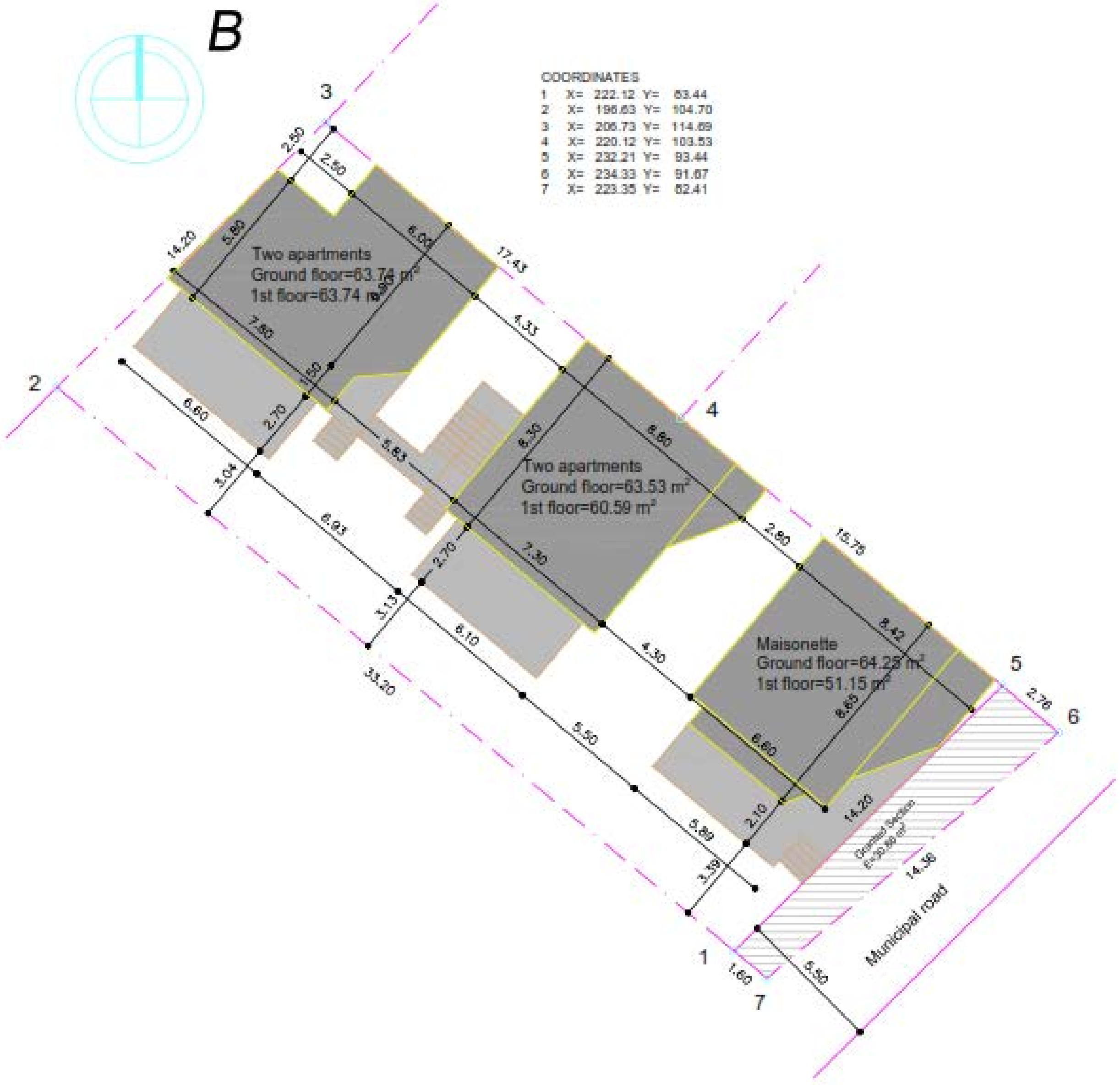
SOUTHEAST SIDE



NORTHWEST SIDE



Picture 28: House side's in 3D

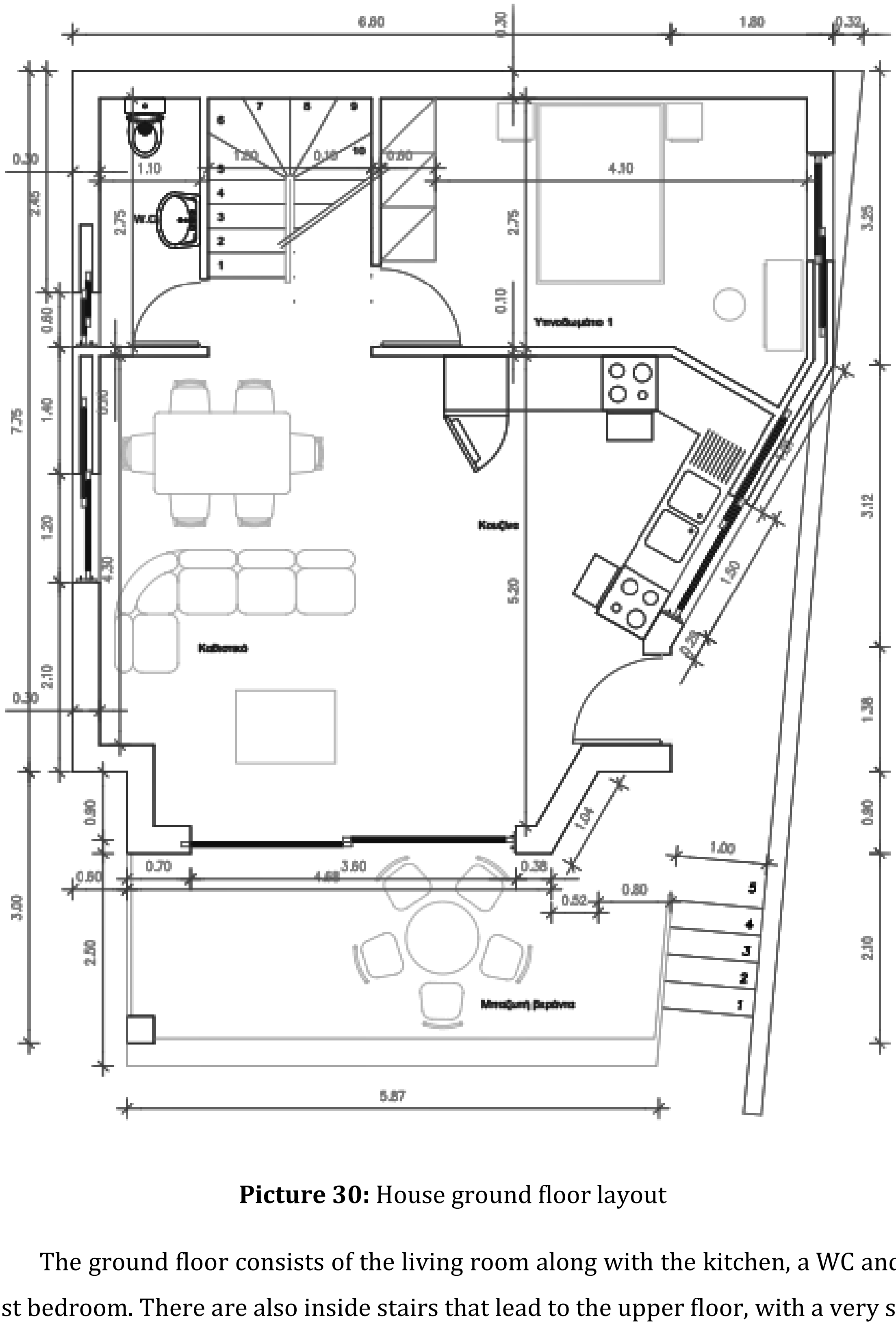


COORDINATES

1	X=	222.12	Y=	83.44
2	X=	196.63	Y=	104.70
3	X=	206.73	Y=	114.69
4	X=	220.12	Y=	103.53
5	X=	232.21	Y=	93.44
6	X=	234.33	Y=	91.67
7	X=	223.35	Y=	82.41

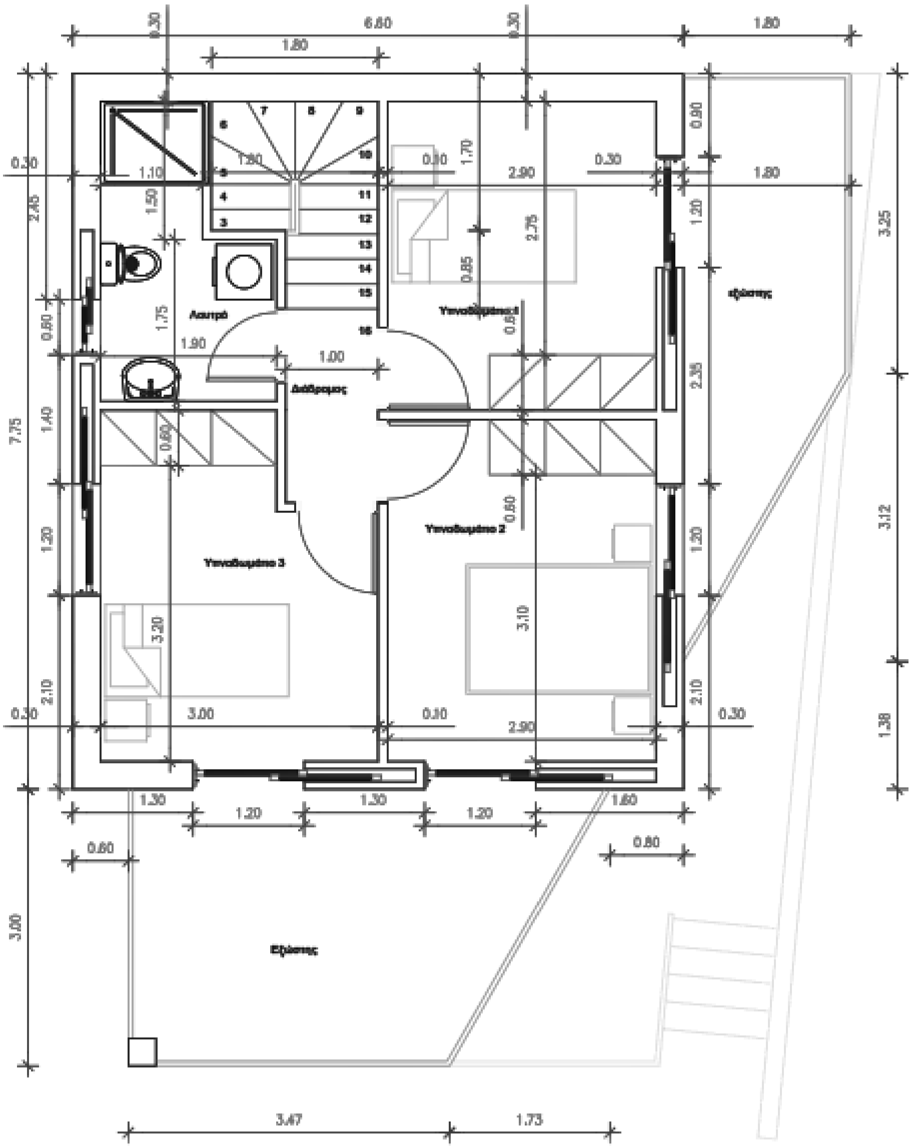
Picture 29: House plot coverage and north point

The building orientation was selected after considering many factors like maximizing thermal gains, minimizing thermal losses, for viewing purposes and also to match adjacent buildings and fully utilize the available plot area. The house has another building adjacent facing northwest. From all the other directions there are no buildings adjacent in the close vicinity. There are no adjacent buildings on south, southeast and southwest sides therefore there is no shading from adjacent buildings.



Picture 30: House ground floor layout

The ground floor consists of the living room along with the kitchen, a WC and the guest bedroom. There are also inside stairs that lead to the upper floor, with a very small storage room beneath. There is a large opening leading to the front balcony and other two on each side of the house.



Picture 31: House upper floor layout

On the upper floor there is a master bedroom with one double bed and two more bedrooms along with a WC. The two bedrooms facing southwest both have openings that lead to the balcony, while the northeast bedroom has an opening for the northeast balcony.

4.2 House analysis

In order to identify the house's energy flows and patterns, an energy audit must first take place. The energy audit/ analysis was carried out with the use of the KENAK software from 4M.

Town	Nafplio (Iria village)
Number of thermal zones	1
Number of floors (1 - 15)	2
Typical height (m)	3
Climatic zone	Zone A
House type - use	Maisonette - Residential
Type of construction	Concrete and filling elements from perforated bricks

Table 6: Building characteristics

ENERGY OUTPUT RANKING	
ENERGY CATEGORY	**CALCULATED CONSUMPTION [kWh/(m^2*year)]**
	◁ 87.80
Calculated annual consumption of primary energy of a reference building [kWh/m_^{2}]: 96.10	**B**
Calculated annual primary energy consumption [kWh/m_^{2}]: 87.80	
Calculated annual emissions CO_2 [KgCO_2/m^2] 29.00	
Annual primary energy consumption per year [kWh/m^2]	
Heating: 52.70	**Cooling: 35.20**

Table 7: Energy output ranking

Table 8: AREA/OCCUPANTS	
Total area (m²)	**115.40**
Useful Heated area (m²)	**115.40**
Useful Cooling area (m²)	**115.40**
Maximum available number of occupants	**7**
Number of occupants	**4**

Table 9: VOLUME	
Total volume (m³)	**346.20**
Useful heated volume (m³)	**346.20**
Useful cooling volume (m³)	**346.20**

Table 10: EXTERNAL WALLS

	Orientation	External Wall area (m²)	Type of construction	Total Thermal Coefficient, U (W/m²*K)
1	SW	5.170	T2	0.450
2	S	2.830	T2	0.450
3	SW	2.160	T2	0.450
4	SE	1.580	T2	0.450
5	S	7.470	T2	0.450
6	NE	6.970	T2	0.450
7	NE	22.680	T2	0.450
8	NW	18.810	T2	0.450
9	SW	1.620	T2	0.450
10	NW	2.430	T2	0.450
11	SW	12.300	T2	0.450

12	SE	16.360	T2	0.450
13	NE	17.820	T2	0.450
14	NW	18.810	T2	0.450

Table 11: MATERIALS OF EXTERNAL WALLS

Type of construction	Building materials	Thickness (m)	Thermal conductivity coefficient λ (W/mK)	Total Thermal Coefficient, U (W/m2*K)
T2	Asbestos cement mortar	0.020	0.870	0.450
	Perforated optoplinthodoxy	0.060	0.510	
	Expanded polystyrene	0.060	0.035	
	Perforated optoplinthodoxy	0.090	0.510	
	Asbestos cement mortar	0.020	0.870	

Table 12: BEARING STRUCTURE				
	Orientation	Bearing structure area	Type of construction	Total Thermal Coefficient U (W/m2*K) 14.2.4
1	SW	1.410	T7	0.432
2	S	0.315	T7	0.432
3	SW	0.240	T7	0.432
4	SE	0.420	T7	0.432
5	S	1.080	T7	0.432
6	SE	0.975	T7	0.432
7	NE	2.520	T7	0.432
8	NW	2.325	T7	0.432
9	SW	0.180	T7	0.432
10	NW	0.270	T7	0.432
11	SW	1.980	T7	0.432
12	SE	2.325	T7	0.432
13	NE	1.980	T7	0.432
14	NW	2.325	T7	0.432

Table 13: BEARING STRUCTURE MATERIALS

Type of construction	Building materials	Thickness (m)	Thermal conductivity coefficient λ (W/mK)	Total Thermal Coefficient, U (W/m2*K)
T7	Asbestos cement mortar	0.020	0.870	0.432
	Concrete reinforced with 2% steel	0.250	2.500	
	Expanded polystyrene	0.070	0.035	
	Asbestos cement mortar	0.020	0.870	

Table 14: ROOF

	Orientation	Angle	Area (m^2)	Type of construction	Total Thermal Coefficient, U (W/m2*K)
1	-	-	51.15	O1	0.397

Table 15: ROOF MATERIALS				
Type of construction	Building materials	Thickness (m)	Thermal conductivity coefficient λ (W/mK)	Total Thermal Coefficient, U (W/m2*K)
O1	Asbestos cement mortar	0.020	0.870	0.397
	Concrete reinforced with 2% steel	0.200	2.500	
	Concrete, lightweight concrete	0.050	0.200	
	Expanded polystyrene	0.070	0.035	
	Asbestos cement mortar	0.020	0.870	

Table 16: FLOOR					
	Area (m^2)	Type of construction	Type of floor	Type of ground	Total Thermal Coefficient, U (W/m2*K)
1	64.250	D2			0.369

Table 17: FLOOR MATERIALS				
Type of construction	Building materials	Thickness (m)	Thermal conductivity coefficient λ (W/mK)	Total Thermal Coefficient, U (W/m2*K)
D2	Ceramic floor tiles	0.005	1.840	0.369
	Cement mortar	0.020	0.870	
	Concrete, lightweight concrete	0.050	0.200	
	Concrete reinforced with 2% steel	0.200	2.500	
	Expanded polystyrene	0.070	0.035	
	Asbestos cement mortar	0.015	0.870	

Table 18: OPENINGS				
	Orientation	Opening area	Type of opening	Total Thermal Coefficient, U (W/m2*K)
1	SW	7.524	A1	2.2
2	SE	2.200	A4	2.2
3	S	2.250	A5	2.2
4	SE	1.800	A6	2.2
5	NW	1.800	A2	2.2
6	NW	0.318	A3	2.2
7	NΔ	2.760	A7	2.2
8	NΔ	2.760	A7	2.2
9	NA	1.800	A6	2.2
10	NA	2.760	A7	2.2
11	BΔ	1.800	A2	2.2
12	BΔ	0.318	A3	2.2

Table 19: THERMAL BRIDGES			
	Building material type	Thermal bridge type	Length (m)
1	A1 - T2	AK - 5	3.60
2	A1 - T2	AK - 5	3.60
3	A1 - T2	L - 5	2.09
4	A1 - T2	L - 5	2.09
5	T2 - O1	EDP - 10 (50%)	4.68
6	T2 - Δ1	EDP - 10 (50%)	4.68
7	T2 - O1	EDP - 10 (50%)	1.04
8	T2 - Δ1	EDP - 10 (50%)	1.04

