Ανοικτό Πανεπιστήμιο Κύπρου

Faculty of Pure and Applied Sciences

Μεταπτυχιακό Πρόγραμμα Σπουδών *Sustainable Energy Systems*

Μεταπτυχιακή Διατριβή 701B
(MASTER THESIS)

Building Energy Consumption Related With User Behavior

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Επιβλέπων Καθηγητής
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Η παρούσα μεταπτυχιακή διατριβή υποβλήθηκε προς μερική εκπλήρωση
των απαιτήσεων για απόκτηση μεταπτυχιακού τίτλου σπουδών
στο Sustainable Energy Systems
από τη Σχολή Θετικών και Εφαρμοσμένων Επιστημών
του Ανοικτού Πανεπιστημίου Κύπρου.

January 2017

Περίληψη
Η αυξανόμενη ζήτηση για ενέργεια έχει προκαλέσει προβληματισμούς σχετικά με την εξάντληση των συμβατικών ενεργειακών πόρων, που απαιτούν αρκετό χρόνο για να ανανεωθούν. Μια άλλη ανησυχία που δημιουργείται από αυτήν την δραστηριότητα παραγωγής ενέργειας είναι οι εκπομπές αερίων που απελευθερώνονται στην ατμόσφαιρα από την καύση συμβατικών καυσίμων και η αύξηση της θερμοκρασίας της ατμόσφαιρας σε παγκόσμιο. Υπολογίζεται ότι οι εκπομπές αερίων του θερμοκηπίου θα έχουν διπλασιαστεί μέχρι το έτος 2100. Προκειμένου να αποφευχθεί αυτό το σενάριο, τα κράτη υιοθετούν διάφορες νομοθεσίες που προάγουν την ανάπτυξη των ανανεώσιμων πηγών ενέργειας, όπως επίσης την ανάπτυξη περισσότερο βιώσιμων τεχνολογιών που τείνουν να έχουν λιγότερες περιβαλλοντικές επιπτώσεις. Το κύριο πεδίο εφαρμογής των παραπάνω μετρήσεων είναι να μειώση των ενεργειακών αναγκών και σε παγκόσμιο επίπεδο. Η βελτίωση της απόδοσης των μονάδων παραγωγής ενέργειας σε συνδυασμό με το βελτιωμένο ενεργειακο προφίλ των καταναλωτών αναμένεται να προκαλέσει μείωση στην ζήτηση ενέργειας. Η πλειοψηφία της ενέργειας που παράγεται,προέρχεται από συμβατικά καύσιμα όπως (λιγνίτης, πετρέλαιο και φυσικό αέριο), κάτι το οποίο είναι ιδιαίτερα ρυπογόνο. Σε αυτή την έκθεση, υπάρχει πρόκειται να αποτυπωθεί η ενεργειακή απόδοσης των κτιρίων στην Ελλάδα, όπως επίσης το εκτιμώμενο μερίδιο της κατανάλωσης ενέργειας σε κάθε κλάδο. Αναφέρονται οι κύριοι δείκτες και παραμέτροιτου εσωτερικού περιβάλλοντος του κτιρίου, όπως επίσης και οι ελάχιστες απαιτήσεις προκειμένου να επιτευχθεί η άνεση στο εσωτερικό ενός κτιρίου. Επιπλέον, αναφέρονται οι κανονισμοί που καθορίζονται από τον ΚΕΝΑΚ καθως και οι ελάχιστες απαιτήσεις θερμομόνωσης. Επίσης αναφέρονται οι δείκτες απόδοσης των διαφόρων στστημάτων καθώς και οι κλιματικές ζώνες για κάθε περιοχή της Ελλάδας. Στην παρούσα έκθεση,καταγράφεται η κατανάλωση ενέργειας δύο ίδιων κτιρίων , και κατά πόσο επιρρεάζονται από τις συνήθειες και την ενεργειακή συμπεριφορά των ενοίκων τους. Πρόκειται να προσδιοριστούν οι παράμετροι που καθορίζουν την θερμική άνεση των ενοίκων και εσωτερική ποιότητα του αέρα. Προκειμένου να εξαχθούν συμπεράσματα, σχετικά με τον τρόπο που η συμπεριφορά των κατοίκων, καθορίζει την

κατανάλωση ενέργειας του κτιρίου, θα επιλεγούν δύο παρόμοια διαμερίσματα με ίδιες ιδιότητες της κατασκευής. Θα υπάρχουν δεδομένα συλλέγονται βασική ενέργεια από την επιχείρηση παροχής ενέργειας. Πιο συγκεκριμένα, θα καταγραφεί η ετήσια κατανάλωση ενέργειας του κάθε κτιρίου και στην συνέχεια θα γίνει μια εκτίμηση της κατανάλωσης ενέργειας του κάθε συστήματος. Η αξιολόγηση αυτή πραγματοποιείται με βάση τη συχνότητα της χρήσης κάθε συστήματος κατά τη διάρκεια ενός τυπικού έτους. Έχουν συλλεχθεί πληροφορίες σχετικά με τις καθημερινές συνήθειες των ενοίκων και προτιμήσεις τους όσον αφορά το εσωτερικό περιβάλλον που μπορούν να επηρεάσουν την κατανάλωση ενέργειας από τα διαμερίσματα. Στο τελικό στάδιο αυτής της έκθεσηςθα ειμαστε σε θέση να βγάλουμε συμπεράσματα σχετικά με το αν η ενεργειακή απόδοση του κτιρίου καθορίζεται από τις προδιαγραφές κατασκευής ή έρχεται σε συνδυασμό με μια βιώσιμη πολιτική διαχείρισης.

Summary

The increasing demand for energy has cause basic consideration about the depletion of conventional energy resources ,which require lots of time to regain their stock. Another concern which comes up by this energy production activity is greenhouse gas emissions that are released to the atmosphere by the conventional fuel combustion and increase the temperature of atmosphere globally and downgrade the environmental conditions of plants and animals. It is estimated that GHG emissions are going to be increased as twice as today by the year 2100. In order to avoid this scenario, country states adopt various legislations that promote the development of renewable energy plants, as also the development of more sustainable technologies that tend to have fewer environmental pollutant emissions. The main scope of the aforementioned measurements is to decrease energy needs and as a consequence, to decrease the energy demand globally. The improved efficiency of energy production units combined with the increased energy profile of the consumers Is expected to cause decreased energy demand. The majority of the produced energy is based on conventional fuel technologies such as (coal,oil and natural gas).These emissions would decrease significantly if there is applied energy savings management. The term "savings" includes restriction of wastefulness and mainly the efficient use of energy. In this report,there is going to be illustrated the energy efficiency of buildings in Greece, as also the estimated share of energy consumption of each section. There are mentioned the main components and factors of the indoor environment of a building, as also the minimum requirements in order to achieve indoor comfort. Additionally,there is reported the national regulations that are established by Kenak and specify thermal insulation requirements,desirable efficiencies of various construction systems and the climate zones for each region of Greece.On the following report,there are going to be recorded the energy consumption of similar buildings depending the habits and the energy behaviour of their occupants in Greece. There are going to be recorded the established construction standarts that are set as minimum requirements for buildings according to the technical guidance of Totee. Furthermore,there are going to be specified the parameters that determine thermal comfort of occupants and indoor air quality.

In order to extract conclusions, of how occupants behaviour,determines the energy consumption of a building,there must be selected two similar apartments with same construction properties.
There will be collected basic energy data from the energy supply enterprise. More specifically,there is acquired,the annual energy consumption of each building and there is made an estimation of the energy consumption of each system. This evaluation is made based on the frequency of use of each system during a typical year. The occupants are requested to provide information about their daily habits and their indoor environment preferences that can affect the energy consumption of the apartments.
On the final stage of this report there will be made conclusions on a basic consideration, if energy efficiency of a building is determined by the construction specifications or it comes in combination with a sustainable policy management.

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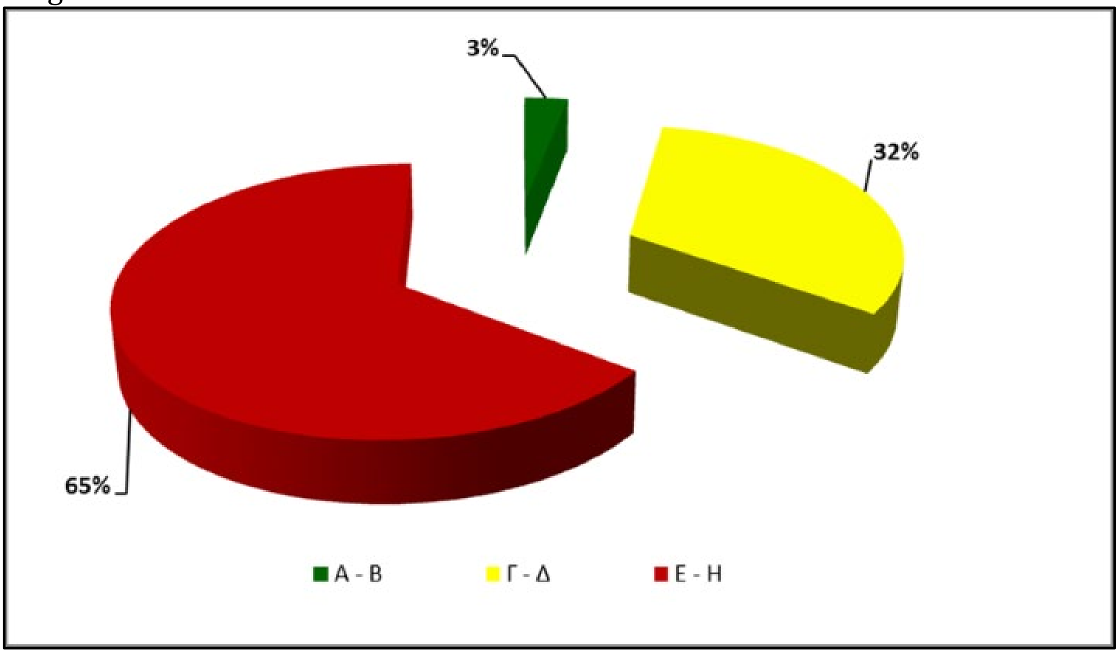
Chapter 1

Energy Efficiency Of Buildings In Greece

During the years 2011-2016 there were acquired 641.662 energy certificates for residential buildings. 83% of these certificates were delivered to apartment flats and 17% to detached houses. The overall percentage of energy certified buildings consist 16% of the total number of buildings in Greece. In respect to the average energy class of buildings,it was found that 65% of them belong to the lowest energy classes between E-H while 32% are rated between C-D. As it is depicted in the diagram below, only 3% were evaluated between A-B class.

Diagram 1

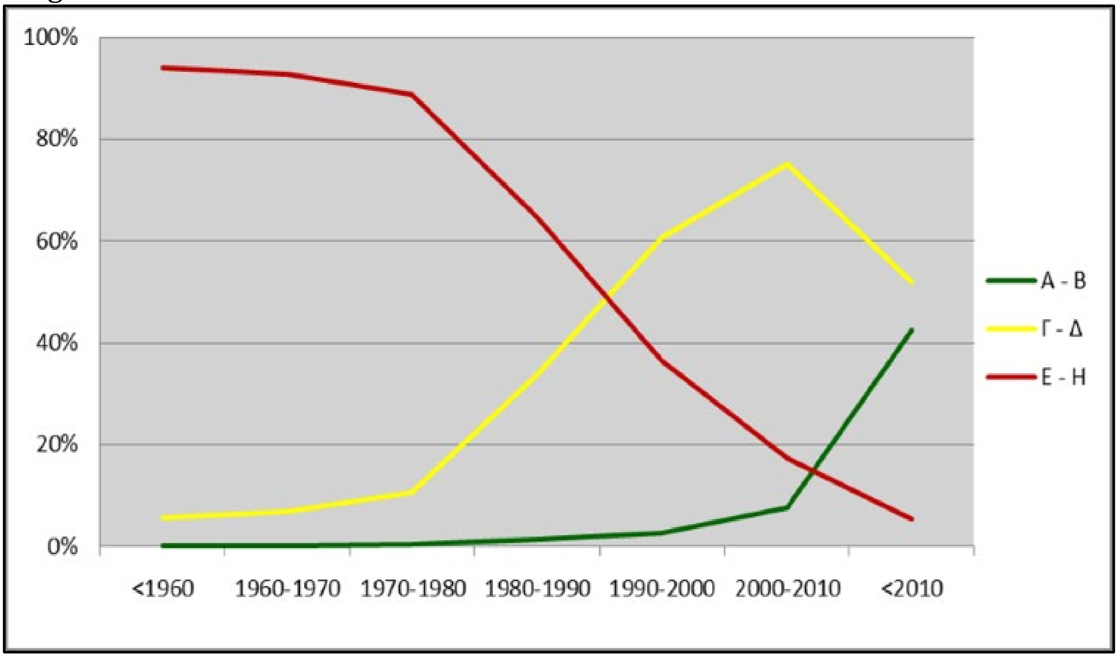


Share of energy class for residential buildings in Greece

(Centre For Renewable Energy Sources)

According to the Center For Renewable Energy Sources (CRES), buildings that are constructed before the application of the thermal insulation regulation (1980), are classified in the lowest energy class (H). On the other hand, the establishment of the relative regulation (1981-2010), effected the thermal insulation efficiency of newer constructions by improving them to C-D class. Furthermore the application of the most recent regulation of KENAK (since 2011) effected the thermal efficiency in a decisive way . Buildings that are constructed after the establishment of the new regulation of KENAK are certified with energy class A-B.

Diagram 2

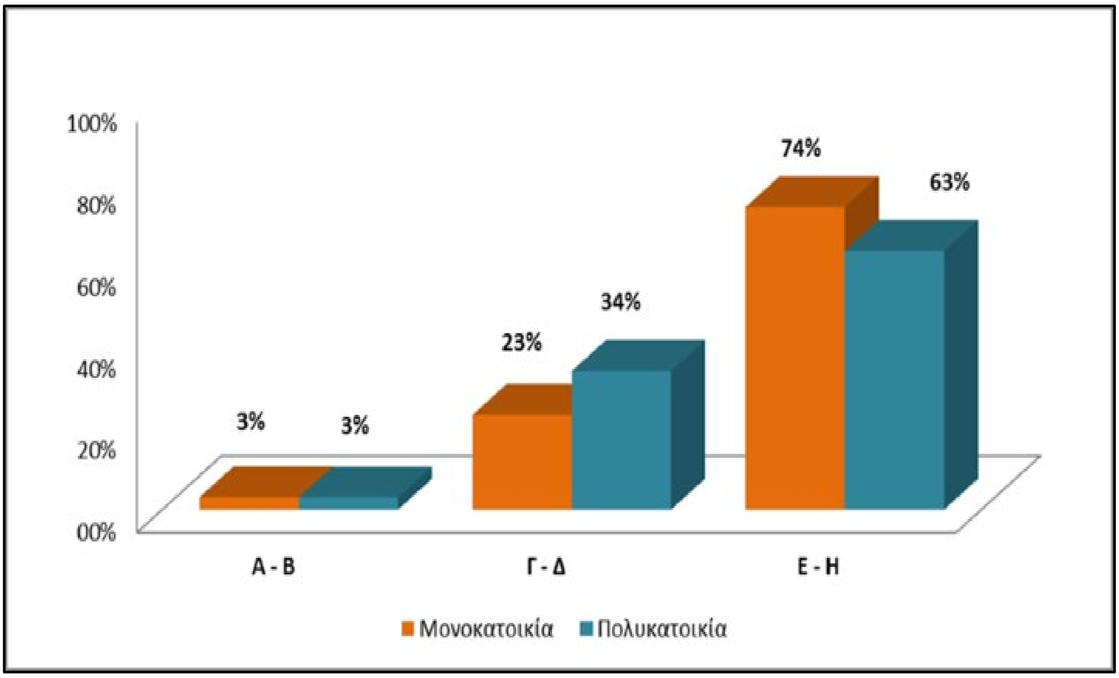


Energy class of buildings based on the year of construction

(Centre For Renewable Energy Sources)

Another element that is worth to mention is the energy class by use. More specifically,it is noticed that the biggest share (74% of them) of detached buildings appear thermal efficiencies equal to E-H class and belong to a lower efficiency class in addition to block of flats buildings that appears slightly better thermal behaviour (63% of them).