9	T2 - O1	EDP - 10 (50%)	0.80
10	T2 - D1	EDP - 10 (50%)	0.80
11	A7 - T2	AK - 5	1.00
12	A7 - T2	L - 5	2.20
13	A7 - T2	L - 5	2.20
14	T2 - O1	EDP - 10 (50%)	1.38
15	T2 - D1	EDP - 10 (50%)	1.38
16	A1 - T2	AK - 5	1.50
17	A1 - T2	AK - 5	1.50
18	A1 - T2	L - 5	1.50
19	A1 - T2	L - 5	1.50
20	T2 - O1	EDP - 10 (50%)	3.60
21	T2 - D1	EDP - 10 (50%)	3.60
22	A1 - T2	AK - 5	1.20
23	A1 - T2	AK - 5	1.20
24	A1 - T2	L - 5	1.50
25	A1 - T2	L - 5	1.50
26	T2 - O1	EDP - 10 (50%)	3.25
27	T2 - D1	EDP - 10 (50%)	3.25
28	T2 - O1	EDP - 10 (50%)	8.40
29	T2 - D1	EDP - 10 (50%)	8.40
30	A1 - T2	AK - 5	1.20
31	A1 - T2	AK - 5	1.20
32	A1 - T2	L - 5	1.50
33	A1 - T2	L - 5	1.50
34	A1 - T2	AK - 5	0.60
35	A1 - T2	AK - 5	0.60

36	A1 - T2	L - 5	0.53
37	A1 - T2	L - 5	0.53
38	T2 - O1	EDP - 10 (50%)	7.75
39	T2 - D1	EDP - 10 (50%)	7.75
40	T2 - O1	EDP - 10 (50%)	0.60
41	T2 - D1	EDP - 10 (50%)	0.60
42	T2 - O1	EDP - 10 (50%)	0.90
43	T2 - D1	EDP - 10 (50%)	0.90
44	A1 - T2	AK - 5	1.20
45	A1 - T2	AK - 5	1.20
46	A1 - T2	L - 5	2.30
47	A1 - T2	L - 5	2.30
48	A1 - T2	AK - 5	1.20
49	A1 - T2	AK - 5	1.20
50	A1 - T2	L - 5	2.30
51	A1 - T2	L - 5	2.30
52	T2 - O1	EDP - 10 (50%)	6.60
53	T2 - D1	EDP - 10 (50%)	6.60
54	A1 - T2	AK - 5	1.20
55	A1 - T2	AK - 5	1.20
56	A1 - T2	L - 5	1.50
57	A1 - T2	L - 5	1.50
58	A1 - T2	AK - 5	1.20
59	A1 - T2	AK - 5	1.20
60	A1 - T2	L - 5	2.30
61	A1 - T2	L - 5	2.30
62	T2 - O1	EDP - 10 (50%)	7.75

63	T2 - D1	EDP - 10 (50%)	7.75
64	T2 - O1	EDP - 10 (50%)	6.60
65	T2 - D1	EDP - 10 (50%)	6.60
66	A1 - T2	AK - 5	1.20
67	A1 - T2	AK - 5	1.20
68	A1 - T2	L - 5	1.50
69	A1 - T2	L - 5	1.50
70	A1 - T2	AK - 5	0.60
71	A1 - T2	AK - 5	0.60
72	A1 - T2	Λ - 5	0.53
73	A1 - T2	Λ - 5	0.53
74	T2 - O1	EDP - 10 (50%)	7.75
75	T2 - D1	EDP - 10 (50%)	7.75

BUILDING SPECIFIC CHARACTERISTICS

1. Floor Area Fd = 51.150 m^2
2. External wall surface in contact with outside air Fw = 155.355 m^2
3. Floor area in contact with outside air Fdl = 0.000 m^2
4. Floor surface area in contact with the ground or with closed non-heated spaces Fg = 64.250 m^2
5. External wall surface area in contact with the ground or with closed Non-heated spaces Fwe = 0.000 m^2
6. Openings surface area Ff = 28.090 m^2
7. Glass façade surface area Fgf = 0.000 m^2
8. Building volume V = 346.200 m3
9. Ratio A/V = 0.863 1/m

TOTAL BUILDING THERMAL COEFFICIENT U = 0.695 W/m^2K

Table 20: MAXIMUM ACCEPTABLE VALUE OF HEAT TRANSFER COEFFICIENT Um = 0.882 W/m²K

A/V m⁻¹	Um (W/m²K)			
	Zone A	Zone B	Zone C	Zone D
<=0.2	1.26	1.14	1.05	0.96
0.3	1.20	1.09	1.00	0.92
0.4	1.15	1.03	0.95	0.87
0.5	1.09	0.98	0.90	0.83
0.6	1.03	0.93	0.86	0.78
0.7	0.98	0.88	0.81	0.73
0.8	0.92	0.83	0.76	0.69
0.9	0.86	0.78	0.71	0.64
>=1.0	0.81	0.73	0.66	0.60

Table 21: CALCULATION OF MIDDLE VALUE HEAT TRANSFER COEFFICIENT U

ZONE 1

Surface type	Orientation	Adjacent	Surface Area F	Factor U	b	bxUxF
T2	SW	EP	5.170	0.450	1.000	2.326
A1	SW	EP	7.524	2.200	1.000	16.553
T7	SW	EP	1.410	2.200	1.000	0.609
T2	S	EP	2.830	0.432	1.000	1.273
T7	S	EP	0.315	0.450	1.000	0.136
T2	SW	EP	2.160	2.200	1.000	0.972
T7	SW	EP	0.240	2.200	1.000	0.104
T2	SE	EP	1.580	0.432	1.000	0.711
A4	SE	EP	2.200	0.450	1.000	4.840
T7	SE	EP	0.420	0.432	1.000	0.181
T2	S	EP	7.470	0.450	1.000	3.361
A5	S	EP	2.250	2.200	1.000	4.950
T7	S	EP	1.080	2.200	1.000	0.467
T2	SE	EP	6.970	0.432	1.000	3.136
A6	SE	EP	1.800	0.397	1.000	3.960
T7	SE	EP	0.975		1.000	0.421
T2	NE	EP	22.680		1.000	10.206
T7	NE	EP	2.520		1.000	1.089
T2	NW	EP	18.810		1.000	8.464
A2	NW	EP	1.800		1.000	3.960
A3	NW	EP	0.318		1.000	0.700
T7	NW	EP	2.325		1.000	1.004

T2	SW	EP	1.620		1.000	0.729
T7	SW	EP	0.180		1.000	0.078
T2	NW	EP	2.430		1.000	1.093
T7	NW	EP	0.270		1.000	0.117
D2			64.250		0.500	11.854
T2	SW	EP	12.300	0.450	1.000	5.535
A7	SW	EP	2.760	2.200	1.000	6.072
A7	SW	EP	2.760	2.200	1.000	6.072
T7	SW	EP	1.980	0.432	1.000	0.855
T2	SE	EP	16.360	0.450	1.000	7.362
A6	SE	EP	1.800	2.200	1.000	3.960
A7	SE	EP	2.760	2.200	1.000	6.072
T7	SE	EP	2.325	0.432	1.000	1.004
T2	NE	EP	17.820	0.450	1.000	8.019
T7	NE	EP	1.980	0.432	1.000	0.855
T2	NW	EP	18.810	0.450	1.000	8.464
A2	NW	EP	1.800	2.200	1.000	3.960
A3	NW	EP	0.318	2.200	1.000	0.700
T7	NW	EP	2.325	0.432	1.000	1.004
O1		EP	51.150	0.397	1.000	20.307
TOTAL			298.845			163.538

Table 22: THERMAL BRIDGES

Suface area 1	Surface area 2	Description	Length	Ψ	b	bxlxΨ
A1	T2	AK - 5	3.60	0.550	1	1.980
A1	T2	AK - 5	3.60	0.550	1	1.980
A1	T2	L - 5	2.09	0.000	1	0.000
A1	T2	L - 5	2.09	0.000	1	0.000
T2	O1	EDP - 10 (50%)	4.68	0.225	1	1.053
T2	D1	EDP - 10 (50%)	4.68	0.225	1	1.053
T2	O1	EDP - 10 (50%)	1.04	0.225	1	0.234
T2	D1	EDP - 10 (50%)	1.04	0.225	1	0.234
T2	O1	EDP - 10 (50%)	0.80	0.225	1	0.180
T2	D1	EDP - 10 (50%)	0.80	0.225	1	0.180
A7	T2	AK - 5	1.00	0.550	1	0.550
A7	T2	L - 5	2.20	0.000	1	0.000
A7	T2	L - 5	2.20	0.000	1	0.000
T2	O1	EDP - 10 (50%)	1.38	0.225	1	0.310
T2	D1	EDP - 10 (50%)	1.38	0.225	1	0.310
A1	T2	AK - 5	1.50	0.550	1	0.825
A1	T2	AK - 5	1.50	0.550	1	0.825
A1	T2	L - 5	1.50	0.000	1	0.000

A1	T2	L - 5	1.50	0.000	1	0.000
T2	O1	EDP - 10 (50%)	3.60	0.225	1	0.810
T2	D1	EDP - 10 (50%)	3.60	0.225	1	0.810
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	L - 5	1.50	0.000	1	0.000
A1	T2	L - 5	1.50	0.000	1	0.000
T2	O1	EDP - 10 (50%)	3.25	0.225	1	0.731
T2	D1	EDP - 10 (50%)	3.25	0.225	1	0.731
T2	O1	EDP - 10 (50%)	8.40	0.225	1	1.890
T2	D1	EDP - 10 (50%)	8.40	0.225	1	1.890
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	L - 5	1.50	0.000	1	0.000
A1	T2	L - 5	1.50	0.000	1	0.000
A1	T2	AK - 5	0.60	0.550	1	0.330
A1	T2	AK - 5	0.60	0.550	1	0.330
A1	T2	L - 5	0.53	0.000	1	0.000
A1	T2	L - 5	0.53	0.000	1	0.000
T2	O1	EDP - 10 (50%)	7.75	0.225	1	1.744
T2	D1	EDP - 10 (50%)	7.75	0.225	1	1.744
T2	O1	EDP - 10	0.60	0.225	1	0.135

		(50%)				
T2	D1	EDP - 10 (50%)	0.60	0.225	1	0.135
T2	O1	EDP - 10 (50%)	0.90	0.225	1	0.202
T2	D1	EDP - 10 (50%)	0.90	0.225	1	0.202
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	L - 5	2.30	0.000	1	0.000
A1	T2	L - 5	2.30	0.000	1	0.000
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	L - 5	2.30	0.000	1	0.000
A1	T2	L - 5	2.30	0.000	1	0.000
T2	O1	EDP - 10 (50%)	6.60	0.225	1	1.485
T2	D1	EDP - 10 (50%)	6.60	0.225	1	1.485
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	L - 5	1.50	0.000	1	0.000
A1	T2	L - 5	1.50	0.000	1	0.000
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	L - 5	2.30	0.000	1	0.000
A1	T2	L - 5	2.30	0.000	1	0.000
T2	O1	EDP - 10 (50%)	7.75	0.225	1	1.744

T2	D1	EDP - 10 (50%)	7.75	0.225	1	1.744
T2	O1	EDP - 10 (50%)	6.60	0.225	1	1.485
T2	D1	EDP - 10 (50%)	6.60	0.225	1	1.485
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	AK - 5	1.20	0.550	1	0.660
A1	T2	L - 5	1.50	0.000	1	0.000
A1	T2	L - 5	1.50	0.000	1	0.000
A1	T2	AK - 5	0.60	0.550	1	0.330
A1	T2	AK - 5	0.60	0.550	1	0.330
A1	T2	L - 5	0.53	0.000	1	0.000
A1	T2	L - 5	0.53	0.000	1	0.000
T2	O1	EDP - 10 (50%)	7.75	0.225	1	1.744
T2	D1	EDP - 10 (50%)	7.75	0.225	1	1.744
TOTAL						44.215

CALCULATION OF HEAT TRANSFER COEFFICIENT OF OPAQUE STRUCTURAL ELEMENTS

Calculation of thermal insulation adequacy of a building

CALCULATION OF HEAT TRANSFER COEFFICIENT OF STRUCTURAL ELEMENT

Table 23: STRUCTURAL ELEMENT: External wall facing the outside environment

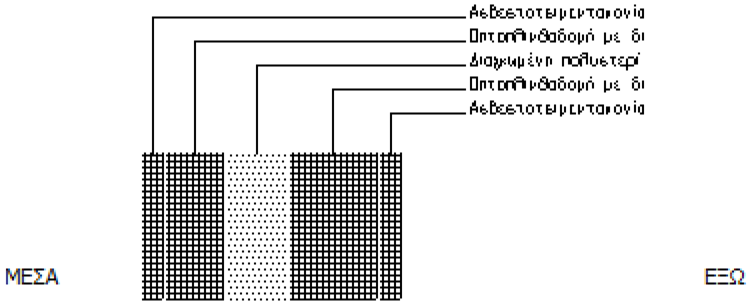
	ZONE A
Cross section 	

Table 24: CALCULATION OF RESISTANCE OF HEAT LOSS ($R_Λ$)

	Layers of structural element	**Density ρ**	**Thickness of layer d**	**Thermal conductivity coefficient λ**	**Ratio d/λ**
		kg/m³	**m**	**W/(mK)**	**(m²K)/W**
1	Asbestos cement mortar	1800	0.020	0.870	0.023
2	Perforated optoplinthodoxy	1500	0.060	0.510	0.118
3	Expanded polystyrene	12-30	0.060	0.035	1.714
4	Perforated optoplinthodoxy	1500	0.090	0.510	0.176
5	Asbestos cement mortar	1800	0.020	0.870	0.023
			Σd=0.250		**$R_Λ$=2.054**

Table 25: CALCULATION OF HEAT TRANSFER COEFFICIENT (U)

THERMAL TRANSFER RESISTANCE			**R_i (inner)**	**R_a (outter)**
Exterior walls and windows (towards outside air)			0.130	0.040
Wall bordering an unheated space			0.130	0.130
Wall in contact with the ground			0.130	0.000
Roofs, roofs (upcoming heat flow)			0.100	0.040
Ceiling bordered by unheated space			0.100	0.100
Floor over open passage (pilotis)			0.170	0.040
Floor above unheated space (descending flow)			0.170	0.170
Floor in contact with the ground			0.170	0.000
1	Thermal transition resistance (internally)	**R_i**	**$(m^2K)/W$**	0.13
2	Heat transfer resistance	**R**	**$(m^2K)/W$**	2.054
3	Thermal resistance (external)	**R_a**	**$(m^2K)/W$**	0.04
4	Heat transfer resistance	**R_{tot}**	**$(m^2K)/W$**	2.224
Heat Transfer Coefficient		**U**	**$W/(m^2K)$**	0.450
Maximum acceptable Heat Transfer Coefficient value		**U_{max}**	**$W/(m^2K)$**	0.6

It must $U <= U_{max}$

And it DOES

Calculation of Building Insulation Sufficiency

Calculation of structural element heat transfer coefficient

Table 26: STRUCTURAL ELEMENT: Column facing outside environment

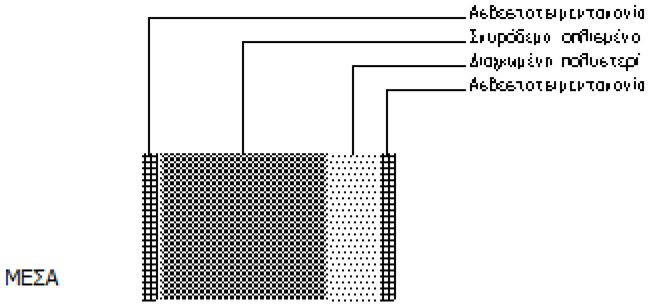
	ZONE A
Cross section 	

Table 27: CALCULATION OF RESISTANCE OF HEAT LOSS (R_Λ)

α/α	**Layers of structural element**	**Density ρ**	**Thickness of layer d**	**Thermal conductivity coefficient λ**	**Ratio d/λ**
		kg/m³	**m**	**W/(mK)**	**(m²K)/W**
1	Asbestos cement mortar	1800	0.020	0.870	0.023
2	Concrete reinforced with 2% steel	2400	0.250	2.500	0.100
3	Expanded polystyrene	12-30	0.070	0.035	2.000
4	Asbestos cement mortar	1800	0.020	0.870	0.023
			Total d=0.360		**R_Λ=2.146**

Table 28: CALCULATION OF HEAT TRANSFER COEFFICIENT (U)

THERMAL TRANSFER RESISTANCE			**R_i (internal)**	**R_a (external)**
Exterior walls and windows (towards outside air)			0.130	0.040
Wall bordering an unheated space			0.130	0.130
Wall in contact with the ground			0.130	0.000
Roofs, roofs (upcoming heat flow)			0.100	0.040
Ceiling bordered by unheated space			0.100	0.100
Floor over open passage (pilotis)			0.170	0.040
Floor above unheated space (descending flow)			0.170	0.170
Floor in contact with the ground			0.170	0.000
1	Thermal transition resistance (internally)	**R_i**	**$(m^2K)/W$**	0.13
2	Heat transfer resistance	**R**	**$(m^2K)/W$**	2.146
3	Thermal resistance (external)	**R_a**	**$(m^2K)/W$**	0.04
4	Heat transfer resistance	**R_{tot}**	**$(m^2K)/W$**	2.316
Heat Transfer Coefficient		**U**	**$W/(m^2K)$**	0.432
Maximum acceptable Heat Transfer Coefficient value		**U_{max}**	**$W/(m^2K)$**	0.6

It must $U<=U_{max}$

And it DOES

Calculation of Building Insulation Sufficiency

Calculation of structural element heat transfer coefficient

Table 29: STRUCTURAL ELEMENT: Ceiling facing the outside environmnent

ZONE A

Cross-section

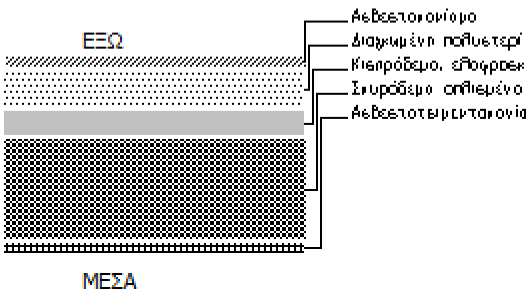


Table 30: CALCULATION OF RESISTANCE OF HEAT LOSS (R_Λ)

α/α	**Layers of structural element**	**Density ρ**	**Thickness of layer d**	**Thermal conductivity coefficient λ**	**Ratio d/λ**
		kg/m^3	**m**	**W/(mK)**	**$(m^2K)/W$**
1	Asbestos cement mortar	1800	0.020	0.870	0.023
2	Concrete reinforced with 2% steel	2400	0.200	2.500	0.080
3	Concrete, lightweight concrete	500	0.050	0.200	0.250
4	Expanded polystyrene	12-30	0.070	0.035	2.000
5	Asbestos cement mortar	1900	0.020	0.870	0.023
			Σd=0.360		**R_Λ=2.376**

Table 31: CALCULATION OF HEAT TRANSFER COEFFICIENT (U)

<table>
<tr><th colspan="3">THERMAL TRANSFER RESISTANCE</th><th>R_i (internal)</th><th>R_a (external)</th></tr>
<tr><td colspan="3">Exterior walls and windows (towards outside air)</td><td>0.130</td><td>0.040</td></tr>
<tr><td colspan="3">Wall bordering an unheated space</td><td>0.130</td><td>0.130</td></tr>
<tr><td colspan="3">Wall in contact with the ground</td><td>0.130</td><td>0.000</td></tr>
<tr><td colspan="3">Roofs, roofs (upcoming heat flow)</td><td>0.100</td><td>0.040</td></tr>
<tr><td colspan="3">Ceiling bordered by unheated space</td><td>0.100</td><td>0.100</td></tr>
<tr><td colspan="3">Floor over open passage (pilotis)</td><td>0.170</td><td>0.040</td></tr>
<tr><td colspan="3">Floor above unheated space (descending flow)</td><td>0.170</td><td>0.170</td></tr>
<tr><td colspan="3">Floor in contact with the ground</td><td>0.170</td><td>0.000</td></tr>
<tr><td>1</td><td>Thermal transition resistance (internally)</td><td>R_i</td><td>$(m^2K)/W$</td><td>0.100</td></tr>
<tr><td>2</td><td>Heat transfer resistance</td><td>R</td><td>$(m^2K)/W$</td><td>2.376</td></tr>
<tr><td>3</td><td>Thermal resistance (external)</td><td>R_a</td><td>$(m^2K)/W$</td><td>0.04</td></tr>
<tr><td>4</td><td>Heat transfer resistance</td><td>R_{tot}</td><td>$(m^2K)/W$</td><td>2.516</td></tr>
<tr><td colspan="2">Heat Transfer Coefficient</td><td>U</td><td>$W/(m^2K)$</td><td>0.397</td></tr>
<tr><td colspan="2">Maximum acceptable Heat Transfer Coefficient value</td><td>U_{max}</td><td>$W/(m^2K)$</td><td>0.5</td></tr>
</table>

It must $U<=U_{max}$

<u>And it DOES</u>

Calculation of Building Insulation Sufficiency

Calculation

Of structural element heat transfer coefficient

Table 32: STRUCTURAL ELEMENT: Floor facing the outside environmnent

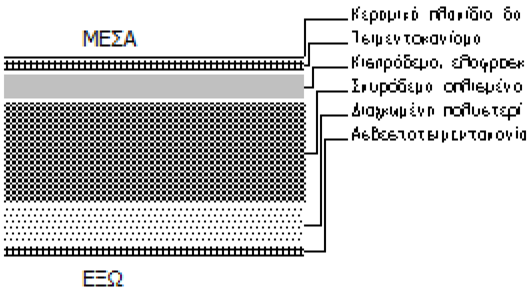
	ZONE A
Cross-section 	

Table 33: CALCULATION OF RESISTANCE OF HEAT LOSS ($R_Λ$)

α/α	Layers of structural element	Density ρ	Thickness of layer d	Thermal conductivity coefficient λ	Ratio d/λ
		kg/m³	m	W/(mK)	(m²K)/W
1	Ceramic floor tiles	2000	0.005	1.840	0.003
2	Asbestos cement mortar	1800	0.020	0.870	0.023
3	Concrete, lightweight concrete	500	0.050	0.200	0.250
4	Concrete reinforced with 2% steel	2400	0.200	2.500	0.080
5	Expanded polystyrene	12-30	0.070	0.035	2.000
6	Asbestos cement mortar	1800	0.015	0.870	0.017
			Σd=0.360		**$R_Λ$=2.373**

Table 34: CALCULATION OF HEAT TRANSFER COEFFICIENT (U)

<table>
<tr><th colspan="3">THERMAL TRANSFER RESISTANCE</th><th>R_i (internal)</th><th>R_a (external)</th></tr>
<tr><td colspan="3">Exterior walls and windows (towards outside air)</td><td>0.130</td><td>0.040</td></tr>
<tr><td colspan="3">Wall bordering an unheated space</td><td>0.130</td><td>0.130</td></tr>
<tr><td colspan="3">Wall in contact with the ground</td><td>0.130</td><td>0.000</td></tr>
<tr><td colspan="3">Roofs, roofs (upcoming heat flow)</td><td>0.100</td><td>0.040</td></tr>
<tr><td colspan="3">Ceiling bordered by unheated space</td><td>0.100</td><td>0.100</td></tr>
<tr><td colspan="3">Floor over open passage (pilotis)</td><td>0.170</td><td>0.040</td></tr>
<tr><td colspan="3">Floor above unheated space (descending flow)</td><td>0.170</td><td>0.170</td></tr>
<tr><td colspan="3">Floor in contact with the ground</td><td>0.170</td><td>0.000</td></tr>
<tr><td>1</td><td>Thermal transition resistance (internally)</td><td>R_i</td><td>$(m^2K)/W$</td><td>0.17</td></tr>
<tr><td>2</td><td>Heat transfer resistance</td><td>R</td><td>$(m^2K)/W$</td><td>2.373</td></tr>
<tr><td>3</td><td>Thermal resistance (external)</td><td>R_a</td><td>$(m^2K)/W$</td><td>0.17</td></tr>
<tr><td>4</td><td>Heat transfer resistance</td><td>$R_{o\lambda}$</td><td>$(m^2K)/W$</td><td>2.713</td></tr>
<tr><td colspan="2">Heat Transfer Coefficient</td><td>U</td><td>$W/(m^2K)$</td><td>0.369</td></tr>
<tr><td colspan="2">Maximum acceptable Heat Transfer Coefficient value</td><td>U_{max}</td><td>$W/(m^2K)$</td><td>1.2</td></tr>
</table>

It must $U<=U_{max}$

And it DOES

Calculation of heat transfer coefficients of transparent structural elements and area measurements

Frame type: Metal with 24mm thermal break

Uf frame: 2.8 W/m^{2}K

Glass type: Double glazing 6mm (metallic10cm)

Ug glass: 3.3 W/m^{2}K

g glass table: 0.75

g glass: 0.68

Linear thermal permeability of glass. and framework Ψg: 0.08 W/mK

Average frame width: 0.100 m

Table 35: Openings and grame characteristics

Frame type	Opening width [m]	Opening height [m]	Number of layers	Window surface area [m^2]
A1	3.60	2.09	2	7.52
A2	1.20	1.50	2	1.80
A3	0.60	0.53	1	0.32
A5	1.50	1.50	1	2.25
A6	1.20	1.50	1	1.80
A7	1.20	2.30	1	2.76

Frame type	**Frame area [m^2]**	**Glass surface area [m^2]**	**Frame percentage**	**Length L_g [m]**	**U of frame [W/(m^{2}K)]**	**g_w of frame**
A1	1.48	6.05	20%	13.96	3.350	0.55
A2	0.76	1.04	42%	6.800	3.391	0.39
A3	0.19	0.13	58%	1.460	3.375	0.28
A5	0.56	1.69	25%	5.200	3.360	0.51
A6	0.50	1.30	28%	4.600	3.366	0.49
A7	0.66	2.10	24%	6.200	3.360	0.52

Table 36: Aggregated data of frames per floor

Floor	**Frame**	**Width [m]**	**Length [m]**	**Type**	**Surface area [m^2]**	**U [W/(m^{2}K)]**	**UxA [W/K]**	**g_w**
1	SW1	3.60	2.09	A1	7.52	2.200	16.55	0.55
	S1	1.50	1.50	A5	2.25	2.200	4.95	0.51
	SE2	1.20	1.50	A6	1.80	2.200	3.96	0.49
	NW1	1.20	1.50	A2	1.80	2.200	3.96	0.39
	NW2	0.60	0.53	A3	0.32	2.200	0.70	0.28
2	SW1	1.20	2.30	A7	2.76	2.200	6.07	0.52
	SW2	1.20	2.30	A7	2.76	2.200	6.07	0.52
	SE1	1.20	1.50	A6	1.80	2.200	3.96	0.49
	SE2	1.20	2.30	A7	2.76	2.200	6.07	0.52
	NW1	1.20	1.50	A2	1.80	2.200	3.96	0.39
	NW2	0.60	0.53	A3	0.32	2.200	0.70	0.28

Table 37: Total surface area of structural elements

Floor	**Area [m²]**	**Σ(UxA) [W/K]**	**n**	**ΣA [m²]**	**nxΣ(UxA) [W/K]**
1	13.69	30.12	1	13.69	30.12
2	12.20	26.84	1	12.20	26.84
Total				25.89	56.96

Zone: 1

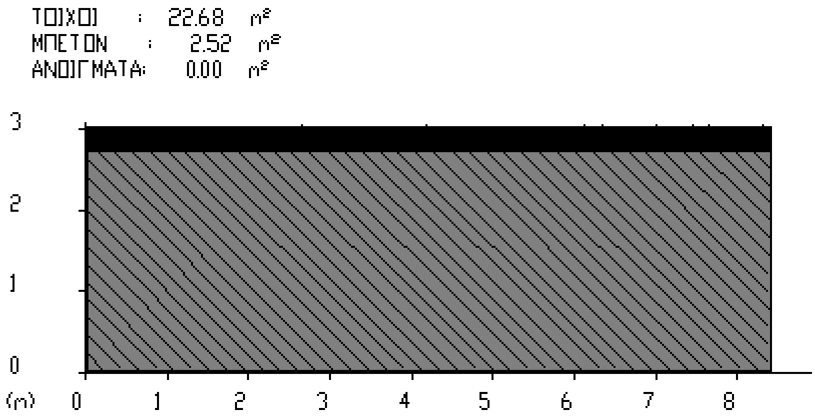
Orientation: NE

Structural element		**Masonry**	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Length [m]**	**Area [m²]**
1	8.40	3.00	22.68
		ΣA =	22.68

Zone: 1

Orientation: NE

Structural element		**Column**	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m²]**
1	8.40	0.30	2.52
		ΣA =	2.52



Zone: 1

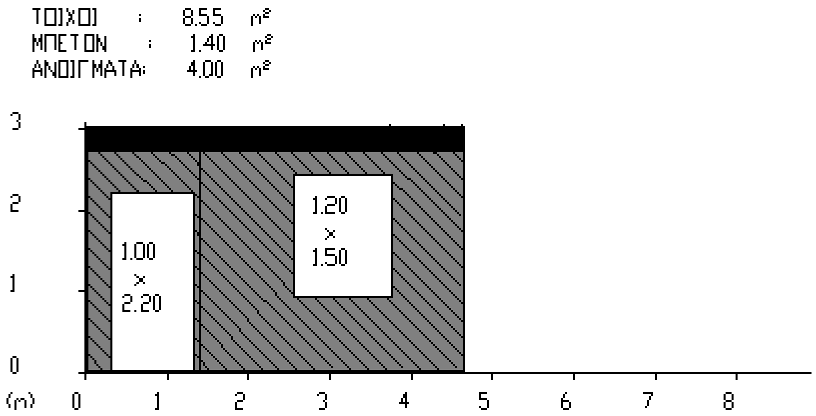
Orientation: SE

Structural element		**Masonry**	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Height [m]**	**Area [m^2]**
1	1.40	3.00	1.58
2	3.25	3.00	6.97
		ΣA =	8.55

Zone: 1

Orientation: SE

Structural element		**Column**	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m^2]**
1	1.40	0.30	0.42
2	3.25	0.30	0.98
		ΣA =	1.40



Zone: 1

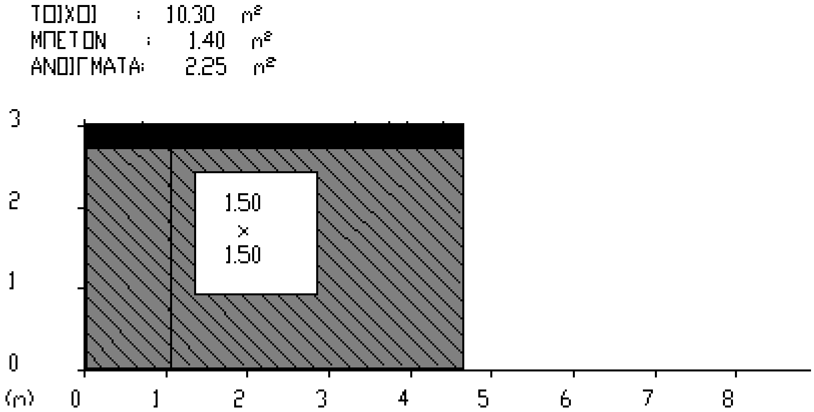
Orientation: S

Structural element		**Masonry**	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Height [m]**	**Area [m²]**
1	1.05	3.00	2.83
2	3.60	3.00	7.47
		ΣA =	10.30

Zone: 1

Orientation: S

Structural element		**Column**	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m²]**
1	1.05	0.30	0.32
2	3.60	0.30	1.08
		ΣA =	1.40



Zone: 1

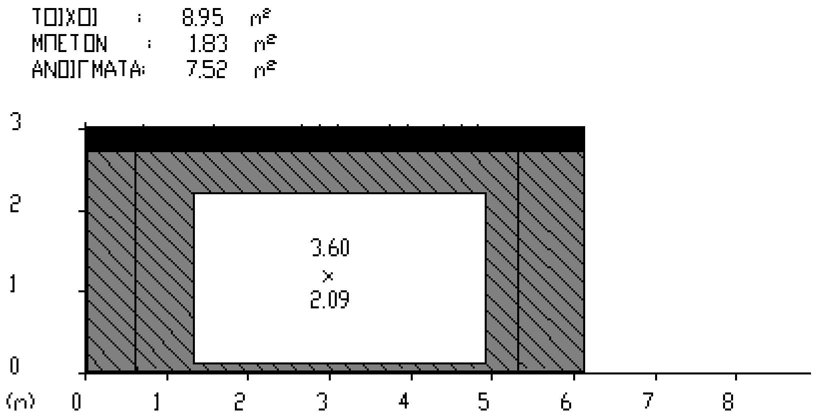
Orientation: SW

Structural element		Masonry	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Height [m]**	**Area [m²]**
1	4.70	3.00	5.17
2	0.80	3.00	2.16
3	0.60	3.00	1.62
		ΣA =	8.95

Zone: 1

Orientation: SW

Structural element		Column	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m²]**
1	4.70	0.30	1.41
2	0.80	0.30	0.24
3	0.60	0.30	0.18
		ΣA =	1.83



Zone: 1

Orientation: NW

Structural element		**Masonry**	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Height [m]**	**Area [m²]**
1	7.75	3.00	18.81
2	0.90	3.00	2.43
		ΣA =	21.24

Zone: 1

Orientation: NW

Structural element		**Column**	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m²]**
1	7.75	0.30	2.33
2	0.90	0.30	0.27
		ΣA =	2.60

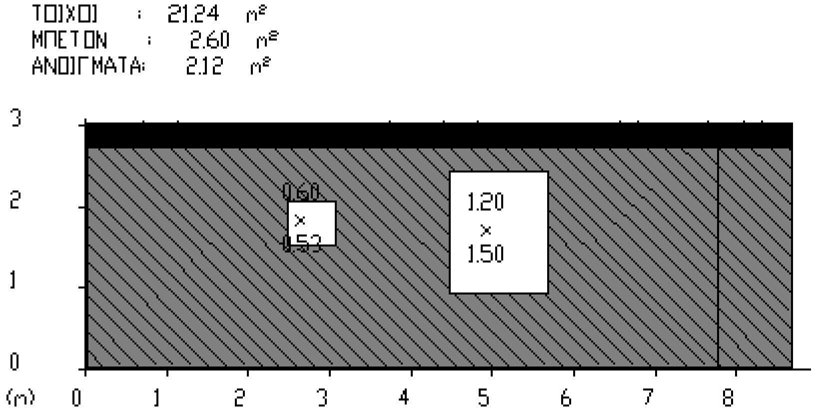


Table 38: Collectibles of vertical structural elements for thermal insulation adequacy calculations

Orientation	**Structural element**	**U [W/(m²K)]**	**A [m²]**	**b**	**ΣbxAxU [W/K]**
NE	Masonry	0.450	22.68	1	10.21
NE	Column	0.432	2.52	1	1.09
SE	Masonry	0.450	8.55	1	3.85
SE	Column	0.432	1.40	1	0.60
S	Masonry	0.450	10.30	1	4.63
S	Column	0.432	1.40	1	0.60
SW	Masonry	0.450	8.95	1	4.03
SW	Column	0.432	1.83	1	0.79
NW	Masonry	0.450	21.24	1	9.56
NW	Column	0.432	2.60	1	1.12
			81.46		36.48

Table 39: Concentrative elements of vertical structural elements for energy efficiency calculations

Orientation	**Structural element**	**U [W/(m²K)]**	**A [m²]**	**b**	**ΣbxAxU [W/K]**
NE	Masonry	0.450	22.68	1	10.21
NE	Column	0.432	2.52	1	1.09
SE	Masonry	0.450	8.55	1	3.85
SE	Column	0.432	1.40	1	0.60
S	Masonry	0.450	10.30	1	4.63
S	Column	0.432	1.40	1	0.60
SW	Masonry	0.450	8.95	1	4.03
SW	Column	0.432	1.83	1	0.79
NW	Masonry	0.450	21.24	1	9.56
NW	Column	0.432	2.60	1	1.12
			81.46		36.48

Zone: 1

Floor:

Orientation: NE

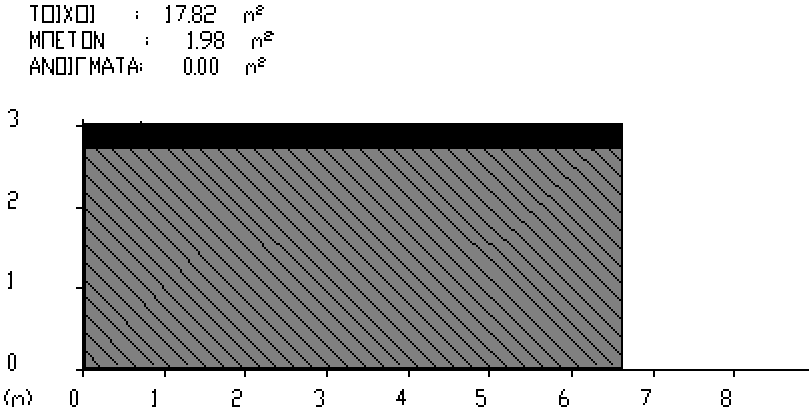
Structural element		**Masonry**	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Height [m]**	**Area [m²]**
1	6.60	3.00	17.82
		ΣA =	17.82

Zone: 1

Floor:

Orientation: NE

Structural element		**Column**	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m^2]**
1	6.60	0.30	1.98
		ΣA =	1.98



Zone: 1

Floor:

Orientation: SE

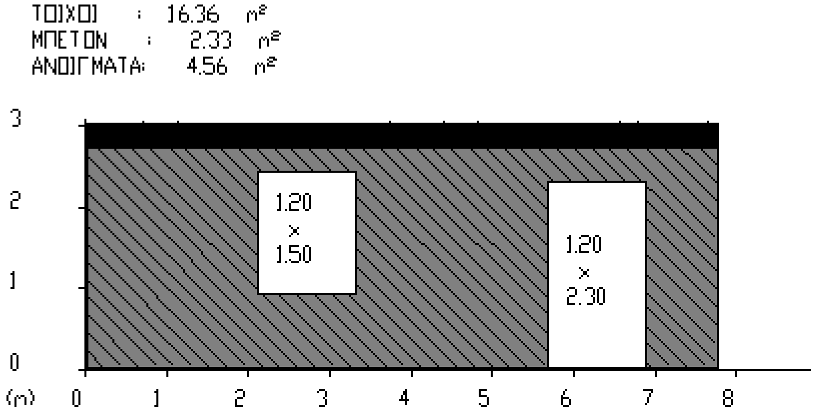
Structural element		**Masonry**	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Height [m]**	**Area [m^2]**
1	7.75	3.00	16.36
		ΣA =	16.36

Zone: 1

Floor:

Orientation: SE

Structural element		**Column**	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m^2]**
1	7.75	0.30	2.33
		ΣA =	2.33



Zone: 1

Floor:

Orientation: SW

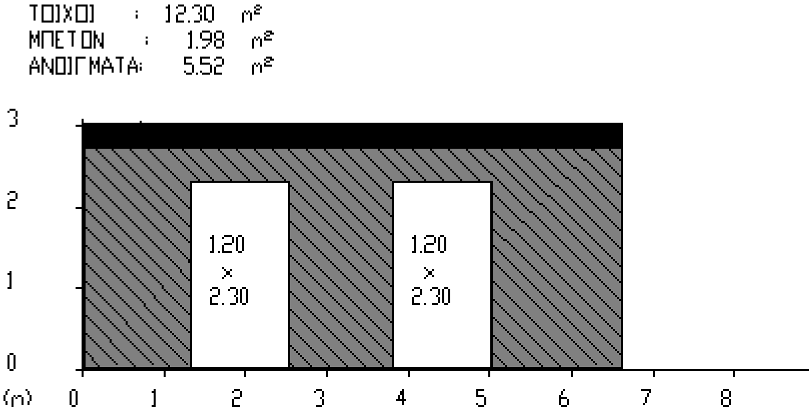
Structural element		**Masonry**	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Height [m]**	**Area [m^2]**
1	6.60	3.00	12.30
		ΣA =	12.30

Zone: 1

Floor:

Orientation: SW

Structural element		**Column**	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m^2]**
1	6.60	0.30	1.98
		ΣA =	1.98



Zone: 1

Floor:

Orientation: NW

Structural element		**Masonry**	
Layer	**1.2**	**U=**	**0.450**
	Width [m]	**Height [m]**	**Area [m^2]**
1	7.75	3.00	18.81
		ΣA =	18.81

Zone: 1

Floor:

Orientation: NW

Structural element		**Column**	
Layer	**1.7**	**U=**	**0.432**
	Width [m]	**Height [m]**	**Area [m^2]**
1	7.75	0.30	2.33
		ΣA =	2.33

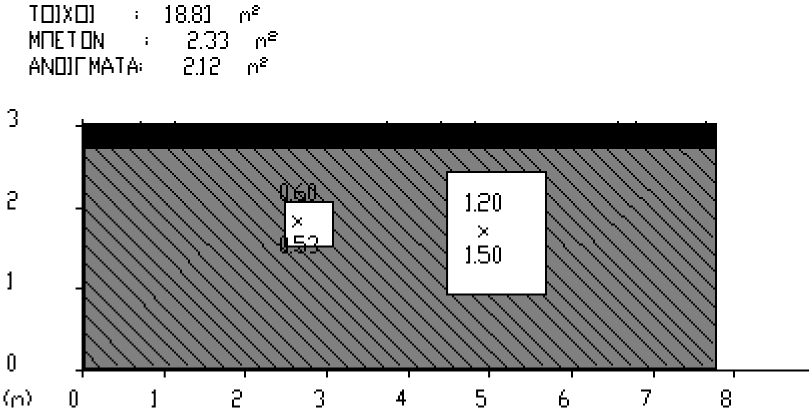


Table 40: Collectibles of vertical structural elements for thermal insulation adequacy calculations

Orientation	**Structural element**	**U [W/(m²K)]**	**A [m²]**	**b**	**ΣbxAxU [W/K]**
NE	Masnory	0.450	17.82	1	8.02
NE	Column	0.432	1.98	1	0.86
SE	Masnory	0.450	16.36	1	7.36
SE	Column	0.432	2.33	1	1.00
SW	Masnory	0.450	12.30	1	5.53
SW	Column	0.432	1.98	1	0.86
NW	Masnory	0.450	18.81	1	8.46
NW	Column	0.432	2.33	1	1.00
			73.90		33.10

Table 41: Concentrative elements of vertical structural elements for energy efficiency calculations

Orientation	Structural element	U [W/(m²K)]	A [m²]	b	ΣbxAxU [W/K]
NE	Masnory	0.450	17.82	1	8.02
NE	Column	0.432	1.98	1	0.86
SE	Masnory	0.450	16.36	1	7.36
SE	Column	0.432	2.33	1	1.00
SW	Masnory	0.450	12.30	1	5.53
SW	Column	0.432	1.98	1	0.86
NW	Masnory	0.450	18.81	1	8.46
NW	Column	0.432	2.33	1	1.00
			73.90		33.10

Horizontal opaque structural elements

Zone: 1

Floor:

Floor to EP (piloti)

Structural element		**Floor to EP (piloti)**	
Layer	**2.2**	**U=**	**0.369**
Section	**Width [m]**	**Length [m]**	**Area [m²]**
1	1	64.25	64.25
			64.25

Zone: 1

Floor:

Ceiling

Structural element		**Ceiling**	
Layer		**U=**	**0.397**
Section	**Width [m]**	**Length [m]**	**Area [m^2]**
1	1	51.15	51.15
			51.15

Table 42: Concentration data for opaque horizontal data for energy efficiency calculations

Floor	**Structural element**	**ΣA [m^2]**	**U [W/(m^{2}K)]**	**ΣAxU [W/K]**	**b**	**bxΣAxU [W/K]**
1	Floor to EP (piloti)	64.25	0.369	23.71	1.000	23.71
2	Ceiling	51.15	0.397	20.31	1.000	20.31
		115.40				44.01

Table 43: Collective data on opaque horizontal data for thermal insulation adequacy testing

Floor	**Structural element**	**ΣA [m^2]**	**U [W/(m^{2}K)]**	**ΣAxU [W/K]**	**b**	**bxΣAxU [W/K]**
1	Floor to EP (piloti)	64.25	0.369	23.71	1.000	23.71
2	Ceiling	51.15	0.397	20.31	1.000	20.31
		115.40				44.01

Transparent structural elements

Concentrated floor elements for thermal insulation adequacy testing

Floor	Frame	Width [m]	Length [m]	Type	Area [m^2]	U [W/(m^{2}K)]	UxA [W/K]
	SW1	3.60	2.09	A1	7.52	2.200	16.55
	S1	1.50	1.50	A5	2.25	2.200	4.95
	SE2	1.20	1.50	A6	1.80	2.200	3.96
	NW1	1.20	1.50	A2	1.80	2.200	3.96
	NW2	0.60	0.53	A3	0.32	2.200	0.70
	SW1	1.20	2.30	A7	2.76	2.200	6.07
	SW2	1.20	2.30	A7	2.76	2.200	6.07
	SE1	1.20	1.50	A6	1.80	2.200	3.96
	SE2	1.20	2.30	A7	2.76	2.200	6.07
	NW1	1.20	1.50	A2	1.80	2.200	3.96
	NW2	0.60	0.53	A3	0.32	2.200	0.70

Table 44: Concentrating window elements for thermal insulation adequacy testing

Floor	Area [m^2]	Σ(UxA) [W/K]	n	ΣA [m^2]	nxΣ(UxA) [W/K]
	13.69	30.12	1	13.69	30.12
	12.20	26.84	1	12.20	26.84
Total				25.89	56.96

Thermal Bridges

Zone: 1

Table 45: Thermal insulation adequacy check

	Floor	Type	Ψ [W/(mK)]	l [m]	b	Σ(bxlxΨ) [W/K]
1	1	AK - 5	0.550	3.60	1	2.0
2	1	AK - 5	0.550	3.60	1	2.0
3	1	L - 5	0.000	2.09	1	0.0
4	1	L - 5	0.000	2.09	1	0.0
5	1	EDP - 10 (50%)	0.225	4.68	1	1.1
6	1	EDP - 10 (50%)	0.225	4.68	1	1.1
7	1	EDP - 10 (50%)	0.225	1.04	1	0.2
8	1	EDP - 10 (50%)	0.225	1.04	1	0.2
9	1	EDP - 10 (50%)	0.225	0.80	1	0.2
10	1	EDP - 10 (50%)	0.225	0.80	1	0.2
11	1	AK - 5	0.550	1.00	1	0.6
12	1	L - 5	0.000	2.20	1	0.0
13	1	L - 5	0.000	2.20	1	0.0
14	1	EDP - 10 (50%)	0.225	1.38	1	0.3
15	1	EDP - 10	0.225	1.38	1	0.3

		(50%)				
16	1	AK - 5	0.550	1.50	1	0.8
17	1	AK - 5	0.550	1.50	1	0.8
18	1	L - 5	0.000	1.50	1	0.0
19	1	L - 5	0.000	1.50	1	0.0
20	1	EDP - 10 (50%)	0.225	3.60	1	0.8
21	1	EDP - 10 (50%)	0.225	3.60	1	0.8
22	1	AK - 5	0.550	1.20	1	0.7
23	1	AK - 5	0.550	1.20	1	0.7
24	1	L- 5	0.000	1.50	1	0.0
25	1	L - 5	0.000	1.50	1	0.0
26	1	EDP - 10 (50%)	0.225	3.25	1	0.7
27	1	EDP - 10 (50%)	0.225	3.25	1	0.7
28	1	EDP - 10 (50%)	0.225	8.40	1	1.9
29	1	EDP - 10 (50%)	0.225	8.40	1	1.9
30	1	AK - 5	0.550	1.20	1	0.7
31	1	AK - 5	0.550	1.20	1	0.7
32	1	L - 5	0.000	1.50	1	0.0
33	1	L - 5	0.000	1.50	1	0.0
34	1	AK - 5	0.550	0.60	1	0.3
35	1	AK - 5	0.550	0.60	1	0.3
36	1	L - 5	0.000	0.53	1	0.0
37	1	L - 5	0.000	0.53	1	0.0

38	1	EDP - 10 (50%)	0.225	7.75	1	1.7
39	1	EDP - 10 (50%)	0.225	7.75	1	1.7
40	1	EDP - 10 (50%)	0.225	0.60	1	0.1
41	1	EDP - 10 (50%)	0.225	0.60	1	0.1
42	1	EDP - 10 (50%)	0.225	0.90	1	0.2
43	1	EDP - 10 (50%)	0.225	0.90	1	0.2
44	2	AK - 5	0.550	1.20	1	0.7
45	2	AK - 5	0.550	1.20	1	0.7
46	2	L - 5	0.000	2.30	1	0.0
47	2	L - 5	0.000	2.30	1	0.0
48	2	AK - 5	0.550	1.20	1	0.7
49	2	AK - 5	0.550	1.20	1	0.7
50	2	L - 5	0.000	2.30	1	0.0
51	2	L - 5	0.000	2.30	1	0.0
52	2	EDP - 10 (50%)	0.225	6.60	1	1.5
53	2	EDP - 10 (50%)	0.225	6.60	1	1.5
54	2	AK - 5	0.550	1.20	1	0.7
55	2	AK - 5	0.550	1.20	1	0.7
56	2	L - 5	0.000	1.50	1	0.0
57	2	L - 5	0.000	1.50	1	0.0
58	2	AK - 5	0.550	1.20	1	0.7
59	2	AK - 5	0.550	1.20	1	0.7

60	2	L - 5	0.000	2.30	1	0.0
61	2	L - 5	0.000	2.30	1	0.0
62	2	EDP - 10 (50%)	0.225	7.75	1	1.7
63	2	EDP - 10 (50%)	0.225	7.75	1	1.7
64	2	EDP - 10 (50%)	0.225	6.60	1	1.5
65	2	EDP - 10 (50%)	0.225	6.60	1	1.5
66	2	AK - 5	0.550	1.20	1	0.7
67	2	AK - 5	0.550	1.20	1	0.7
68	2	L - 5	0.000	1.50	1	0.0
69	2	L - 5	0.000	1.50	1	0.0
70	2	AK - 5	0.550	0.60	1	0.3
71	2	AK - 5	0.550	0.60	1	0.3
72	2	L - 5	0.000	0.53	1	0.0
73	2	L - 5	0.000	0.53	1	0.0
74	2	EDP - 10 (50%)	0.225	7.75	1	1.7
75	2	EDP - 10 (50%)	0.225	7.75	1	1.7
				192.10		44.2

Table 46: For energy efficiency calculations

	Floor	Category	Ψ [W/(mK)]	l [m]	b	Σ(bxlxΨ) [W/K]
1	1	AK - 5	0.550	3.60	1	2.0
2	1	AK - 5	0.550	3.60	1	2.0
3	1	L - 5	0.000	2.09	1	0.0
4	1	L - 5	0.000	2.09	1	0.0
5	1	EDP - 10 (50%)	0.225	4.68	1	1.1
6	1	EDP - 10 (50%)	0.225	4.68	1	1.1
7	1	EDP - 10 (50%)	0.225	1.04	1	0.2
8	1	EDP - 10 (50%)	0.225	1.04	1	0.2
9	1	EDP - 10 (50%)	0.225	0.80	1	0.2
10	1	EDP - 10 (50%)	0.225	0.80	1	0.2
11	1	AK - 5	0.550	1.00	1	0.6
12	1	L - 5	0.000	2.20	1	0.0
13	1	L - 5	0.000	2.20	1	0.0
14	1	EDP - 10 (50%)	0.225	1.38	1	0.3
15	1	EDP - 10 (50%)	0.225	1.38	1	0.3
16	1	AK - 5	0.550	1.50	1	0.8
17	1	AK - 5	0.550	1.50	1	0.8
18	1	L - 5	0.000	1.50	1	0.0

19	1	L - 5	0.000	1.50	1	0.0
20	1	EDP - 10 (50%)	0.225	3.60	1	0.8
21	1	EDP - 10 (50%)	0.225	3.60	1	0.8
22	1	AK - 5	0.550	1.20	1	0.7
23	1	AK - 5	0.550	1.20	1	0.7
24	1	L - 5	0.000	1.50	1	0.0
25	1	L - 5	0.000	1.50	1	0.0
26	1	EDP - 10 (50%)	0.225	3.25	1	0.7
27	1	EDP - 10 (50%)	0.225	3.25	1	0.7
28	1	EDP - 10 (50%)	0.225	8.40	1	1.9
29	1	EDP - 10 (50%)	0.225	8.40	1	1.9
30	1	AK - 5	0.550	1.20	1	0.7
31	1	AK - 5	0.550	1.20	1	0.7
32	1	L - 5	0.000	1.50	1	0.0
33	1	L - 5	0.000	1.50	1	0.0
34	1	AK - 5	0.550	0.60	1	0.3
35	1	AK - 5	0.550	0.60	1	0.3
36	1	L - 5	0.000	0.53	1	0.0
37	1	L - 5	0.000	0.53	1	0.0
38	1	EDP - 10 (50%)	0.225	7.75	1	1.7
39	1	EDP - 10 (50%)	0.225	7.75	1	1.7
40	1	EDP - 10	0.225	0.60	1	0.1

		(50%)				
41	1	EDP - 10 (50%)	0.225	0.60	1	0.1
42	1	EDP - 10 (50%)	0.225	0.90	1	0.2
43	1	EDP - 10 (50%)	0.225	0.90	1	0.2
44	2	AK - 5	0.550	1.20	1	0.7
45	2	AK - 5	0.550	1.20	1	0.7
46	2	L - 5	0.000	2.30	1	0.0
47	2	L - 5	0.000	2.30	1	0.0
48	2	AK - 5	0.550	1.20	1	0.7
49	2	AK - 5	0.550	1.20	1	0.7
50	2	L - 5	0.000	2.30	1	0.0
51	2	L - 5	0.000	2.30	1	0.0
52	2	EDP - 10 (50%)	0.225	6.60	1	1.5
53	2	EDP - 10 (50%)	0.225	6.60	1	1.5
54	2	AK - 5	0.550	1.20	1	0.7
55	2	AK - 5	0.550	1.20	1	0.7
56	2	L - 5	0.000	1.50	1	0.0
57	2	L - 5	0.000	1.50	1	0.0
58	2	AK - 5	0.550	1.20	1	0.7
59	2	AK - 5	0.550	1.20	1	0.7
60	2	L - 5	0.000	2.30	1	0.0
61	2	L - 5	0.000	2.30	1	0.0
62	2	EDP - 10 (50%)	0.225	7.75	1	1.7

63	2	EDP - 10 (50%)	0.225	7.75	1	1.7
64	2	EDP - 10 (50%)	0.225	6.60	1	1.5
65	2	EDP - 10 (50%)	0.225	6.60	1	1.5
66	2	AK - 5	0.550	1.20	1	0.7
67	2	AK - 5	0.550	1.20	1	0.7
68	2	L - 5	0.000	1.50	1	0.0
69	2	L - 5	0.000	1.50	1	0.0
70	2	AK - 5	0.550	0.60	1	0.3
71	2	AK - 5	0.550	0.60	1	0.3
72	2	L - 5	0.000	0.53	1	0.0
73	2	L - 5	0.000	0.53	1	0.0
74	2	EDP - 10 (50%)	0.225	7.75	1	1.7
75	2	EDP - 10 (50%)	0.225	7.75	1	1.7
				192.10		44.2

Calculation of maximum allowable and feasible Um of the building

Table 47: Calculation of heated building volume

Thermal zone	**Area [m^2]**	**height [m]**	**Volume [m^3]**
Zone 1	115.40	3.00	346
Total			346

	ΣA [m²]	**Σ[bxUxA] [W/K] ή Σ[bxΨxl] [W/K]**
vertically opaque building blocks	155.4	69.6
horizontal opaque structural elements	115.4	32.2
transparent building blocks	28.1	61.8
Thermal bridges	-	44.2
Total	298.8	207.8

ΣA/V=298.85(m^2)/346.20(m^3)=0.863

Therefore maximum allowed $U_{m,max}$ 0.882[W/(m^{2}K)]

Realizing U_m=207.8(W/K)/298.85(m^2)=0.695<0.882[W/(m^{2}K)]

Unwanted ventilation calculation

Table 48: Concentrated floor elements for calculating unintentional ventilation

Floor	**Type**	**Frame**	**Width [m]**	**Height [m]**	**Area [m²]**	**Air penetration [m³/(m²h)]**	**Air penetration [m³/h]**
	Window	A1	3.60	2.09	7.52	8.12	61
	Door	A4	1.00	2.20	2.20	10.34	23
	Window	A5	1.50	1.50	2.25	8.12	18
	Window	A6	1.20	1.50	1.80	8.12	15
	Window	A2	1.20	1.50	1.80	8.12	15
	Window	A3	0.60	0.53	0.32	8.12	3
	Window	A7	1.20	2.30	2.76	8.12	22
	Window	A7	1.20	2.30	2.76	8.12	22
	Window	A6	1.20	1.50	1.80	8.12	15
	Window	A7	1.20	2.30	2.76	8.12	22
	Window	A2	1.20	1.50	1.80	8.12	15
	Window	A3	0.60	0.53	0.32	8.12	3
Total							233

Air permeability coefficient R = 0.7 and position coefficient H = 1.87 have been taken into account in the air penetration, according to paragraph 3.4.2 of TOTEE (Energy G. M., 2017)

GENERAL BUILDING OBJECTIVES

The building was constructed in Iria, so based on K.E.N.A.K. (Energy G. M., 2017) belongs to the A climatic zone. Each structural element must have a coefficient of thermal conductivity lower than those given in the table below for the A climate zone.