Diagram 3

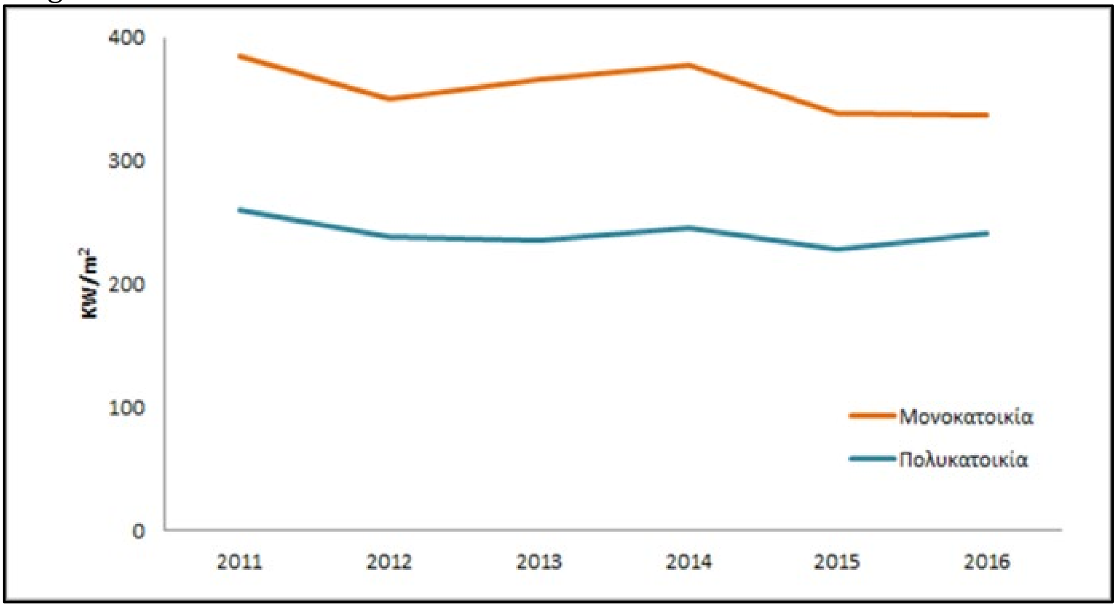


Share of energy class based on the type of the Residence

(Centre For Renewable Energy Sources)

In terms of average primary energy consumption,it is reported that the most costly buildings to domestic use are detached buildings with annual average primary energy consumption close to 358.7 kWh/m^2,while a block of flats appears energy consumption close to 241.6 kWh/m^2.

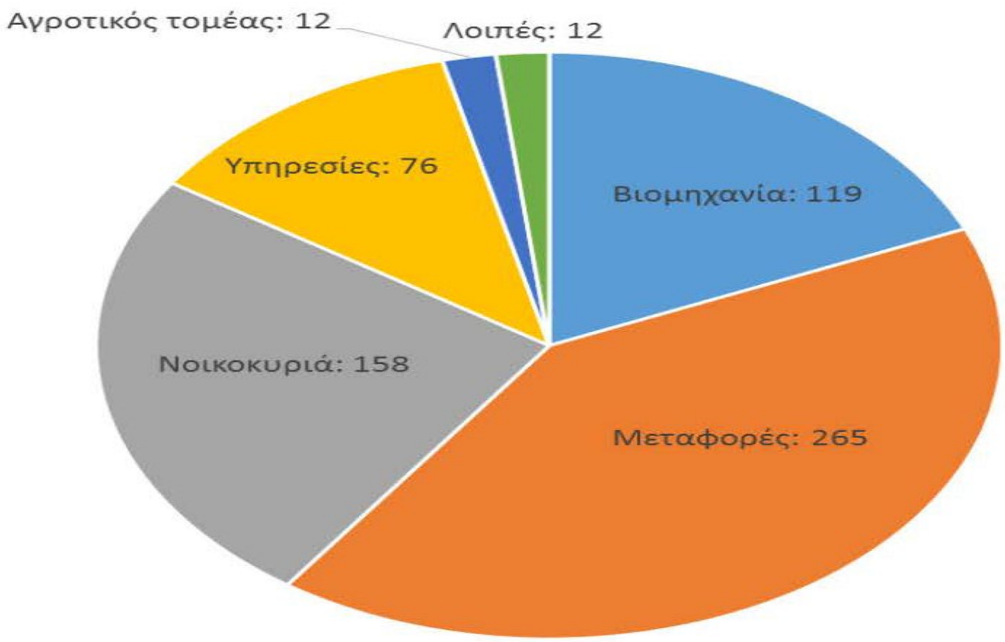
Diagram 4



Annual Average Primary Energy Consumption
(Centre For Renewable Energy Sources)

The biggest amount of primary energy is consumed for heating use. The average annual primary energy consumption for heating is estimated to be 171.18 kWh/m^2.In Greece the building sector consumes 35% of the total energy consumption, 25% of water for household uses,70% of electricity.

Diagram 4



Final Energy Consumption Per Sector

On the diagram above there is presented the allocation of the final energy consumption according to sector in Greece. It is estimated that 61% of the total energy consumption is used for heating and cooling purposes,25% for lighting and apparatus operation,while 14% is used for domestic hot water.

(Papamanolis)

Chapter 2

Indoor Environment Of Building

The term indoor environment refers to the area that is constructed to accommodate people. This place may be a building. On the other hand,outdoor environment is determined by the surrounding environment of the buildings. These two environments are outlined by the building's shell. The conditions of these environments are determined by various factors such as environmental and climate conditions. Indoor environments are of great significance for people. 80% of the time is spent on indoor activities on a daily basis. Due to this estimation,indoor comfort is an important factor for buildings and can be defined by different variables such as temperature,humidity,indoor air quality,lighting and noise. The aforementioned conditions must be kept in decent levels,primarily by natural means and without the use of electromechanical systems that will affect the energy behaviour of the building. The building shell must be invulnerable from the outdoor conditions.A quality shell promotes a well kept and healthy indoor environment without the use of supplementary equipment.

The parameters that affect indoor environmental conditions are:

I. Temperature: Determines the indoor thermal comfort and can be matched with specific values temperature and humidity. Ensuring proper thermal comfort conditions can be accomplished by controlling the interactions of temperature between indoor and outdoor temperatures. This interaction is possible to happen in two ways

a. Through building shell
b. By infiltration through doors,windows,walls and roof. On the occasion of infiltration, the air that is exchanged through the openings, the

transfers ambient temperature on both sides.Both of the aforementioned losses can be decreased either by thermal insulation, which is implemented on the shell or by decreasing the infiltration level which is estimated that comprises 30% of the total energy losses.

Thermal protection of building helps us achieve better indoor thermal comfort with minimum energy consumption in order to:

a. Decrease the construction cost of heating systems
b. Achieve an environmental improvement (reduction of pollution)
c. Protection of builing's materials
d. Compliance with the established thermal protection regulations for buildings.

Temperature, humidity,and indoor air quality are affected by :

- Climatic aspects(Ambient temperature, Humidity, Precipitation,Insolation ,Wind).
- Building's parameters(Location and elevation of buildings,space arrangement,shell surface and volume of material, thermal properties of the buildings shell,infiltration of the shell).
- Environmental aspects(air pollution of local environment which may affect the ventilation density of the building).

II.Insolation is used for heating or cooling the interior of a building. In combination with solar systems. Solar systems are separated on active and passive systems. Active systems usually use electromechanical devices. On the other hand, passive systems are based on natural processes. The orientation of the walls,the size of windows and openings and the proper allocation of usage and activities helps us to take advantage of solar energy as much as possible. Passive solar systems are mostly used as heating systems with only exception solar chimneys which provide natural ventilation and space cooling of a building.