The entrance of the apartment building and the staircase are considered heated spaces, so they must be insulated. The first and second basements, with the exception of the staircase, are considered unheated spaces.

The collection of geometric data and the calculations of the thermal characteristics of the building surfaces is done taking into account the following:

- In order to calculate the energy consumption and consequently the energy efficiency of the building, it is necessary not only the thermal and geometric characteristics of the heated spaces but also of the non-heated ones in contact with the heated ones.
- The structural elements of the building adjacent to heated buildings, during the thermal adequacy test of the building are considered to be in contact with the external environment while for the calculation of energy consumption are considered non-passive,
- The thermal zone structural elements of the building adjacent to another thermal zone of the same building are considered adiabatic,
- Opaque and transparent surfaces have solar gains which depend on their orientation and shading,
- According to T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017) for simplification reasons, for the calculation of energy efficiency of buildings, for vertical structurally opaque elements with a coefficient of thermal conductivity less than 0.60 W / (m^2K), the shading factor can be considered equal to 0.9.

TEMPERATURE PROCEDURE ELECTION OF INDEPENDENT STRUCTURAL BUILDINGS

Table below gives a summary of the coefficients of thermal conductivity of the structural elements of the heated and non-heated areas of the building, which meet the minimum requirements of k.e.n.a.k. (Energy G. M., 2017) coefficients of thermal conductivity.

Table 49: Heat permeability coefficient of the structural elements of the heated and non-heated areas of the building

Structural element	**Under check layer**	**U[W/(m^{2}K)]**	**U$_{max}$[W/(m^{2}K)]**
Masonry	1.1	0.450	0.6
Column	1.2	0.432	0.6
Ceiling	1.3	0.397	0.5

According to T.O.T.E.E. 20701-2 / 2010 (Energy G. M., 2017) for values of the coefficient of thermal conductivity of building materials with a value of $\lambda \leq 0{,}18$W / (m.K) the values given in table 49 of T.O.T.E.E. (Energy G. M., 2017) are indicative. The prices taken into account for the thermal insulation materials emerged after a market research and with the responsibility of the researchers. In the phase of the energy inspection that will be done with the completion of the construction and before closing the file of the building in the competent Urban Offices, the energy inspector must check the consignment notes of the thermal insulation materials as well as the appropriate certificates accompanying them.

Based on T.O.T.E.E. 20701-1 / 2010 and T.O.T.E.E. 20701-2 / 2010 (Energy G. M., 2017)the thermal conductivity coefficients of structural elements that are included in the calculation of the average coefficient of thermal conductivity of the building and the calculation of energy consumption are the equivalent coefficients of thermal conductivity U′ and not those given in the table above. Their detailed calculation is based on the methodology developed in section 2.1.6 of T.O.T.E.E. 20701-2 / 2010 (Energy G.

M., 2017).

TEMPERATURE PROCESSING TECHNICIAN OF DIFFERENT STRUCTURAL ELEMENTS

The building will function as a detached house. According to k.e.n.a.k., for the a climate zone, the frames that will be installed must have a coefficient of thermal conductivity U⩽ 3.2 w / (m^2k).

The calculation of the U of the frames was done based on the relation 49 and of T.O.T.E.E. 20701-2 / 2010 (Energy G. M., 2017). These calculations are given in detail in the Computer Issue that accompanies this study.

Table 50 gives a summary of the heat transfer coefficients of the building's frames. As shown in the tables, the heat transfer values of the frames meet the minimum requirements.

The designer may alternatively use the thermal conductivity values of the CE marking of the frames. In the phase of the energy inspection that will be done with the completion of the construction, the energy inspector must check the consignment notes of the frames as well as the appropriate CE certificates that accompany them. The CE marking of the frames is mandatory based on the JMC No. 12397/409 Government Gazette B 1794 / 28-8-2009 from 1 February 2010.

Table 50: Roof heat transfer coefficient

Frame number	Opening width [m]	Opening height [m]	Frame area [m²]	U Of frame [W/(m²K)]	U max [W/(m²K)]
1	3.60	2.09	7.52	2.200	3.2
2	1.50	1.50	2.25	2.200	
3	1.20	1.50	1.80	2.200	
4	1.20	1.50	1.80	2.200	
5	0.60	0.53	0.32	2.200	
6	1.20	2.30	2.76	2.200	
7	1.20	2.30	2.76	2.200	
8	1.20	1.50	1.80	2.200	
9	1.20	2.30	2.76	2.200	
10	1.20	1.50	1.80	2.200	
11	0.60	0.53	0.32	2.200	

WEATHER REPAIR COMPANY ELECTOR

To control the thermal insulation adequacy of the building, it is necessary to calculate the ratio of the external surrounding surface of the heated parts of the building to their volume. In the computer issue, the way of calculating the a / v ratio is given in detail.

As it turned out a / v = 0.863 m-1 which from table 49 corresponds to a maximum allowable um, max = 0.882 w / (m^2k). Table 51 summarizes the areas of the structural elements, the sums of the uxas, and the sums of the ψxl. As it turns out, the average coefficient of thermal conductivity of the building is equal to:

$$U_m=0.695\ W/m^2K <= U_{m,max}=0.882\ W/m^2K$$

Therefore the building is sufficiently thermally insulated.

Therefore, according to the minimum requirements of K.EN.AK. (Energy G. M., 2017) for the average Um heat transfer coefficient, the building is sufficiently insulated. All calculations are given in detail in the Computer Issue that accompanies this study.

Table 51: Collective building data

	ΣA [m²]	**Σ[bxUxA] [W/K] ή Σ[bxΨxl] [W/K]**
vertically opaque building blocks	155.4	69.6
horizontal opaque structural elements	115.4	32.2
transparent structural elements	28.1	61.8
Thermal bridges	-	44.2
Total	298.8	207.8
[Σ(bxUxA)+Σ(bxΨxl)]/ΣA		0.695

Observations on construction solutions heat loss reductions due to thermal bridges

Ground floor frames are installed externally, and then with thermal insulation in almost all places. On the contrary, the placement of the frames on the floors is internal. To reduce the losses from the thermal bridges that are created in the candles, the upper and the lower part, there is a continuation of the thermal insulation, perpendicular to the candles, the upper and the lower part of the frames.

Table 52 below shows the cooling capacity (Btu / h), the rated (consumed) power consumption (kW) and the EER efficiency of the air-cooled heat pumps installed in the individual properties of the buildings, according to the units. selected during the refrigeration study.

Table 52: Technical characteristics of heat for each property

System	Type	Drawn electrical power [KW]	Index Efficiency EER	Fuel
1	Air cooled heat pump	4.0	3.000	Electricity

Remark: If the building under study did not provide for the installation of a cooling system, for the calculations it is considered that the building is cooled and the cooling system will have the technical characteristics of the respective reference building, as defined in the T.O.T.E. E. 20701-1 / 2010 (paragraph 4.2.1) and in K.E.N.A.K (Energy G. M., 2017). In this case, the present paragraph will describe the technical characteristics of the cooling system of the reference building.

MINIMUM STANDARDS OF AIR CIRCULATION SYSTEM

The building, depending on its use, covers its needs for ventilation through natural or technical ventilation and always in accordance with the minimum requirements of fresh air defined in the T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017) in paragraph 2.4.3.

The details of the ventilation system of the building under study are presented in the table below.

Table 53: Ventilation system components

Zone	**Use**	**Type of ventilation**	**Demand for fresh air [m^3/h/m^2]**
Zone 1	Detatched house	Natural	0.75

DEPARTMENT OF HEATED WATER USE PRODUCTION SYSTEM

The consumption of hot water for the study section is defined in paragraph 2.5 of T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017) per use, and it is this value that will be used in the calculations.

DETACHED HOUSE: 2.50 LT / DAY / M^2. The total daily consumption for heated water in the building is 289.

The average temperature of hot water for use is set at 50 ^{o}C, while the water temperatures of the network of Iria as defined in the T.O.T.E.E. 20701-3 / 2010 (Energy G. M., 2017).

The daily required thermal load Qd in (kWh / day) to meet the needs of the building for heated water given by the following relation:

$$Q_d = V_d \cdot \frac{c}{3600} \rho \cdot \Delta T$$

Where:

Vd [lt /day] the daily load, Vd = 289 (lt/day),

ρ [kg/lt] the average density of hot water use, ρ = 0,998 (kg/ lt), c [kJ/(kg.K)] the specific heat, c = 4,18 kJ/(kg.K),

ΔT [K] ή [°C] temperature difference between main water and hot water.

Applying the above relation for the network water temperatures, the daily thermal load (kWh / day) for heated water of the building for each month was calculated.

Table 54: Daily thermal load

Zone	Use	Vd [lt/day]	Vstore [lt]	Q_D [kWh/day]	Pn [kW]
Zone 1	Detatched house	288.50	57.70	10.15	2.03

MINIMUM REQUIREMENTS FOR HEATED WATER PRODUCTION SYSTEM

To meet the hot water needs of the building under study, the following systems will be installed, as shown in the following tables.

The calculation relations for the total capacity and the thermal power are in accordance with the corresponding ones mentioned in the T.O.T.E.E. 20701-1 / 1010 (Energy G. M., 2017) and the results are presented in the following tables.

Table 55: System elements for heated water

System	**Type**	**Power [KW]**	**Efficiency**	**Fuel**
1	Solar water heating		0.000	Solar power

The piping of the water heating distribution network will be thermally insulated according to the minimum requirements of article 8 of K.E.N.A.K. and the provisions of the relevant T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017). To calculate the coverage of solar panels in the present study, the curve method f (S. klein, W.A. Beckman and J.A

Duffie) was applied. This method gives approximately the same results to cover the hot water load, with the detailed calculation method given by the European standard ELOT EN ISO 12976.2: 2006, and for the needs of the present study is sufficient.

For this building, the application of solar panels was studied in order to cover at least one part of the required load for hot water use.

The optimal angle of inclination of solar panels depends on the latitude of the area and the orientation of their placement. According to the empirical rule, for the Greek regions, the optimal slope of a solar collector for annual use is approximately equal to the latitude of the area, where for Iria it is 37.36 °. In the building under study, the orientation of the solar panels as well as the angle of inclination of their installation can be seen in the following table:

Table 56: Optimal solar panel angle and orientation

System	Orientation	Angle [°]
1	S	45

Detailed calculations were made for individual angles of inclination of solar panels, where small differences were presented in the load load of the building under study.

Table 57 shows the values of the average monthly daily solar radiation (kWh / m^2), for the area of Iria, for a horizontal surface and for a surface with a slope of 45 °.

Table 57: Average monthly daily incident sunlight (kWh / m^2) for horizontal surface and sloping surface 40^o.

	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Average daily solar radiation in horizontaL level (kWh/m2)	68.7	83.6	127.7	159.5	202.5	220.6	229.0	206.4	157.2	115.5	74.8	59.2
Average daily solar radiation. in level 45.0°	114.0	114.0	147.0	156.0	177.0	183.0	194.0	193.0	172.0	153.0	121.0	105.0

In order to properly position the solar panels and to avoid shading, the appropriate distance between them to the north-south axis was calculated. This distance was calculated for the day of the year with the lowest solar altitude being December 21 (winter solstice). For the area of Iria (latitude φ = 37.36 °), the solar deviation on December 21 is d = -23.45 °.

For the solar deviation this zenith angle (θz) at sunrise is about 61 °. Based on this angle and the geometric characteristics of the solar collector, the minimum distance that solar collectors should be between them, when placed at an angle, is calculated so that they do not overshadow each other.

Based on the minimum installation distance of solar panels, their dimensions and the available surface, which does not present shading problems, the number of solar panels that can be installed in the building under study was estimated. Then the coverage load for the specific solar panels as calculated in the dimensioning study and the specific inclination and orientation orientation were calculated. In Table 58, the results of calculations for the installation of solar panels are given in detail.

Table 58: Calculation results for heated water load coverage by solar panels

Average daily solar radiation in horizontaL level (kWh/m2)	Average monrthly load (kWh/mo)	Average monthly load covered by solar water heating (kWh/mo)	Load percentage coverage from SWH - fi (%)
I	337.84	176.47	52.2
F	305.15	176.47	57.8
M	337.84	227.56	67.4
A	326.94	241.49	73.9
M	337.84	274.00	81.1
J	326.94	283.28	86.6
J	337.84	300.31	88.9
A	337.84	298.76	88.4
S	326.94	266.26	81.4
O	337.84	236.84	70.1
N	326.94	187.31	57.3
D	337.84	162.54	48.1
Total	3977.82	2831.29	
Year Average			71.2

According to the results of the calculations, the average annual percentage of cargo coverage for hot water use is 71.18%. The individual monthly cargo coverage rates proposed by solar collectors range from 48.1% to 88.9%. The highest coverage is in July for the given installation slope.

Installing a larger area of solar panels would create problems between the surfaces, especially during the winter months. There is a possibility that the inclination of solar panels will change, especially in the spring and autumn months, so that there will be even greater utilization of solar radiation and consequently coverage of thermal loads for DHW by solar panels. In the event of a change in the installation slope of the solar panels, it may not exceed the selected slope.

For the calculation of the energy efficiency of each part of the building with a different main use, the data of the various parameters and technical sizes are defined as defined in article 5 of K.E.N.A.K. and in the relevant T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017). During the application of the calculation methodology in the specific building and per study section, the following parameters and data were taken into account: House use, Detatched house.

- The desired indoor environmental conditions (temperature, humidity, ventilation, etc.) and the operating characteristics of the building (schedule, internal gains, etc.).
- The climatic data of the area of the building (temperature, relative and absolute humidity, solar radiation).
- The geometric characteristics of the structural elements of the building shell (shape and form of the building, transparent and non-transparent surfaces, shading, etc.), their orientation, the characteristics of the internal structural elements (eg interior walls) and others.
- The thermal characteristics of the structural (transparent and non-transparent) elements of the building shell, such as: heat permeability, thermal mass, absorption in solar radiation, permeability to solar radiation, etc.
- The technical characteristics of the space heating installation, such as: the type of thermal energy production unit, their efficiency, the losses in the hot water distribution network, the type of terminal units, etc.
- The technical characteristics of the installation of cooling / air conditioning installations, such as: the type of refrigeration production units, their efficiency, the losses in the distribution network, the type of terminals, etc.
- The technical characteristics of the heated water production facility, such as: the type of hot water production unit, its efficiency, the losses of the hot water distribution network, the storage system, etc.
- The technical characteristics of the lighting installation regarding the spaces of the stores.

- Passive solar systems selected from the design study for the building.
- The installation of solar panels to cover part of the load for heated water.

BUILDING DEPARTMENT

The area and volume of the section under study per use are given in Table 59.

Table 59: Area and section volume

Climatic zone	Heated surface[m^2]	Cooling surface [m^2]	Heated volume [m^3]	Cooled volume [m^3]
Zone 1	115.40	115.40	346.20	346.20

THERMAL ZONES

According to article 3 of K.EN.AK. And T.O.T.E.E. 20701-1 / 2010, the distinction of a building into thermal zones is made with the following criteria:

1. The desired indoor temperature should differ by more than 4 °C for the winter and / or summer season.
2. There are spaces with different use / function.
3. There are spaces in the building that are covered with different heating and / or cooling and / or air conditioning systems due to different internal conditions.
4. There are spaces in the building that show large differences in internal and / or solar gains and / or thermal losses.
5. There are spaces where the mechanical ventilation system covers less than 80% of the floor plan of the space.

Based on T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017) for the separation of the building into thermal zones it is recommended to follow the following general rules:

- The building should be divided into the smallest possible number of zones, in order to achieve savings in the number of input data and in the computational time,
- The determination of the thermal zones to be done by recording the real picture of the operation of the building,

- Parts of the building with an area of less than 10% of the total area of the building to be considered integrated in other thermal zones, as similar as possible, even if their operating conditions justify their view as independent zones.

Based on the above, the general data for each thermal zone of the building under study are given in the following tables.

Table 60: General data for thermal zones

General data of thermal zone 1 (Detached house)		
Use of climatic zone	Detatched house	
Total zone area (m^2)	115.4	
Spotted special heat capacity [kJ/(m^2K)]	260	
Category of automation control devices for electromechanical equipment	A	T.O.T.E.E. 20701-1/2010, table 5.5
Ventilation		
Air penetration (m^3/h)	233	Calculation issue
Natural ventilation (m^3/h/m^2)	0.75	T.O.T.E.E. 20701-1
Ventilation utilization rate	1	100% for houses

Internal thermal zone operation conditions

In T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017) the desired operating conditions (temperature, humidity, ventilation, lighting) and internal thermal loads have been determined by users and devices.

The data on the operating conditions of the housing department are given in detail in table 61.