III. Illumination: Is a crucial parameter of indoor quality. It can be either natural or artificial. Natural lighting is very important because it affects the mood of the occupants. Furthermore,natural lighting has a positive impact on the energy balance of the structure. Additionally,lighting (natural or artificial) is immediate correlated with inflows of heat in a building. These thermal imports can be either desirable or not depending each season. The level of interior lighting is always lower when compared to the outdoor illumination levels. The average accepted levels of an interior place are between 500-1000 lux. The total amount of lighting is calculated by the aggregation of immediate radiation,radiation which is reflected to the outdoor surface and finally through radiation that enters the building through the openings of the shell. It is calculated by the following equation $E_C = E_{SC} + E_{RC} + E_{IRC}$

IV. The difference of natural lighting between interior and exterior environment is calculated by the daylight factor which is equal to:

i. $D_F = \frac{E_i}{E_o} * 100\%$

Table 1

Room	Average DF	Minimum DF
Tertiary sectors building		
Offices	5%	5%
Teaching Room	5%	5%
Residential Use		
Kitchen	2%	
Living Room	1%	
Bedrooms	0.5%	

(Papamanolis)

If lighting is distributed evenly on indoor space there is achieved optical comfort improvement. This means that the demand for artificial lighting is less. The total luminance depends on the size of the room,shell openings and natural obstacles that are placed in the interior of the building,furthermore it depends on the reflectivity of the indoor surfaces.

V. Humidity impact on the building on a negative way,higher concentrations of humidity can cause :

Health issue problem to occupants

Indoor quality degradation

Failure of building materials due to decomposition,chemical reactions etc.

An essential unit of humidity measurement is relative humidity which represents the quantity of vapor included on a specific quantity of air and is equal to $\Phi=\frac{e}{e_s}$*100%.

Wind is another factor that affects the energy behaviour of a structure. Wind speed is measured in Beaufort scale. More specifically referring to buildings the negative impacts are distinguished on 3 categories.

a. Construction fatigues
b. Negative impacts on open spaces and on the closer environment near a building
c. Damages that are caused to the building shell by the indirect influence of the wind.

VI. Ventilation is crucial parameter for a building because it removes air pollutants and supplies,indoor spaces with clear air and oxygen. Ventilation,changes temperature and relative humidity of the indoor environment. Furthermore,it improves the energy behaviour and thermal condition of a structure. It is mainly measured as air changes per hour (ac/h). The proper rate of air changes is determined on the appendix below:

Table 2

Space Per Person(m^2)	**Air Supply Per Person(L/S)**	**Ventilation(ac/h)**
3	17	20
6	11	6.5
9	8	3.2
12	6	1.8

(Papamanolis)

Ventilation rate on more crowed spaces are 10 ac/h. The ventilation type that is chosen on each occasion depends to the indoor space geometry, the orientation of a building and the number of the available shell openings. Ventilation of a building may occur also by infiltration(undesired ventilation through little cracks and openings usually under the doors,openings e.t.c). It is estimated that on conventional buildings the strain of infiltration is enough high to cover the ventilation needs of a residence. Ventilation systems are summarized on 3 basic categories

a. Natural ventilation. The air alternation is done through shell openings
b. Mechanical ventilation which is done through pipes with mechanical help
c. Mixed ventilation which is used in larger buildings,when natural ventilation is inadequate to cover their needs.On warmer climates,it is wilful to obtain ventilation and natural cooling through windows and openings that are installed on opposite sides of the building in order to achieve better air flow.

Table 3

Natural Ventilation System	
Advantages	**Disadvantages**
No energy consumption required	They can't be applied for ventilation of large buildings
Simple to Operate	They don't offer adjustable mix of air quantity
No maintenance required	Efficiency of operation s determined by electric power of the system
Natural Cooling is occasionally achieved	They don't offer control of external pollution

(Papamanolis)

Table 4

Mechanical Ventilation System	
Advantages	**Disadvantages**
Performance Tuning	Require energy Consumption
Meet Specific Ventilation Requirements Of a Building	Increased Installation Cost
Adjustable Mix of Air Quantity Option	Maintanace Required
Pollution Control Options (filters)	Interraption Of Operation May Cause Adverse Indoor Conditions
They Can be Mounted With Other Electromechanical Components	Harmful Micro-organisms Can Be Created On Some Elements
They Confine Humidity of a Building	Noise production

(Papamanolis)

VII. Indoor Air Quality: Among the other parameters that determine the healthier condition of the indoor environment of a building is the indoor air quality. As mentioned before,humans spend most of their time indoors and that makes the indoor air quality very important index of indoor comfort.

Indoor air quality is affected by 4 determinants.

- Air pollutant sources
- Heating,Cooling and Ventilation systems
- Air pollutants route
- The behaviour of occupants

VIII. Noise levels: the sound power is measured in Watts and the difference between 2 sound signals, is expressed as decibel (dB).

$L_W = 10 \text{ Log } 10(\frac{P_1}{P_0})$. Sound intensity represents the transferred energy by the waves of sound per unit of surface area and time. The unit of sound intensity is W/m^2 and is expressed as I_r=$\frac{Pac}{A}$=$\frac{Pac}{4\pi r^2}$

Sounds are separated on two types.

Desirable sounds such as music and speaking

Noise sounds that cause disturbance to the occupants.

The effect of sound may cause bad indoor quality due to the disturbance levels. It is probably for the occupants to keep the windows and opening closed in order to avoid noise. On this occasion the indoor comfort quality will be affected due to the lack of natural ventilation.

(Papamanolis)

Chapter 3
Kenak Regulation

K.E.N.A.K is the energy performance regulation of the building sector,which is established recently by the Greek authorities in order to certify and set the minimum requirements for more efficient buildings. The purpose of the implementation of this regulation is to save energy by reducing CO_2 emissions to the environment. This can be achieved in two ways :

- By protecting the building shell and reduce thermal losses.

Taking advantage of the building orientation ,its solar gains and benefits that come up by natural ventilation,lighting and heating

- By equipping the mechanical part of the building with proper,more efficient apparatus.

In order to acquire K.E.N.A.K certification, an energy study must be done,which will examine the efficiency of the aforementioned building's aspects.

After the successful implementation of the K.E.N.A.K standarts on a building,it is expected that the overall conventional energy consumption will be reduced.

During an energy study there is determined the primary energy consumption on the following sectors:

a. Building uses and desired indoor conditions(Temperature, humidity and ventilation)
b. Climate data of the region that the building is located(temperature,relative humidity,dry bulb humidity,wind speed and solar radiation).

c. Geometrical characteristics of structural elements of the building's envelope (shape of the building,e.t.c), as also the orientation of the structure.
d. Thermal properties of the structural elements (thermal conductivity, reflectivity and thermal emission radiation)
e. Technical characteristics of space heating systems(efficiency,type of system)
f. Technical characteristics of the mechanical ventilation systems if there is available such as efficiency, type of system and pipelines.
g. Technical characteristics of domestic hot water system(efficiency,type and distribution network)
h. Passive solar systems

There is also evaluated the presence of natural ventilation,lighting,as also the existence of active solar systems which will improve the energy balance of a building.

The evaluation of the energy performance in the aforementioned aspects is executed according to the Technical instruction of the technical chamber of Greece(T.O.T.E.E) on each study case.

During the energy evaluation of a building there is taken into account the climate zone of each location. The climate zone of each location is mentioned on the relative technical instruction (T.O.T.E.E) 20701-3/2010

(Y.P.E.K.A)

3.1 Reference Building

The reference building has the minimum requirements that are defined by the technical chamber of Greece. Every inspected building must comply with the reference building operation profile,geometry and orientation of the external building elements. The reference building has specific technical properties of the structural elements as also for heating,cooling,domestic hot water and ventilation systems. Additionally,it is evaluated by B energy efficiency grade and its shell is thermally insulated.The main features of this structure are specified below:

Building envelope

- External masonry surfaces are painted with bright colours in order to reflect solar radiation with a coefficient of 0.35
- The emission factor of solar radiation is 0.8
- Glazes have a specific diffusion coefficient of solar radiation
- The opaque surfaces of the reference building present low shade efficiencies for all seasons
- Infiltration of reference building is set to 5.5 m^3/h for each m^2 of opening's frame
- It is equipped with necessary external sunshade (overhangs, louvers and balconies). The average shading coefficient of its openings during the summer is 0.5 for southern sides of the building and 0.6 foe Eastern and Western sides
- The thermal mass of the reference building is equal with 250kJ/m^2 of heated surface building.
- Electromechanical installations

For heating systems, there are specified the minimum requirements below:

- The reference building has gas or oil boiler central heating system
- The boiler is certified with energy efficiency of 3 stars
- The heating system is designed according to the technical guidance T.O.T.E.E. In order to secure full load coverage under the worst predicted weather conditions

Cooling System

- The reference building has ceiling fans on the 30% of the air conditioned spaces
- The reference building has local cooling systems with energy efficiency EER=3.0
- Energy consumption of the cooling system is equal to 50% of the estimated consumption based on the net total surface area of the residence

Media Distribution

- The average coefficient of thermal losses on the pipeline network is 7%

Ventilation System

- The reference building is considered to be ventilated by natural type of ventilation

Domestic Hot Water

- Domestic hot water needs are covered through the central heating boiler system or separated boiler system enforced with solar panels which are reserved by electrical resistance

DHW systems have the following properties:

- Central boiler for DHW is certified by 3 star energy performance rate
- The average coefficient losses through central distribution network is 20%.