Table 61: Internal operating conditions

Internal operating conditions of climatic zone 1 (Detached house)		
Opening hours	18	
Operating days	7	Predetermined parameter from T.O.T.E.E. 20701-2/2010 and 20701-3/2010
Operating months	12	
Heating period	1/11 until 15/4	
Cooling period	15/5 until 15/9	
Average internal heating temperature (° C)	20.00	
Average internal cooling temperature (° C)	26.00	
Fresh air required (m3 / h / m^2)	0.75	
General lighting level (lux)	200.0	
Lighting power per unit area for reference building (W / m^2)	3.6	

Annual hot water consumption (m3 / m^2year)	0.9	
Average desired hot water temperature (° C)	50	
Average annual water network temperature (° C)	19.7	
Temperature released by users per unit area of the thermal zone (W / m^2)	4.0	
Average user presence rate	0.8	
Dissolved temperature by devices per unit area of the thermal zone (W / m^2)	5.6	
Average device operating rate	0.8	

BUILDING SHELL

Data on opaque building elements in contact with outside air

The building elements of the building will be coated with light colored coating. Where appropriate, layers of pavement slabs or ceramic tiles, etc. may be used. In any case, the absorption coefficients and the emission coefficients of the structural elements are taken from table 3.14 of T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017).

Table 62: Data required for the calculations.

Floor	**Type**	**Structural element**	**$\gamma 1$**	**U [$W/(m^2K)$]**	**A [m^2]**	**$\alpha 2$**	**$\varepsilon 3$**
	Masonry	T2	225	0.450	5.17	0.00	0.00
	Masonry	T7	225	0.432	1.41	0.00	0.00
	Masonry	T2	180	0.450	2.83	0.00	0.00

	Masonry	T7	180	0.432	0.32	0.00	0.00
	Masonry	T2	225	0.450	2.16	0.00	0.00
	Masonry	T7	225	0.432	0.24	0.00	0.00
	Masonry	T2	135	0.450	1.58	0.00	0.00
	Masonry	T7	135	0.432	0.42	0.00	0.00
	Masonry	T2	180	0.450	7.47	0.00	0.00
	Masonry	T7	180	0.432	1.08	0.00	0.00
	Masonry	T2	135	0.450	6.97	0.00	0.00
	Masonry	T7	135	0.432	0.98	0.00	0.00
	Masonry	T2	45	0.450	22.68	0.00	0.00
	Masonry	T7	45	0.432	2.52	0.00	0.00
	Masonry	T2	315	0.450	18.81	0.00	0.00
	Masonry	T7	315	0.432	2.33	0.00	0.00
	Masonry	T2	225	0.450	1.62	0.00	0.00
	Masonry	T7	225	0.432	0.18	0.00	0.00
	Masonry	T2	315	0.450	2.43	0.00	0.00
	Masonry	T7	315	0.432	0.27	0.00	0.00
	Floor	D2		0.369	64.25	0.00	0.00
	Masonry	T2	225	0.450	12.30	0.00	0.00
	Masonry	T7	225	0.432	1.98	0.00	0.00
	Masonry	T2	135	0.450	16.36	0.00	0.00
	Masonry	T7	135	0.432	2.33	0.00	0.00

	Masonry	T2	45	0.450	17.82	0.00	0.00
	Masonry	T7	45	0.432	1.98	0.00	0.00
	Masonry	T2	315	0.450	18.81	0.00	0.00
	Masonry	T7	315	0.432	2.33	0.00	0.00
	Ceiling	O1		0.397	51.15	0.00	0.00

DATA ON TRANSPARENT BUILDING BLOCKS

Below the characteristics of the frames are presented in detail and will be used in the building under study on a case by case basis.

The factor of solar gain "g" in the vertical impact of the glass is stated by the manufacturer and is shown in the detailed calculations listed.

In detail, the calculations on the transparent building blocks are given in the Computer Issue that accompanies this study.

For each window, the Fhor horizon shading factor, the Fov access shading factor and the Ffin side shading factor were calculated.

The ENAK-6 to ENAK-9 drawings show the shading angles of the frames from distant obstacles (building environment), shelters and side shading.

Table 63 gives the data required for the calculations for the southern openings (direct profit).

Table 63: Direct profit window data

Floor	Frame	γ	Surface area [m²]	U [W/(m²K)]	gw	Fhor heating	Fhor cooling	Fov heating	Fov cooling	Ffin heating	Ffin cooling
	S1	180	2.25	2.200	0.51	1.00	1.00	1.00	1.00	1.00	1.00

Table 64: Ceiling data

Floor	Frame	γ	Surface area [m²]	U [W/(m²K)]	gw	Fhor heating	Fhor cooling	Fov heating	Fov cooling	Ffin heating	Ffin cooling
	SW1	225	7.52	2.200	0.55	1.00	1.00	1.00	1.00	1.00	1.00
	SE2	135	1.80	2.200	0.49	1.00	1.00	1.00	1.00	1.00	1.00
	NW1	315	1.80	2.200	0.39	1.00	1.00	1.00	1.00	1.00	1.00
	NW2	315	0.32	2.200	0.28	1.00	1.00	1.00	1.00	1.00	1.00
	SW1	225	2.76	2.200	0.52	1.00	1.00	1.00	1.00	1.00	1.00
	SW2	225	2.76	2.200	0.52	1.00	1.00	1.00	1.00	1.00	1.00
	SE1	135	1.80	2.200	0.49	1.00	1.00	1.00	1.00	1.00	1.00
	SE2	135	2.76	2.200	0.52	1.00	1.00	1.00	1.00	1.00	1.00
	NW1	315	1.80	2.200	0.39	1.00	1.00	1.00	1.00	1.00	1.00
	NW2	315	0.32	2.200	0.28	1.00	1.00	1.00	1.00	1.00	1.00

Electromechanical building installations

The data used in the calculations of the energy efficiency of the building under study and related to its electromechanical installations, are as follows:

- Space heating system,
- Space cooling system,
- Hot water production system,
- Solar collector system for the production of hot water,

In the following paragraphs, the data used in the calculation of the energy efficiency of the building, in the software, are given in detail.

- Data for space heating system

The following table summarizes all the data for the heating system that will be used for the climatic zone using "Detached House".

Table 65: Data on the heating system of the "Housing" section

Climatic zone heating system 1 (Detached house)											
Heat production unit: Central air cooled heat pump power 4 kW											
Thermal efficiency of a unit or COP: 2,700											
Fuel type: Electricity											
Over-dimensioning factor ng_1: 1,000											
Insulation factor ng_2: 1,000											
Monthly percentage of thermal load coverage of the thermal zone by the system (%)											
JAN	1	FEB	1	MAR	1	APR	1	MAY	0	JUN	0
JUL	0	AUG	0	SEP	0	OCT	0	NOV	1	DEC	1
Space: Internal spaces ☐ Outer spaces over 20% •											
Temperature supply temperature in the distribution network (^{o}C): 50											

Heat return temperature in the distribution network (°C): 35		
Degree of thermal efficiency of distribution network: 95%		
Type of space heating terminals Immediate performance in interior wall		
Auxiliary type systems	**Number of systems**	**Power of auxiliary systems (W/m²)**
		5.00
Operating time of operating systems: 50% of the operating time of the building		

The calculated power of the boiler-burner was checked for over-sizing according to the relation 4.1 of T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017). The oversizing factor (ng1) is a unit, as is the boiler insulation factor (ng2). As a result, the final efficiency of the boiler will be the same as that given by the manufacturer, according to the heating study.

The circulator used to circulate hot water has a power given by the manufacturer. Because it covers each section under study, its power should be divided according to the thermal loads of the sections calculated by the heating study.

In Table 66 all the data for the heating system of the department with the use of "Detached house" are given collectively

- Data for space cooling system

The following table summarizes all the data for the cooling system of the department using "Detached house"

Table 66: Data on the cooling system of the "Detached House" section

Climatic zone cooling system 1 (Detached house)
Refrigeration production unit: Air-cooled heat pump power 4 kW
EER efficiency level: 3,000

Fuel type: Electricity											
Monthly rate of cooling load of the thermal zone by the system (%)											
JAN	0	FEB	0	MAR	0	APR	0	MAY	0.5	JUN	0.5
JUL	0.5	AUG	0.5	SEP	0.5	OCT	0	NOV	0	DEC	0
Space: Internal spaces ☐ Outer spaces over 20% •											
Cold medium supply temperature in the distribution network (° C):											
Cold medium return temperature in the distribution network (° C):											
Distribution refrigeration efficiency rating: 98%											
Auxiliary type systems				**Number of systems**				**Power of auxiliary systems (W/m^2)**			
								5.00			
Operating time of operating systems: 30% of the operating time of the building											

- Ventilation system data

The ventilation that is applied in all areas of the building is natural and according to T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017), the air supply will be equal to the required fresh air.

From table 2.3 of T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017) natural ventilation is obtained according to the use of the section under study as follows:

- Detached house: 0.75 m3 / h / m2.
- Data for hot water system

The data (power, fuel, distribution network, etc.) of the system used in the building under study for the production of hot water are presented in Table 67 below.

The distribution network is insulated according to the minimum specifications of T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017) and with a percentage of losses shown below.

Table 67: Hot water system data

Water heating system Climatic zone 1 (Detatched house)											
Type of hot water production unit: Solar water heater and electric water heater											
Thermal efficiency of a unit or COP: 0.80											
Fuel type: Solar power and electricity											
Monthly percentage of thermal load coverage for water heating by the system (%)											
JAN	1	FEB	1	MAR	1	APR	1	MAY	1	JUN	1
JUL	1	AUG	1	SEP	1	OCT	1	NOV	1	DEC	1
Heated water recirculation system: NO											
Network space: Indoors • Outdoors over 20% •											
Heated water heat distribution efficiency (%): 100%											

- Data for solar panel system

The solar panels that will be installed on the roof, have the ability to cover part of the building's CNS. The type, surface, degree of utilization, but also the other elements used for the calculations of the energy efficiency of the building are given in table 6.9. following:

Table 68: Solar collector system data

Solar water heaters Climatic zone 1 (Detatched house)	
Type of solar water heater	**Flat solar water heater**
Solar utilization rate for hot water use (%):	34
Solar utilization rate for space heating (%):	34
Area of solar panels (m^2):	4.5
Tilt of solar panels (°):	45
Orientation of solar panels (°):	180
F-s shading factor:	1.00

- Data for lighting system

The technical characteristics of the lighting systems of the building, where they must be taken into account according to the T.O.T.E.E. (Energy G. M., 2017), are summarized below:

The luminaires that will be used for the residential areas and for the common non-heated areas, are not taken into account in the calculations.

- Reference building data

The data of the reference building are automatically entered by the software, in parallel with the introduction and depending on the use and operation of the building or the thermal zones and in accordance with the provisions of article 9 of the Code of Civil Procedure. and in T.O.T.E.E. 20701-1 / 2010 (Energy G. M., 2017).

RESTORATION RESULTS

The following paragraphs detail the results for specific energy consumption (kWh / m^2), such as:

Required loads for heating and cooling

Annual final energy consumption (kWh / m^2), total and per use (heating, cooling, ventilation, DHW, lighting), per thermal zone and per form of energy used (electricity, oil, etc.)

Annual reduced primary energy consumption (kWh / m^2) per year (heating, cooling, ventilation, DHW, lighting) and corresponding emissions of carbon dioxide.

The coefficients of conversion into primary energy and emission of gaseous pollutants, according to K.EN.AK. and T.O.T.E.E. 20701-1 / 2010 (paragraph 1.2) (Energy G. M., 2017) are as follows:

Table 69: Coefficients of conversion into primary energy and emission of gaseous pollutants

Energy source	**Rate of conversion to primary energy**	**Dissolved pollutants per unit of energy ($kgCO_2/kW$)**
Natural gas	1,05	0,196
Oil for heating	1,10	0,264
Electricity	2,90	0,989
Liquid gas	1,05	0,238
Biomass	1,00	---

The increased use of electricity significantly burdens the final consumption of primary energy in the building, as well as the release of gaseous pollutants, according to the rates of conversion of primary energy.

ENERGY CONSUMPTION

The section under study has the use of "Detached house" and the required loads for heating and cooling are given in Table 70.

These loads also include ventilation loads for each season.

Table 70: Required cooling parts for building section cooling

Use: Detached house

Required heating / cooling loads (kWh / m²)													
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT
Heating	9.10	7.60	5.10	0.60	0.00	0.00	0.00	0.00	0.00	0.00	2.80	7.40	32.60
Cooling	0.00	0.00	0.00	0.00	3.40	14.90	20.70	19.30	5.20	0.00	0.00	0.00	63.60

The corresponding energy consumption per final use is given in the table below. The final consumption for heating and cooling includes the electrical consumption of the auxiliary systems of each installation.

Table 71: Final energy consumption per final use

Use: Detached house

Final energy consumption per final use (kWh / m²)													
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT
Heating	4.50	3.80	3.10	0.50	0.00	0.00	0.00	0.00	0.00	0.00	2.30	3.90	18.20
Solar energy for heating	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Cooling	0.00	0.00	0.00	0.00	0.40	2.90	3.80	3.60	0.60	0.00	0.00	0.00	11.40
Solar power for heated water	1.50	1.50	2.00	2.10	2.40	2.40	2.60	2.60	2.30	2.00	1.60	1.40	24.00
Total	4.50	3.80	3.10	0.50	0.40	2.90	3.80	3.60	0.60	0.00	2.30	3.90	29.60

The corresponding fuel consumption per fuel (useful energy source) is given in Table 72.

Table 72: Fuel consumption - "Detached house"

Use: Detached house

Fuel consumption (kWh/m^2)	
Electricity	29.6
Solar power	23.0
Geothermal	0.0
Total	29.6

The primary energy consumption per final use of the building section is given in Table 73 following.

Table 73: Consumption of primary energy per final use

Use: Detached house

Final use	**Consumption of primary energy (kWh/m^2)**	
	Reference building	**Examined building**
Heating	53.1	52.7
Cooling	43.0	35.2
Water heating	0.0	0.0
Total	96.1	87.8

The corresponding primary energy consumption and CO2 emissions per fuel are given in Table 74.

Table 74: Consumption of primary energy and emission of gaseous pollutants per fuel

Use: Detached house

Final use	**Consumption of primary energy sources (kWh/m^2)**	**Gas emissions (kg/year/m^2)**
Electricity	29.6	29.0
Solar power	23.0	0.0
Geothermal	0.0	0.0
Total	29.6	29.0

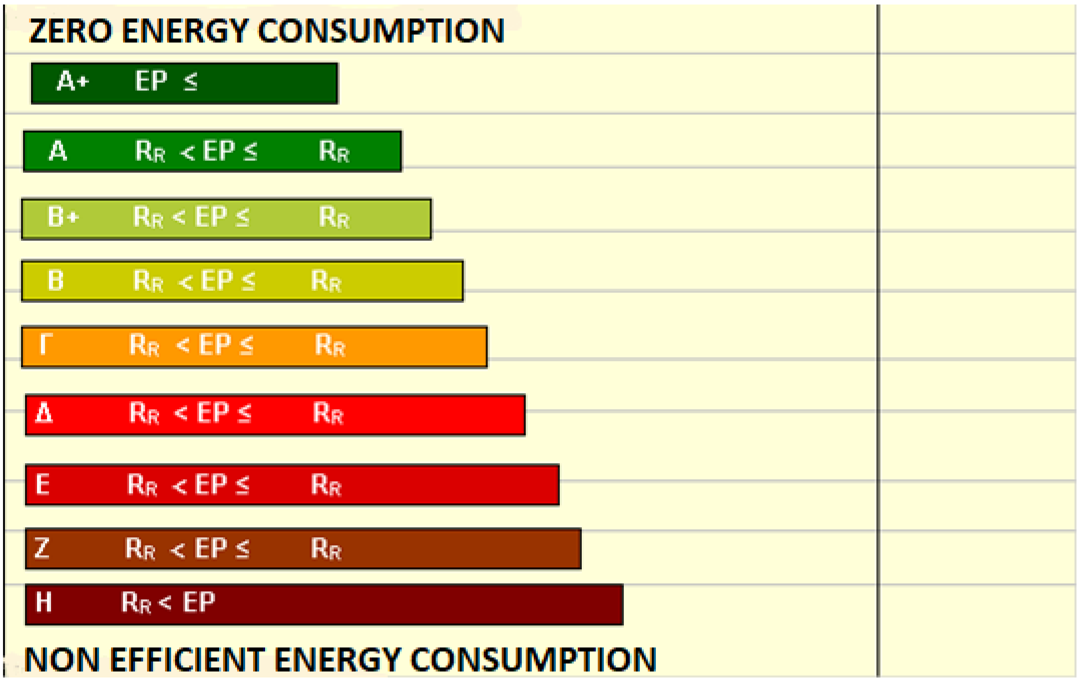
ENERGY CONSTRUCTION USE OF BUILDING

According to the results of the calculations for the reduced primary energy consumption (table 74) of the section of the building under study, it seems to belong to category B (see next figure figure).

Therefore, the minimum requirements of KENAK for the consumption of primary energy are as high as possible, equal to that of the reference building.

B

87.80 kWh/m^2



This whole analysis and the data gathered, are carried out by the author who is a certified mechanical enginner. They are calculated with the KENAK software from 4M using real world data. The data can be used in the next chapter in order to have a more realistic image of the energy flows in and out of the house for the comparison of the two families scenario.

4.3 Two families comparison scenario

As mentioned before, the impact that user behavior can have on energy use cannot be easily measured. This is due to the substantial difference that each user has from one another, as well as different characteristics of them like gender, age, nationality, community, religion, work, hobbies, family and many more. A direct comparison of two families with different user behavior, both living in an identical house (with a different house layout), can show just how much user behavior can impact energy use. In this chapter such a comparison is analysed, aiming to show the impact user behavior can have.

The comparison scenario will be as close to reality as possible using real world data. At first, all the characteristics for each family are going to be analyzed, leading further into the direct comparison between the two families. In this case the difference in user behavior is caused by the economic gap betweem the two families. The first family is more coservant with its energy uses, while the second one has the luxury to be more consuming.

The first family is an agricultural one. It consists of four members, the two parents and two underaged kids. The occupation of the father is a farmer, while the mother is a housewife. The family is considered to be in the medium-average economic class. The children are attending school.

The second family is again a four member family. It consists of the two parents and two kids. The parents are both private employees. The husband is a bank manager and the wife is a bank employee. The family is considered to be in the mid to upper economic class. The children are attending school.

The results from the KENAK software, provide a real world point of view regarding the energy needs of the house for heating, cooling, lighting and hot water. However the modern way of using energy for heating, cooling and hot water must also be considered. In nowadays, people use HVAC systems as much as they can afford and not as much as needed to fully cover the house's needs. For the comparison scenario, the energy use of the HVAC systems for the two families was calculated while considering the needs of the house (with data drawn from the previous chapter), as well as the financial status of each family.

The first family belongs in the mid-average economic class. With this taken into consideration, the electrical appliances and their respective energy uses were distributed accordingly. The financial status of this family limits their energy uses. For each family there are certain energy uses that are not corresponded to a specific user, but to the whole house, like alarm systems, exterior lighting and more.