(Y.P.E.K.A)

3.2 Climate Zones

According to K.E.N.A.K , the Greece is divided in four climatic zones based on their heating degree days. An important parameter during the evaluation of a climatic zone is the elevation of the area. Areas where the elevation is greater that 500 m are considered one level colder that the category of their prefecture. The appendix below Depicts the climate zones of various areas

Figure 1

(KENAK)

Climatic zones in Greece, according to KENAK

(KENAK)

3.3 Building's Orientation

The orientation of a building is an important factor because it promotes passive design of a building. The term passive design refers to the ability of a building to exploit energy gains by solar energy and achieve reduced energy demand, minimizing heating, cooling lighting and ventilation needs by proper orientation of the building. Generally North orientation facades have few solar gain benefits. Buildings that face East-West axis appear more solar heat gains which are very difficult to avoid them during the summer season.However these orientations provide better natural ventilation that the others. On the other hand the most advantageous orientation is south. South facades appear more heating gains by solar, especially during the winter months when solar inclination is more horizontal than summer.

Additionally,solar on the south façade of a building is easier to be prevented during summer because it impinges more vertically than winter.

(Yao)

3.4 U-value

Each material that is used in a building appears individual thermal properties which define the ability to transfer heat from higher to lower temperatures through the materials of the building. The most important factor that must be determined in order to estimate the thermal insulation efficiency of a structure is U-Value which is referred as the overall heat transfer coefficient and expresses the ease that a building element contacts or transfers heat through one square metre of a structure compared to the temperature difference across the building It is expressed by the following equation: U= $\frac{1}{R_i+\sum_{j=1}^{n}\frac{d_j}{\lambda j}+R_\delta+R_\alpha}$, R=$\frac{d}{\lambda}$, R_Λ=$\sum_j^n R_j$ and measured on W/m^2K.

n=number of material layers.

d(m)=Thickness of each Layer

λ= thermal conductivity coefficient

R_δ,R_i,R_a= Thermal resistance of air

According to the tables Of the technical guidance of KENAK, there is specified the the thermal conductivity of each material that is installed on a masonry. There are presented some indicative values from the aforementioned table of 'T.O.T.E.E. 20701-2/2010'

(Y.P.E.K.A)

Table 5

material	**K value (W/m*K)**
Gravel, concrete	0.640
Self-compacting concrete	0.2000
Reinforced concrete>1% iron	2030
Asphalt fabric	0.230
Extruded polystyrene	0.033
Brick	0.470
Coating	0.87
Polystyrene	0.038

Additionally, in order to define the heat transfer coefficient of windows there are established equations that define that value (U_w-Value)

More specifically: $U_w = \frac{A_f * U_f + A_g * U_g * i_g * \Psi_g}{A_f * A_g}$

U_w= Thermal coefficient of the sashes

U_f= Thermal coefficient of the frame

U_g= Thermal coefficient of the glass pane

A_f= Size of Frame

A_g=Size Of Glass Panel

i_g= Length Of thermal bridge of the glass perimeter

(Y.P.E.K.A)

3.5 Heating efficiency

In order to achieve the desired thermal conditions of the indoor environment, there must be paid attention during the selection of the preferred heating system. There are various types of heating systems that can be installed on a building such as boiler systems,heat pumps, HVAC units and local heating devices (Convectors). Each of the previous heating systems has some properties that are defined by the efficiency of operation factor which indicates the amount of thermal energy produced from a specific amount of primary energy that is consumed. The technical chamber of Greece provides information through its technical guidance about the ideal efficiency of each system and the calculation methods.

More specifically : COP=$\frac{Q}{W}$=$\frac{Power\ Input}{Power\ Output}$ Q=heat supplied by the heating system and W= work required by the system to produce the amount of heat.(primary consumption)

COP_{max}=$\frac{T_C}{T_H - T_C}$, $T_C = Cold\ tmperature\ and$ T_H=Hot temperature.

The minimum requirements that are established for the specific technical guidance for heat pump heating systems is efficiency greater than COP =3.2. If the coefficient of performance is under the specific standard,the heat pump consumes more primary energy for heating and it is desirable to choose boiler as a heating system. The Cop factor is estimated on ambient temperature 7 C^o and coolant temperature of 45 C^o.

(Y.P.E.K.A)

3.6 Cooling System

Cooling systems are designed to offer thermal comfort to the occupiers, mostly during the summer season when the outdoor temperatures are generally higher. The desirable indoor thermal conditions are between 20 C^o-26 C^o. Cooling demand also depends on ventilation of a building. In order to achieve thermal comfort during the hottest month of the year, there are used Cooling systems such as air conditioners and HVAC systems.

The basic parameters that must be determined in order to calculate the size of a cooling system are: cooling needs ,the use of the building and operational hours during the day. The minimum requirements that are established on the relative technical guidance for cooling systems are ate least EER=3.0. The specific value is established for ambient air =35C^o and coolant temperature 7C^o.

$$EER = \frac{Output\ Cooling\ Energy\ in\ BTU}{Input\ Electrical\ Energy\ in\ W} \qquad \text{(Y.P.E.K.A)}$$

Chapter 4
Post Occupant Behaviour

Post occupancy evaluation is an assessment of a building behaviour after its occupancy. During an evaluation, it is figured out if the constructed building operates as it was designed and if not, what kind of corrective actions can be taken. In other words, is an evaluation process of a building after a period of occupation. More specifically, Post Occupancy Evaluation (POE) tests how a building influences health and safety, indoor quality and occupiers of a building.
There are three available surveys in order to evaluate the indoor quality: Through occupant satisfaction, occupant satisfaction as regard to the building quality and a web based occupant satisfaction survey. All the aforementioned methods aim to record the occupant satisfaction. POE is separated into three levels: Indicative that is the most applied, Investigative that includes more detailed approach of a POE. Diagnostic form of a POE is an extensive, detailed and focused approach.

(*Implementation Of Post-Occupancy Evaluation: A Potential Tool For Building Asset Management And Creating More Productive, Cost- Effective And Sustainable Buildings At MSU White Paper*)

The benefits by contacting a POE can be multilevel, from short term benefits such as: Identification of a building, improved space utilization and feedback on building performance, improved attitude of building occupants due to their involvement in their evaluation process. Additionally, medium term benefits offer significant cost savings that are relative to energy savings throughout the life cycle of a building, quantification of building elements and quantification of a building's performance. Long term benefits to offer long term improvement of performance. In order to execute a POE analysis, there must be collected objective variables such as: Gender, age, Proximity to windows and external walls and various control types (window blinds, overhangs). Except objective variables, there can be noted the subjective variables such as occupant satisfaction, thermal comfort, air quality and lighting quality.

(Architect & Design Sustainable Design Leaders)

4.1 Occupant Behavior

The difference between estimated energy use and energy consumed is called the energy performance gap. It worth to mention that the actual energy use is bigger than estimated energy use. This difference between estimated and actual energy use is caused by the occupation behaviour of a building.