Certain energy uses are fixed or constant for the house. Such as the HVAC system, a percentage of the total energy used for lighting, the dryer, the fridge, the microwave oven, the stereo, the telephone and the wifi router. Some of these loads are constant, while others are semi constant or even instant at different times per day.

For the first family, the husband that is a farmer, is considered to be absent from home at least 9-10 hours each weekday, 7-8 hours on Saturday and 3-4 hours on Sunday. Due to his line of work, he uses heated water every day and has little spare time, that he spends watching television and sitting on the computer.

The wife is unoccupied and has the role of the housewife. She is absent from the house 2 hours on average every day. Because she is in the house for most of her day and because she does all the chores and the cooking, she uses more energy that the other individuals. She also uses much more energy intensive loads, like the electric cooker, the hair dryer, the iron and the vacuum cleaner. The housewife uses different electrical appliances like the electric cooker simultaneously with the mixer, the microwave oven and the television for example.

The children are considred as one individual in the calculations and the tables, because their energy uses are almost identical. The children are absent from home for about 7-8 hours on weekdays and 4-5 hours on the weekend. Their energy uses are water heating and hair dryer every day, as well as television, computer and gaming console in ther free time.

The second family belongs in the upper economic class. With this taken into consideration, the electrical appliances and their respective energy uses were distributed accordingly. The financial status of this family allows more freedom on the amount of energy used. For each family there are certain energy uses that are not corresponded to a specific user, but to the whole house, like alarm systems, exterior lighting and more.

For the second family, the husband is a bank manager and is considered to be absent from home 9 hours on average on weekdays. On the weekend 5 hours on average each day. Due to his line of work, there is an every day use of heated water, washing machine and dryer. In his spare time he watches televeision and sits on the computer. The chores of the house are separated between the husband and wife.

The wife is a bank employee that works alongside the husband. She is absent from home 9 hours on average on weekdays. On the weekend 5 hours on average every day. Due to her line of work she also uses heated water, the washing machine and the dryer every day. She does half of all the house chores. In her spare time she watches television, sits on the computer and also uses the treadmill.

Again the children are considered us on individual in the calculations and the tables, because their energy use is almost identical. The children are absent from home for about 7-8 housrs on weekdays and 4-5 hours on the weekend. Their energy uses are water heating and hair dryer, as well as television, computer and gaming console in their free time.

Chapter 5
Results and suggestions for improvements and implementation

In order to compare the energy use of the two families in question, their respective energy uses must be monitored. The way of monitoring is through talking with the families and figuring out just how much each electrical appliance is used on a weeklong basis. This chapter will display the results of the analysis and will provide a comparison, improvement methods and their implementation.

After figuring out for how long each appliance is used, the exact power usage of each appliance is determined. The data for every load is gathered from the appliance's manufacturers. All the appliances are considered to be of modern construction, manufactured in the last 5-8 years. In order for the comparison scenario to be focused on user behavior, the appliances each family has are considered to be the similar, with some exceptions. Data were gathered for the energy uses of the two families, for the period of a week. The weeklong time period was selected, in order to have a result much closer to reality and to also be able to calculate the yearlong energy consumption. The way energy consumption was calculated, was first through taking data from the two families. After energy consumption for every appliance were distributed on a table in kW. Every family member as well as the house itself, have certain hours attributed to them for the use of each load. These hours times the load in kW equal the energy consumption measured in kilowatt hours (kWh).

The results for each family member, the house and their respective energy consumption are displayed in the tables below in kWh, for weeklong and yearlong time periods.

Agricultural family - medium/average economic class																						
Energy uses	The House	Husband (kWh/day)							Wife (kWh/day)							Children (kWh/day)						
	Weeklong (kWh/week)	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Lighting	1.68	0.12	0.12	0.12	0.12	0.12	0.15	0.18	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.12	0.12	0.12	0.12	0.12	0.18	0.18
HVAC	21																					
Television 55"																						
Television 32"		0.05	0.05	0.05	0.05	0.05	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Television 28"		0.02	0.02	0.02	0.02	0.02	0.04	0.04	0.08	0.08	0.08	0.08	0.08	0.08	0.08							
Computer		0.13	0.13	0.13	0.13	0.13	0.19	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.5	0.5	0.5	0.5	1	1
Water heating		0.2	0.2	0.2	0.2	0.2	0.2	0.2		0.2		0.2		0.2		0.8	0.8	0.8	0.8	0.8	0.8	0.8
Electric Cooker									2.4	2.4	2.4	2.4	2.4	2.4	2.4							
Dryer	6																					
Wasking machine	0.75																					
Dishwasher																						
Fridge	6.3																					
Hair dryer										0.02		0.02		0.02		0.02	0.02	0.02	0.02	0.02	0.02	0.02
Iron									0.28	0.28	0.28	0.28	0.28	0.28	0.28							
Vacuum cleaner									2.8				2.8									
Microwave oven	0.24																					
Mixer	0.24																					
Nightlight									0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Sewing machine									0.15	0.15	0.15	0.15	0.15	0.15	0.15							
Stereo	1.05																					
Telephone	0.336																					
Wifi router	1.008																					
Toaster		0.01														0.01	0.01	0.01	0.01	0.01	0.01	0.01
Gaming console																						
Alarm																						
Treadmill																						
Total:	**38.604**	**4.1845**							**33.65**							**14.949**						
Weeklong total:	**91.3875**																					
Yearlong total:	**4752.15**																					

Table 75: Agricultural family energy uses (measured in kWh)

Bank employees family - Upper class family																						
Energy uses	The House	Husband (kWh/day)							Wife (kWh/day)							Children (kWh/day)						
	Weeklong (kWh/week)	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Lighting	2.52	0.12	0.12	0.12	0.12	0.12	0.15	0.18	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.12	0.12	0.12	0.12	0.12	0.18	0.18
HVAC	42																					
Television 55"		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Television 32"		0.05	0.05	0.05	0.05	0.05	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Television 28"																						
Computer		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1
Water heating		0.2	0.2	0.2	0.2	0.2	0.2	0.2		0.2		0.2		0.2		0.8	0.8	0.8	0.8	0.8	0.8	0.8
Electric Cooker		2.4		2.4		2.4		2.4		2.4		2.4		2.4								
Dryer	6																					
Wasking machine	1.75																					
Dishwasher	9.45																					
Fridge	6.3																					
Hair dryer										0.03		0.03		0.03		0.05	0.05	0.05	0.05	0.05	0.05	0.05
Iron		0.33		0.33		0.33				0.33		0.33		0.33								
Vacuum cleaner		2.8											2.8									
Microwave oven	0.24																					
Mixer	0.24																					
Nightlight									0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Sewing machine																						
Stereo	1.75																					
Telephone	0.336																					
Wifi router	1.008																					
Toaster		0.01														0.01	0.01	0.01	0.01	0.01	0.01	0.01
Gaming console																0.18	0.18	0.18	0.18	0.18	0.36	0.36
Alarm	1.68																					
Treadmill		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25							
Total:	**73.274**	**23.682**							**24.35**							**18.879**						
Weeklong Total:	**140.185**																					
Yearlong Total:	**7289.62**																					

Table 76: Private employees family energy uses (measured in kWh)