Generally energy demand determinants can be divided into two types: The physical and the behavioural. The behavioural factors,mostly depend on human factor and secondly on climate. Some of them are: occupancy factors,occupancy density,beliefs as also the scale of interaction that an occupant has with a more efficient building in order to make use of the energy advantages of the building. Behavioural determinants involve energy conscious decisions on an hourly-daily-weekly basis. The second category that determines the behaviour of occupants in a building is physical and includes all these factors that has to do with climate and building design. In this category are attached: the energy use, dwelling size,building design and space heating systems. The energy efficiency of a building does not depend only on the construction advantages of a building It demands energy management by the occupants. Poor energy management,impacts on a negative way in energy savings.

(Guerra Santin 311-327)

Energy end use determines how occupants exactly impact upon building energy use. The assessment various systems that are installed in a residence, such as heating, ventilation, cooling, lighting, Domestic hot water and other apparatus systems are assessed. Despite the upgrades of the aforementioned electric systems, there must be installed control systems that are easy to use in order to achieve better energy use. Occupant interaction with the building varies among different households. The most important factors of interaction between the occupants and buildings are: Physiological, psychological, financial and climatic. Those factors are barriers to the energy behavioural change of occupants.

Design related barriers:In order to achieve overall efficiency of a building there must be achieved increased efficient use through management devices, such as control panels,timing switches, windows, blinds and all the necessary modules that assist the users to operate various domestic systems.

Sociological related barriers are also another consideration. More specifically buildings with big number of occupants are hard to be managed in order to ensure energy savings. Due to variances on indoor conditions and beliefs about energy use there is very important for establishing internal rules that must be followed by all the occupants of the building in order to avoid desirable wastes.

The parameters that define the estimated primary energy consumption are: Occupant behaviour,structural quality and rebound effect. More specifically it was found that occupants which live in more efficient buildings are used to higher indoor temperatures and lower ventilation rates. However the improvement of insulation materials has decreased energy consumption of these buildings. An important factor of energy consumed for heating is occupant behaviour which is determined by household characteristics, lifestyle,motivation and building interactions. Additionally it is concluded that the type of ventilation and temperature control influences the occupant behaviour. The wider the variations of heating and ventilation systems, the wider the differences in occupant behaviours. Heating behaviour is expressed as the thermostat settings. In other words the total operation hours during the day. The same settings determine the ventilation system efficiency. Buildings that accommodate more people are considered to have higher heating demand than building will less occupants. This is another factor that affects the energy efficiency of building comparing with the number of occupants. In cases with higher ventilation rate, heating demand is less. The main characteristics that affect the energy behaviour of a building are : year of construction(due to the existence of insulation or not), type of heating system,shape, size and orientation as also thermal properties of a building. (Ucci 175-178)

Additionally, it seems that houses with lack of temperature control tend to consume more energy for heating. Houses with mechanical ventilation consume more energy than those which are naturally ventilated. Naturally ventilated buildings have less heating demand than buildings with mechanical ventilation. Especially in the winter season,lower temperatures prevail on houses with natural ventilation. This is explained because the occupants are not so sensitive to the temperature variations and the lower temperatures. Older houses use to ventilate less because infiltrations cover most of the ventilation share.

(Guerra Santin 311-327)

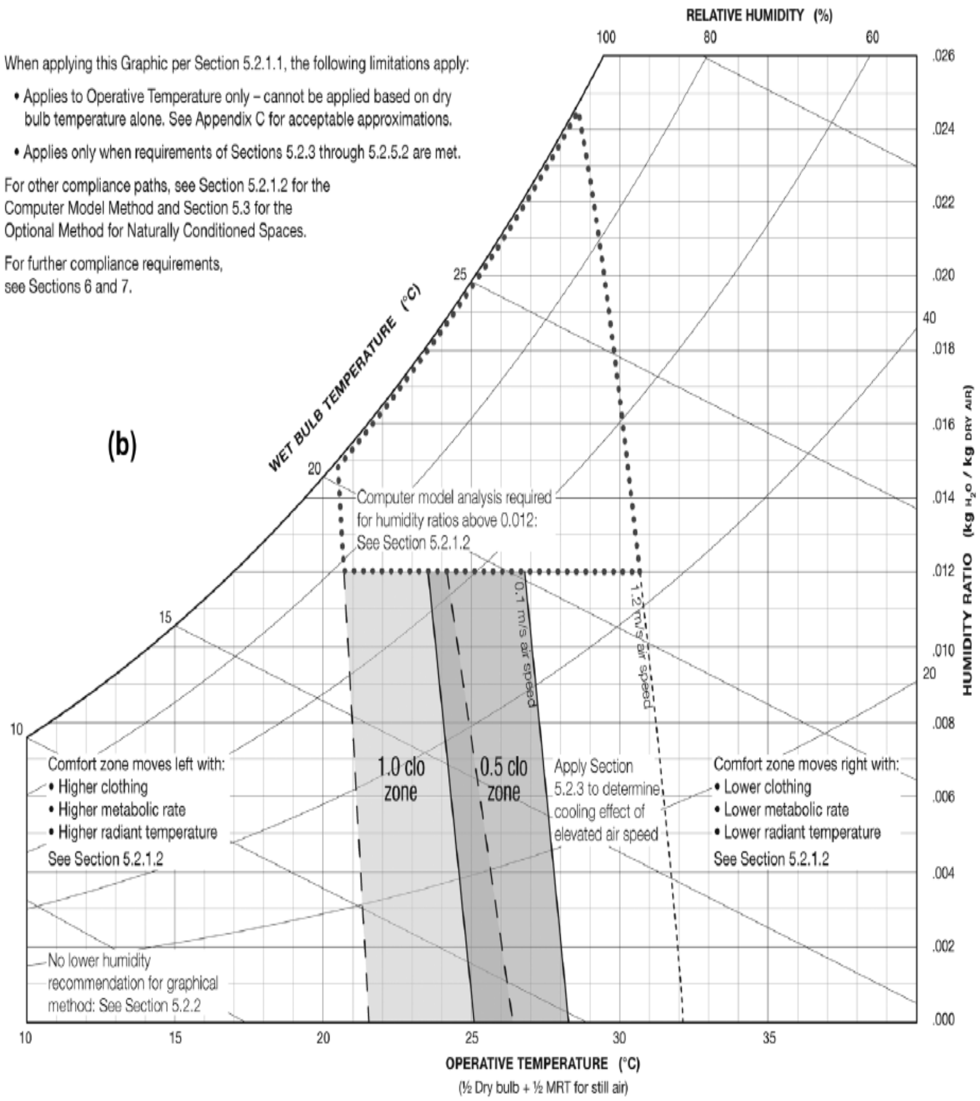
4.2 Rebound Effect

Rebound effect expresses the reduction of expected gains by the improvement of efficiency of a building. This reduction may occur by behavioural or other responses. These responses affect the benefits of the most recently applied technologies and usually offsets the beneficial effects of new technologies or other measures taken. The rebound effect distinguished in two basic categories.
Direct rebound effect which is an increase in the consumption of a good,due to the lower cost of use. The second type is the indirect rebound effect that expresses the increased consumption of energy due to lower cost of a service or other goods.
In the case of heating of a building,rebound effect increase in more heating demand due to the reduced energy costs. In other words the occupants of a building with better thermal efficiency and less heat losses use to seek for higher temperature set points which sometimes are unnecessary. It was found that occupants living in more efficient dwellings,prefer indoor temperatures that are above average indoor temperatures. However the biggest demand for heating doesn’t mean higher energy consumption. The rebound effect generally does not offset the energy savings,but undermines them. This practically means that a part a part of financial benefits that entail by the insulation instalment are reduced. This explains why actual earnings are less than the expected. As a conclusion rebound effect seems to be a psychological effect that is created to the occupants of more efficient houses and makes them seek warmer and less ventilated houses. (Guerra Santin 311-327)

4.3 Ideal Indoor Conditions

Due to the assessment of energy efficiency of a building, there are established international standards for internal temperatures of buildings. The ideal indoor temperatures depend to the humidity of the indoor environment. The estimation of the proper indoor temperature can be calculated by the use of the graphics below:

Figure 2

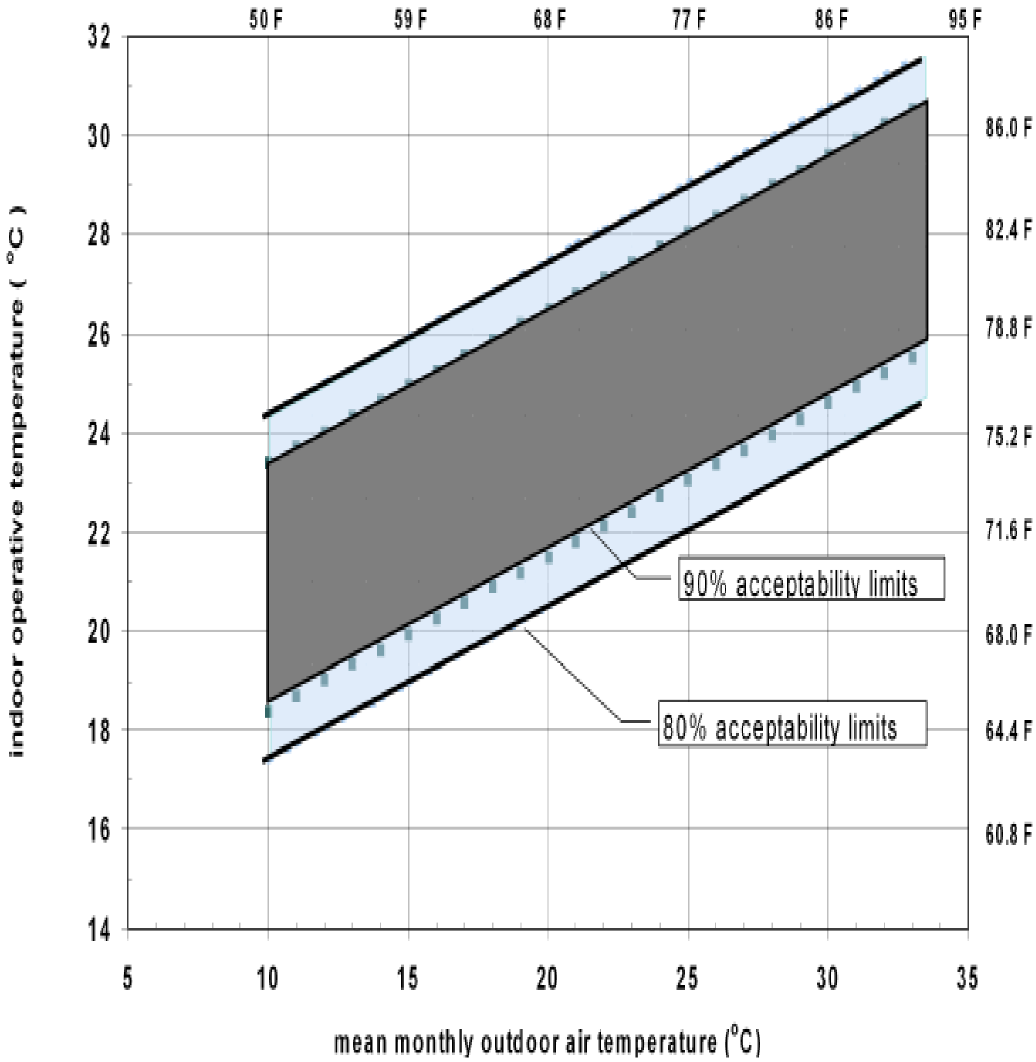


(ASHRAE)

According to the diagram above, with standardized metabolic rates between 1.0 and 1.3, and clothing factor between 0.5 and 1. It was found that the accepted

levels of relative humidity vary from 40% to 60%. The desired levels of indoor thermal comfort are between $20\,C^o$ and $26C^o$. The aforementioned temperatures that are specified by humidity-temperature diagram are chosen with an 80% occupancy acceptance to the indoor thermal conditions,plus 10% dissatisfaction that may occur.Furthermore,for natural ventilated indoor environments,the allowable indoor operative temperatures are specified according to the outdoor temperature conditions that prevail on each season.
The diagram below provides data information of temperatures with minimum and maximum acceptable limits

Figure 3



(ASHRAE)

According to the above diagram, for a typical winter, the preferred indoor temperature for the winter season is between 18-20C^o and during summer 24-26C^o

4.4 Thermal Comfort Indicators

Due to the fact that people react with various ways to the temperature changes in order to maintain their body temperature steady.There must be defined the proper parameters that provide indoor comfort. Indoor comfort of a person is influenced by the clothing and level of activity. There were developed indices to specify indoor environments such as the predicted mean vote (PMV) and predicted percentage of dissatisfied people.(PPD) by Fanger. The application of these two indices offers an objective assessment of indoor environments. Thermal comfort indicators as mentioned before are dependent on Temperature,humidity,wind speed, solar radiation(locally and temporally), clothing and the metabolism of occupants. The limits of PMV are between -0.5 and +0.5

4.5 Predicted Mean Vote Index

The predicted mean vote is an index as mentioned before that determines the level of thermal comfort. It determines the level of thermal comfort and is defined as the state on which the actual skin temperature is equal to the internal temperature of the human body as defined by Fanger. The PMV index expresses the satisfaction level of the occupants in a building. During thermal comfort state,the thermal load is zero. During the evaluation of thermal comfort there is defined the level of thermal sensation according to the rating scale that is presented below:

Table 6

Personal rate of discomfort	
Hot	+3
Warm	+2
Slightly warm	+1
Neutral	0
Slightly cool	-1
Cool	-2
Cold	-3

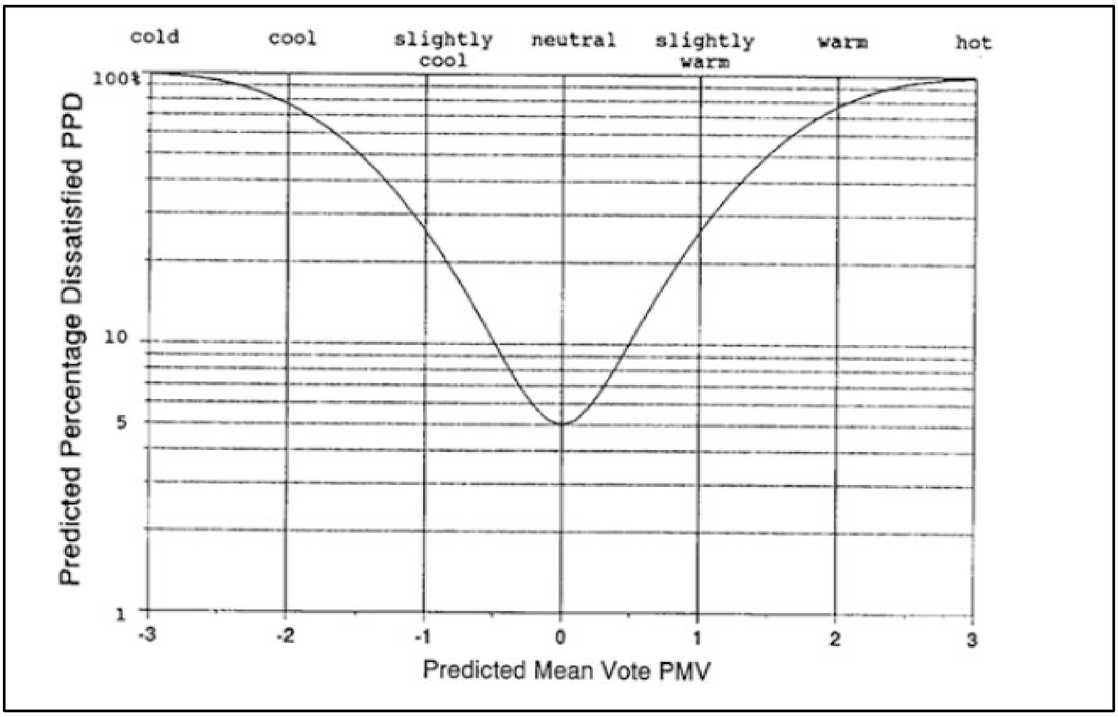
4.6 Predicted Percent Of Dissatisfied People

Predicted percent of dissatisfied people is an index that expresses the proportion of dissatisfied occupants of a building by its thermal comfort conditions. Thermal discomfort is caused on an indoor environment by rapid and unexpected changes in the environmental conditions, as also on the objective parameters of thermal comfort. The estimation of PPD depends on the value of PMV due to the equation that correlates these two indexes and is given by the following equation:

PPD=100-95*exp-(0.03353 *PMV^4+0.2179PMV^2)

The PPD in the physical world expresses the number of potential complainers for specific indoor conditions. The maximum range of PPD for thermal comfort is 10%.