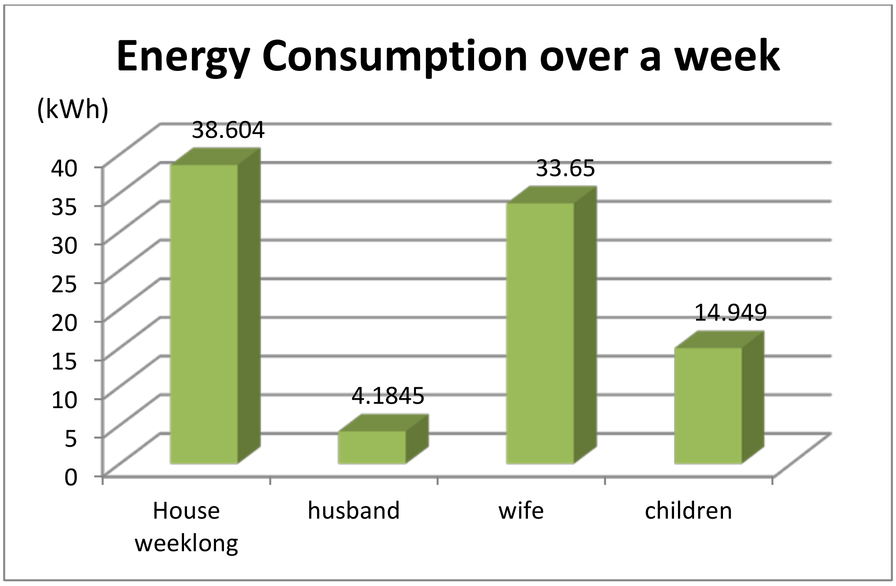


Diagram 1: Energy consumption for the first family for over a week

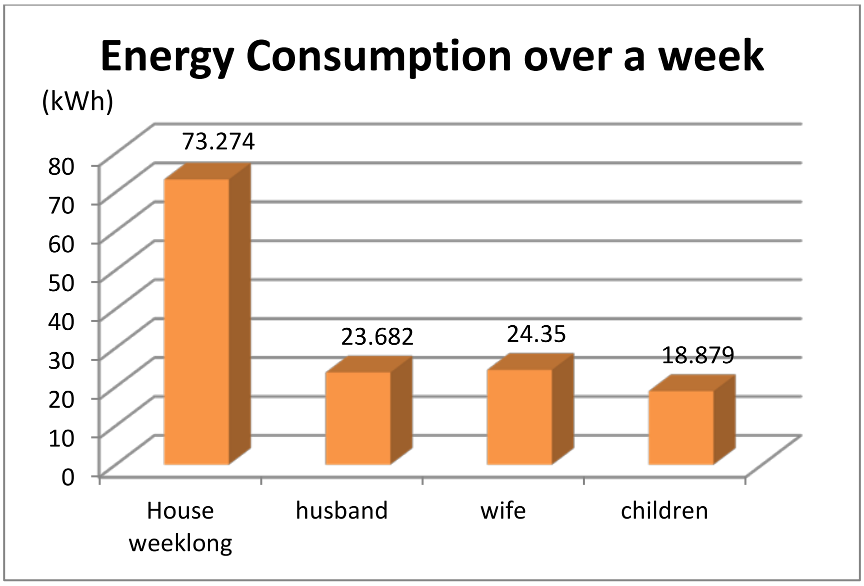


Diagram 2: Energy consumption for the second family for over a week

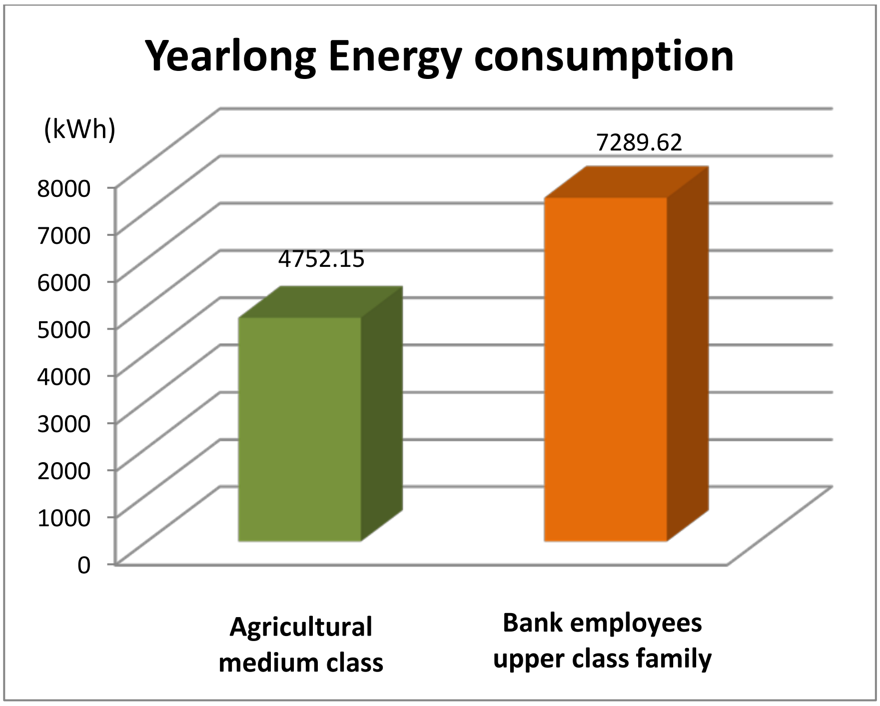


Diagram 3: Yearlong energy consumption for the two families

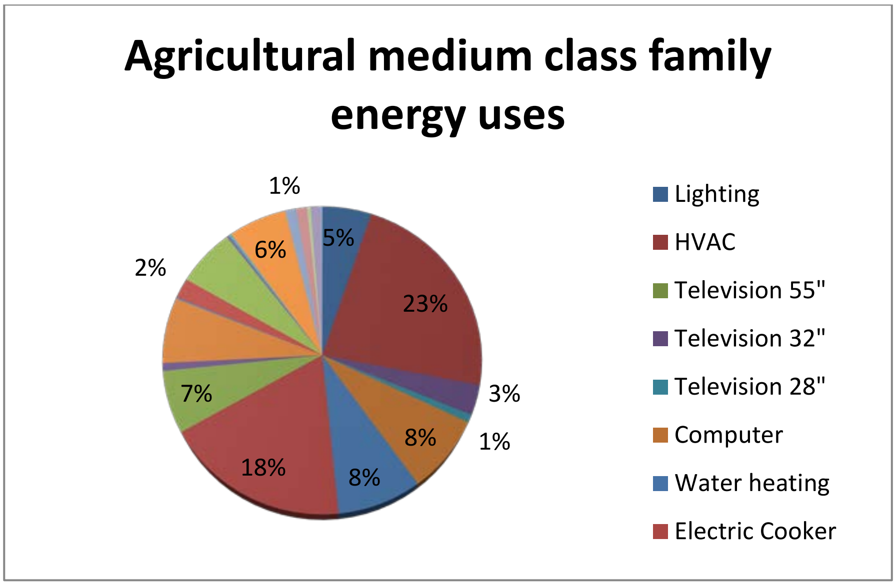


Diagram 4: Medium class family energy uses

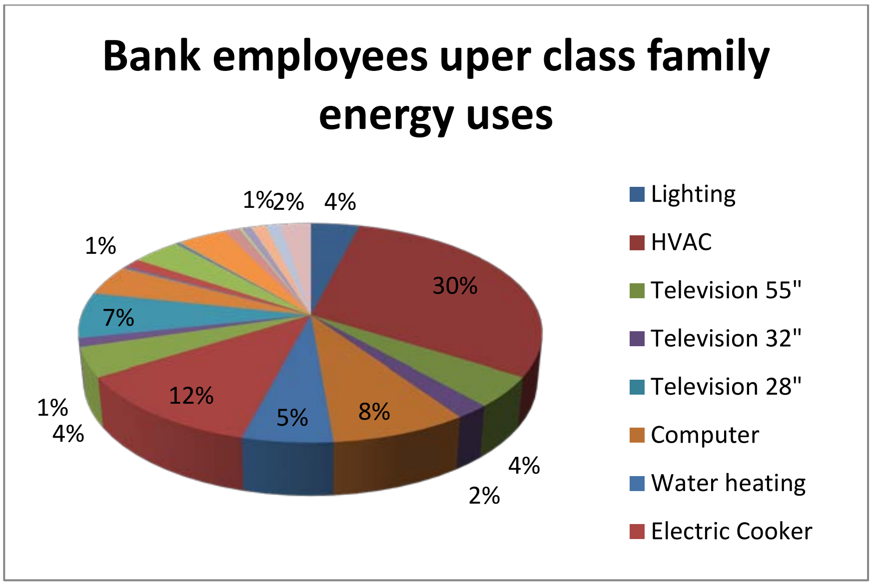


Diagram 5: Upper class family energy uses

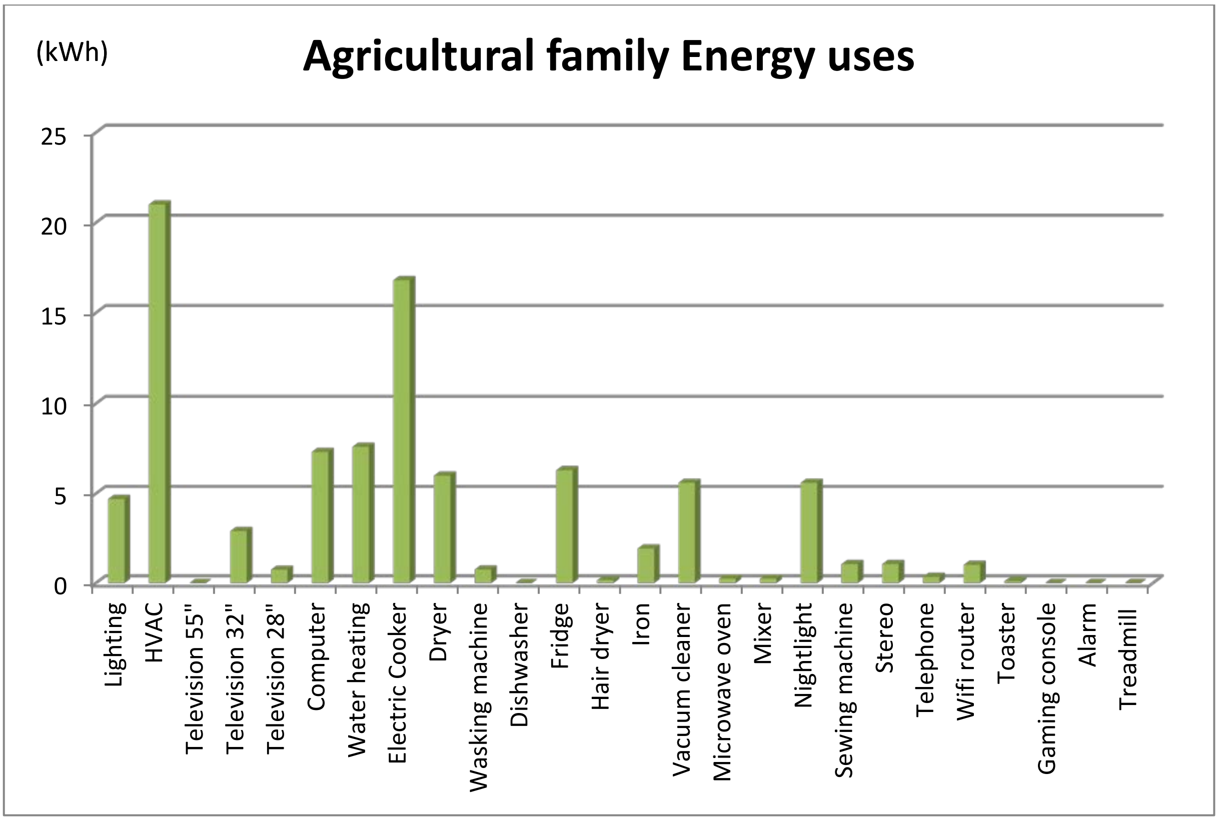


Diagram 6: Medium class family energy consumption per use

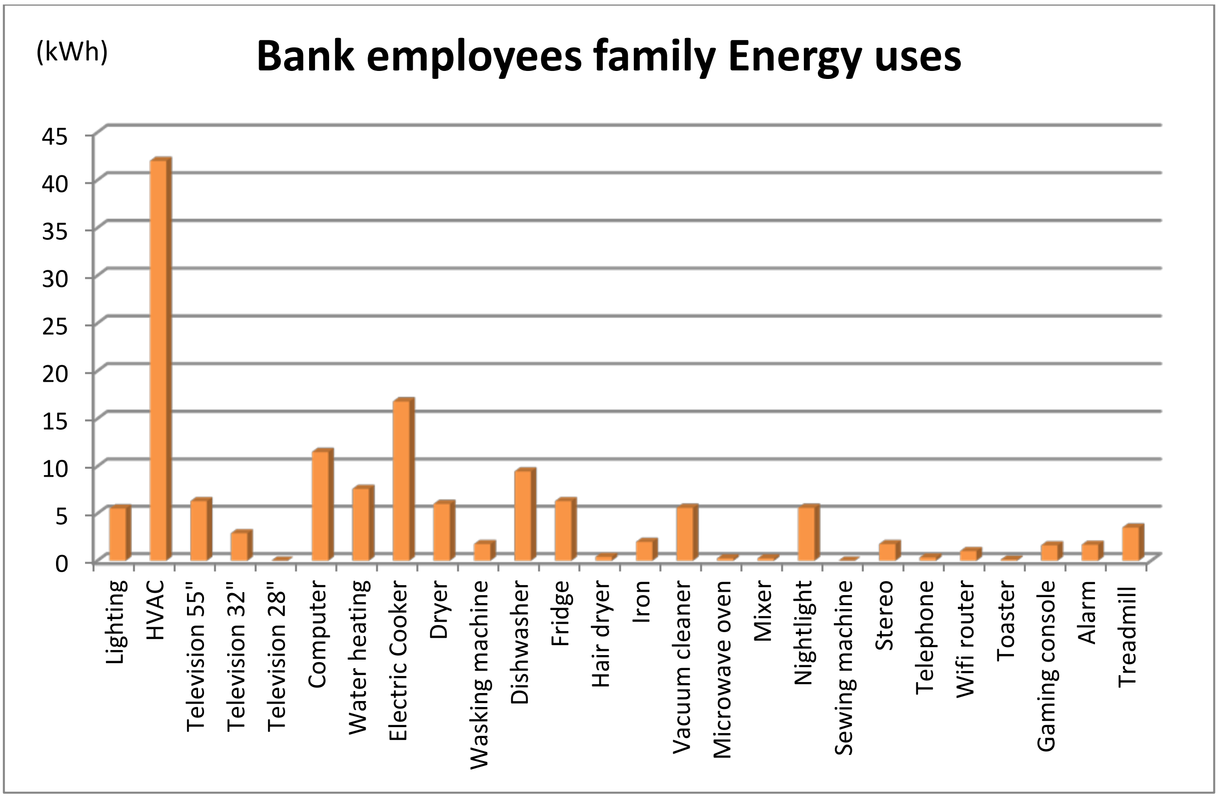


Diagram 7: Upper class family energy consumption per use

Comparison per energy use

- HVAC

The first family uses the HVAC system in very hot or cold conditions and in many cases the family lives out of their comfort zones due to economic difficulties. The second family is able to afford the use of the HVAC system to cover their needs and keep everyone well-in their comfort zone. These loads are the biggest for both families and the second family's is almost double than the first's.

- Lighting

The first family is as conservative as they can be and use lighting only where they need to and for their work, to organize their agricultural equipment early in the morning or late afternoon when the darkness falls. The second family is not as conservative with their use of lighting. They use more and have loads that are not necessary, like lights for the garden, the parking space and the stairs for aesthetic reasons.

- Water heating

Regarding water heating both families have similar usage. Both husbands use heated water daily, due to their line of work, one gets dirty every day as a farmer and the other has to follow the dressing code every day as a bank manager. Both wives use heated water day by day, because they do not need it daily. The children for both families also use heated water every day. For both families the use of heated water is normal and during the summer the largest part of Spring and Autumn the load are covered from the solar water heater as the KENAK analysis shows. For the rest of the year the use of electricity for water heating is necessary.

- Electric cooker

Both families have the same almost usage of the electric coocker as both have four members. This load is one of the highest as electric cookers draw more than 2 kW.

- Washing machine and dryer

Both families use the washing machine and the dryer often. The second family uses the washing machine more, because both adults have a certain dressing code for their jobs and must have fresh clean clothes. As for the first family, the husband who is a farmer, can reuse this clothes and change them day by day. The housewife does not need clean clothes so often. The children for both families have similar usages.

- Fridge

Both families have similar use of the fridge, as it is difficult to change the amount of this load, regardless of user behavior.

- Microwave oven, mixer, toaster

These applliances are used in the same pattern for both the families.

- Vacuum cleaner, iron, hair dryer

These two loads are similar for both families with the exception that for the first the housewife uses these appliances and as for the second, both adults use them by turn. Hair dryer has similar usage from both families, by the wives and children.

- Television, computer

Both families have two televisions, although the second family's are bigger and therefore consume more energy. The second family also uses the televisions more than the first family. The first family has less and older computers than the second family and consume less in total. The second family use the computers a lost in their freetime and have a substantial load.

- Telephone, wifi router, stereo

Telephone and wifi router are constant loads for both families. The stereos are mostly used by the children, but the second family has a larger and more modern stereo which also consumes more energy.

- Loads not common for both families

The first family due to economic reasons, cannot afford luxuries or expensive appliances for entertainment. The housewife uses the sewing machine every day as a hobby and to repair damaged clothes for the rest of the family or even make new. The second family has the luxury to afford more electrical appliances, for comfort and security and entertainment purposes. First they use the dishwasher on a daily basis, that is a considerable load. The second family also has an alarm system installed, which is a constant but small load. The adults use the treadmill for half an hour each, every day, which is a medium load . The children of the second family also have a gaming console that they use in their spare time every day. It is a rather small load.

The two families have different energy usage due to their gap in economic class and also because of their daily patterns. The agricultural family limits their energy use, according to what they can afford, with priority to cover their basic needs first. Their energy use is limited and in some cases their needs for heating and cooling are not fully coverd. Their energy use for heating and cooling is not as efficient, because the heat pump is turned in and off, without maintaining a stable temperature. This leads to more energy consumed as the heat pump has to work on maximum power in order to reach the set point. However the second family, consumes more energy for heating and cooling, but their energy use is more efficient because the heatp pump maintains the room temperature, instead of working always on full. User behavior in this case affects energy consumption, as the members of the second family overconsume energy for heating and cooling, because they are used to and do not really bother changing set points or chaning HVAC operational hours. As far as the rest of the loads, like lighting and electrical appliances the first family although using some appliances less, still use a lot of energy because they are aoutdated and old. However the second family, although they have more modern and therefore more efficient electrical appliances, still consume more energy. Their energy use patterns regarding meeting their basic needs, besides heating and cooling, are very similar.

Improvement methods

Energy consumption for both families is not perfect but is not the worst either. There is still room for improvement. The house is relatively new still, it is well insulated and has modern double glazing windows. An improvement for both families would be sealing and weather stripping of doors, specifically the only door leading outside. It would minimize thermal losses in winter and thermal gains in summer as every other opening has proper weather stripping and sealing. Another improvement for both families would be the installation of shading in the southeast side of the house where it lacks. The installation of shading would lower unwanted thermal gains during the summer. While solar water heaters in Greece do not have to be of very high efficiencly, due to plenty of sunlight, a higher efficiency solar water heater would minimize or almost absolve the use of electricity for water heating. However such units are very expensive. One more way of lowering energy use for both families would be the replacement of every light with LED, that have a higher efficiency and life expectancy. A way that would lower energy use as well as energy bills and perhaps is one of the most important improvents, is the installation of renewable energy technologies such as solar panels or wind turbines. Such systems, specifically in Greece, use netmetering which is the offsetting of energy produced by the renewables and energy used by the users. Then the energy produced is removed from the energy used, thus lowering the total amount that is charged, or if it is higher it is added and pays back the user. The second family can also utilize the smart home applications which after being properly set up would need minimal or even zero feedback from the user to operate. Every house electrical appliance would be controlled by the system including HVAC and lighting without the user bothering to change set points.

All of the above suggested methods will undoubtably benefit both families and lower their energy use, each on a different amount and scale. However almost all of them require an initial investment, where the families might not be able to afford or do not consider it a priority. Also the payback period for each improvement might be longer than what the families expect. Here is a suggestion that can solve such problems. The Greek government has introduced a program called saving at home, support by the EU, that aims to increase the energy efficiency of residential buildings and lower their energy use. The way this program works, is that it uses the family's financial information to decide on the amount of subsidy the family is going to receive. This also depends on the condition of the house and the results of an energy audit for the house. In the case of the two families in question, the first family would get full coverage from the program because of their economic status, however the house receives a B mark in the energy audit (as shown in the house analysis resulting from the KENAK software) so there are not many possibilities that the program covers. The program is capable of covering almost 70% for the installation of a high efficiency solar water heater and shading. The rest of the improvements suggested cannot be covered by this specific program. The second family is not capable of receiving and subsidy because of their financial status and because of the good condition of the house. The only thing that the program can give is easier terms for a loan that covers everything they replace. Another suggestion for both families is to utilize the so called night bill of the Greek Public Power Corporation (D.E.I.). This night charge allows the user for a few hours during midday and the whole night, to have a substantial discount to his/hers energy bill. The user can utilize this by using high power loads during this time like, electric water heating, dishwasher, electric cooker, dryer, washer, iron and more.

Regarding user behavior the second family has room to improve, while the first is not overconsuming because they cannot afford to. An improvement method and also a suggestion for the second wealthier family would be to attend a seminar about energy conservation and consumption or energy use special courses. The adult family member can learn how to use less energy while achieving very similar results in comfort and use.

The children can attend courses in their education, that will help raise their awareness towards the environment and help them conserve more energy without overconsuming, These methods will change the general attitude of the second family, which does not really care about overconsuming or using energy under not ideal conditions.

Conclusion

Climate change and energy performance have become two of the most pressing issues of the modern age. Energy performance and sustainability is directly connected with residential energy use, as it affects them significantly. Therefore each and everyone can assist in lowering energy use and consumption by improving their own consumption through the many methods analyzed and proposed in this study. But before improving, first the issues must be identified through an energy audit. After, identifying the issues, improvement methods and their implementation are proposed. This is where user behavior comes in to play, as it is a factor that cannot that easily be monitored, but is able to improve energy efficiency with minimal effort. This study shows how much user behavior affects energy consumption, by comparing two different families living in identical houses. The first family cannot afford to overconsume and therefore is very sensitive and conscious about their energy consumption, while the second overconsumes and is not that conscious regarding their energy use. The first family is forced to be sensible while the second is not. So, the second family must also be forced in a way, which is the main issue of modern generations, through educating acts, seminars, advertisements and legislation. User behavior proved to affect residential energy performance substantially and how much people will adapt or change their behavior in the future will play a significant part on problems like climate change, global warming and pollution. Therefore raising people's awareness about their energy use is of outmost importance.

Bibliography

(FSEC), F. S. (2014). *Windows Orientation and Shading*. Ανάκτηση από Florida Solar Energy Center (FSEC): http://www.fsec.ucf.edu/en/consumer/buildings/homes/windows/shading.htm

Administration, U. E. (2015). *2015 Residential Energy Consumption Survey.*

Agency, E. E. (n.d.). *Member States must cut emissions across all sectors to achieve EU climate targets by 2030.* Ανάκτηση από https://www.eea.europa.eu/themes/climate/trends-and-projections-in-europe/national-action-across-all-sectors/national-action-across-all-sectors

AMDEA. (2011). *Energy Labels*. Ανάκτηση από Time to Change: http://www.t2c.org.uk/chilling/energy-labels/

Antonio Paone, J.-P. B. (2018). The Impact of Building Occupant Behavior on Energy Efficiency and Methods to Influence It: A Review of the State of the Art. *Energies*.

Atkinson J, C. Y.-S. (2009). *Natural Ventilation for Infection Control in Health-Care Settings.* Geneva: World Health Organization.

Barbu A.D., G. N. (2013). *Achieving Energy Efficiency through Behaviour Change: What Does It Take?* Copenhagen, Denmark.

Beerepoot, M. (2007). *Energy policy instruments and technical change in the residential building sector.*

Caniggia, G. M. (2001). *Architectural Composition and Building Typology.* Alinea.

Cinta. (1996). *White UPVC Double Glazed Windows*. Ανάκτηση από Indiamart: https://www.indiamart.com/proddetail/upvc-double-glazed-windows-19910748655.html

Council, E. P. (2018). *Directive 2012/27/EU on Energy Efficiency.*

Darling, D. (2007). *Weatherstripping*. Ανάκτηση από DavidDarling: https://www.daviddarling.info/encyclopedia/W/AE_weatherstripping.html

E.Shove, G. (2014). *What is energy for? Social practise and energy demand.*

Encyclopedia, B. O. (2017, 02 15). *Water Heating.* Ανάκτηση από Wikipedia: https://en.wikipedia.org/wiki/Water_heating

Energuide. (2019). *How much energy do my household appliances use?* Ανάκτηση από energuide.be: https://www.energuide.be/en/questions-answers/how-much-energy-do-my-household-appliances-use/71/

Energy, G. M. (2017). *Analytical National parameters description for the calculation of building energy efficiency and the issue of the building energy audit.* Ανάκτηση από TEE: http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/GR_ENERGEIAS/kenak/files/TOTEE_20701-1_2017_TEE_1st_Edition.pdf

Energy, O. o. (n.d.). *Selecting a new water heater*. Ανάκτηση από Energy Saver: https://www.energy.gov/energysaver/water-heating/selecting-new-water-heater

Gallucci, M. (2019). *Energy equity: bringing solar power to low-income communities*. Ανάκτηση από GreenBiz: https://www.greenbiz.com/article/energy-equity-bringing-solar-power-low-income-communities

Ganti, A. (2019, September 23). *Rational Choice Theory*. Ανάκτηση από Investopedia: https://www.investopedia.com/terms/r/rational-choice-theory.asp

GreenMatch. (2019). *Households Fight Greenhouse Gas Emissions*. Ανάκτηση από GreenMatch: https://www.greenmatch.co.uk/blog/2019/02/households-fight-greenhouse-gas-emissions

Grondzik, W. T. (2007). *Air-conditioning System Design Manual.* Elsevier.

Guerra-Santin, O. (2012). *The effect of energy performance regulations on energy consumption, Energy and Buildings.*

Gynther L., L. B. (2015). *Monitoring of energy efficiency trends and policies in the EU. An Analysis Based on the ODYSSEE and MURE Databases.* Aigues Vives, France.

Jackie, C. (n.d.). *Smart House - Definition of Architecture Terms.* Ανάκτηση από http://architecture.about.com/od/buildyourhous1/g/smarthouse.htm

Jester, T. C. (2014). *Twentieth-Century Building Materials: History and Conservation.* Getty Publications.

Joeri Rogelj, D. S. (2018). *Mitigation Pathways Compatible with 1.5 oC in the Context of Sustainable Development.*

John Littler, R. T. (2003). *Design with energy The conservation and use of energy in buildings.*

Kvols Heiselberg, E. B. (2002). Impact of Open Windows on Room Air Flow and Thermal Comfort. *International Journal of Ventilation*.

Michael J. Brandemuehl, K. M. (2011). *Effects of variations of occupant behavior on residential building net zero energy performance.* Colorado.

Myles R. Allen (UK), O. P. (n.d.). Global Warming of 1.5 oC. Στο O. P. Myles R. Allen (UK), *Global Warming of 1.5 oC.*

Planton, S. (2016). *Annex III. Glossary: IPCC - Intergovernmental Panel on Climate Change.*

Quotev. (n.d.). *Should you live in an urban, suburban or rural area?* Ανάκτηση από Quotev: https://www.quotev.com/quiz/10009200/Should-you-live-in-an-urban-suburban-or-rural-area

Reports, G. (2015). *Education increases awareness and concern for the environment*. Ανάκτηση από World Education Blog: https://gemreportunesco.wordpress.com/2015/12/08/education-increases-awareness-and-concern-for-the-environment/

Sato, D. M. (2019). *GISS Surface Temperature Analysis*. Ανάκτηση από NASA: https://data.giss.nasa.gov/gistemp/graphs_v4/

Sean Barker, S. K. (n.d.). Empirical Characterization and Modeling of Electrical Loads in Smart Homes. Στο S. K. Sean Barker, *Empirical Characterization and Modeling of Electrical Loads in Smart Homes.* Massachusetts.

Simone Ferrari, V. Z. (2016). *Building Energy Performance Assessment in Southern Europe.*

Steffen, M. (2014). *Residential Lighting Design.* The Crowood Press Ltd.

Superstore, I. (2019). *External wall insulation diagram*. Ανάκτηση από Insulation Superstore: https://www.insulationsuperstore.co.uk/blog/how-to-install-external-wall-insulation/external-wall-insulation-diagram/

Tettey, U. Y. (2017). *Primary Energy Use of Residential Buildings - Implications of Materials, Modelling and Design Approaches.*

Valerie Masson-Delmotte, P. Z. (n.d.). *Global warming of 1.5 Celcius.*

West, L. (2020). *Solar Water Heaters: What are the Benefits?* Ανάκτηση από ThoughtCo: https://www.thoughtco.com/solar-water-heaters-benefits-1204179

Wikipedia. (2020, February 21). *Climate*. Ανάκτηση από Wikipedia: https://en.wikipedia.org/wiki/Climate

Wikipedia. (n.d.). *List of home appliances*. Ανάκτηση από Wikipedia: https://en.wikipedia.org/wiki/List_of_home_appliances

Wkipedia. (2020, 2 10). *Building typology*. Ανάκτηση από Wikipedia: https://en.wikipedia.org/wiki/Building_typology

Yasa, A. (2017). Evaluation of the Effect of the Different Distances between Two Facades Natural Ventilation on Atrium Buildings with DSF and PMV-PPD Comfort. Στο A. Yasa.

Zarifopoulos. (2016). *The world smart home market will overcome 14 billion dollars by 2017*. Ανάκτηση από Zafiropoulos: https://zarifopoulos.com/global-smart-home-market-to-exceed-14-billion-in-2017/