Diagram 5



(Yao)

It can be noticed that PPD increases proportional with PMV (increase dissatisfaction of the indoor environment). Even when PMV equals to Zero, PPD is 5%. This means that there are objective parameters that affect thermal comfort

Chapter 5
Study Case

The present case study is about the comparison of energy consumption of two buildings with similar properties. More specifically,there is gong to be analysed their primary energy consumption for a typical year. There is going to be determined if the energy behaviour and habits of occupiers affect the energy efficiency of each apartment. Due to this comparison,there is going to be an extensive record of the building's basic structural elements and the energy behaviour of the occupiers.

Physical Data Of Building

In this paragraph there is going to be specified basic information about the construction. The buildings that are going to be compared are two apartments of a block of flats in the city Of Preveza at a height of 11 metres above the sea level and belongs in the region of Epirus. According to the relative technical guidance it is estimated that Preveza belongs to climate zone B. The orientation of the 2 apartments is East and they are constructed on the fourth floor of a block of flats. The north and the south sides of the two apartments are detached to other flats. The apartments have windows and openings on their East and West sides.

The block of flats was constructed in 1995 according to the regulation for thermal insulation that was implemented for dwelling of that time and is classified under the D energy class. Both of the household use solar heaters for Domestic Hot Water use. The thickness of the masonry is 31 cm and the openings are aluminium single glass panels.

The size of apartment A is 80 m^2 and the size of apartment B is 90 m^2.

The interior fitting of spaces is similar to both apartments. More specifically the bedrooms are on the East side of the apartment and the living room is placed on the west. On both apartments there is installed awnings on their Western sides in order to provide shading during the summer months. There is also installed solar heat panels for domestic hot water use in combination with electric heater.

More specifically the surface of he masonry and the openings are estimated in the table below for each apartment:

Table 7

Building Envelope			
Building A (m^2) $80m^2$		Building B (m^2) $90m^2$	
Masonry	125,6	Masonry	150
Windows	10,08	Windows	11

The installed windows of the apartments are aluminium single glass which is considered to appear low U values according to the relative technical guidance. And the main entrance of the apartments have wooden doors. The material and the oldness of windows and openings are affecting the infiltration rate of the apartments. Due to the lack of air tightness and low thermal insulation.

The orientation of the building is considered to provide adequate natural ventilation on the dwelling with major openings on the East and West sides The thickness of the building envelope is 31 cm as mentioned before with the following dimensions of each material:

Table 8

Building Envelope			
Building A (cm)		Building A (cm)	
Exterior Coat Of Plaster	3	Exterior Coat Of Plaster	3
Brick	9	Brick	9
Insulation Material	7	Insulation Material	7
Brick	9	Brick	9
Interior Coat of Plaster	3	Interior Coat of Plaster	3

Operational Data

Artificial Lighting

According to the technical guidance of the Technical Chamber of Greece there are established relative tables that indicate the desirable illumination level for each type of interior spaces. More specifically,for an apartment it is computed that the illumination that is required is 200 lux(lm/m^2) while the power that is established for lighting in the reference building is 6.5 w/m^2. On the table below there are calculated the total energy required to achieve the desirable artificial illumination on both apartments according to the surface of their floor area and led type Lamp with 70 lumen/W efficacy. Both buildings A and B have installed led lights on all rooms. Its is noted that the first apartment has less consumption for lighting than the established limits.(Y.P.E.K.A)

Table 9

Lighting consumption			
Building A (m^2)		Building B (m^2)	
Desired energy (W)	230	Desired energy (W)	260
Calculated energy(W)	204	Predicted energy(W)	250

Heating/Cooling System:

Due to the argument between tenants of the building for oil supply , it was decided to use split units instead of central heating system in order to cover the heating and cooling needs of the households. This has affected the electrical energy consumption of each apartment. The first apartment has installed and individual oil boiler with heat output power 14400 kW,while on the second apartment there have been installed 2 split unit systems. one in the living room which is about 24000 Btu and the second split unit is installed on the bedroom 7000 Btu.The apartment number A mentioned that they don't use any cooling system due to the adequate natural ventilation rates even during the summer sean. The second apartment uses split units for cooling during these days. The relative systems and their properties are recorded on the tables below:

Table 10

Building A	
Heating System(kW)	14,4
Cooling System	

Table 11

Building B				
Heating System		COP	Nomical Heating Capacity(kW)	Power Consumption(kW)
Split Unit 1	7.000 Btu	4,55	3	0,66
Split Unit 2	22.000 Btu	3,61	8	2,21
Cooling System		EER	Nomical Cooling Capacity(kW)	Power Consumption(kW)
Split Unit 1	7.000 Btu	4,35	2	0,46
Split Unit 2	22.000 Btu	3,23	7,1	2,1

The space heating needs of apartment A are covered by an oil Boiler System that operates 2 or 3 hours per day for a period of 6 months.Between November and April. The annual oil consumption during 2015 was 900 litre of Oil. In the tables below,there is figured the Heating degree days for the city Of Preveza as also the Cooling degree days

Table 12

HEATING DEGREE DAYS						
October	**November**	**December**	**January**	**February**	**March**	**April**
6	**165**	**276**	**310**	**252**	**202**	**102**

Table 13

COOLING DEGREE DAYS			
June	**July**	**August**	**Septeber**
673	**1290**	**1297**	**137**

(Y.P.E.K.A)

Occupant behaviour:

The occupants of the two apartments were requested to answer a questionnaire that provides information about their habits, profession, marital status and various parameters that can interact with the use of each building and affect its energy consumption and behaviour. Each question was developed to provide essential information about demographic data of the occupants,electrical apparatus use,indoor conditions of each apartment.Specifically on this section is evaluated the sensation of indoor conditions. For example,how occupants feel on the current indoor conditions. There is also recorded the energy behaviour of the occupants and their habits.

The occupiers of the first apartment area young couple without children. Both of them are working during the day, mainly in the morning between 7 and 3 o clock in the noon. This means that the specific dwelling is unoccupied until noon. On the other hand on apartment B lives a four member family. An adult couple and 2 children that are attending primary school. Both of the parents work during mornings an the apartment number B is unoccupied until 13:30 in the noon.

Furthermore the 2 families were asked to record their activities during a typical day.

The first household has stated that they usually cook once per day. They also stated that the hot water,which is provided by the solar heater is adequate for their daily hot water demand for a period of time between March and October. During the Winter the DHW needs are mainly covered by the oil boiler which has the capability to provide space heating and domestic hot water. They rarely use the electric water heater. The space heating needs of apartment A are covered by an oil Boiler System that operates 2 or 3 hours per day for a period of 6 months.Between November and April. The preferred thermostat settings are 22 C^o . The annual oil consumption during 2015 was 900 litres of Oil.

The specific apartment doesn’t use any cooling system, due to the high natural ventilation rates. However,they supplementary use local ventilation system during the warmer months of the year. It is worth to mention that according to the results of the questionnaire, the users of the first apartment were more concerned about energy conservation. This is imprinted on their daily behaviour, they close lights when leaving a room, avoid to operate electric hot water heater and generally switch off electric devices when not used. Furthermore the first household uses as main electric devices : Televison for average time of three hours per day and 2 laptops that are considered to operate for 2 hours per day. Additionally, they make use the washing machine every 3 days.

On the other hand occupiers of apartment B usually make use of the electric Oven twice per day. As mentioned before, the B apartment uses split units for heating and cooling needs. The heating system is estimated to operate 4 hours per day during the colder months(November,December,January,February ,March) and 2 hours during (April, October). While Cooling system operates 3 hours per day during (July, August) and 1 hour on June and September.

Household B also covers DHW demands by solar panels, however sometimes they make complementary use of the electric water heater during the day in March,April, September and October. In the winter season they operate electric water heater for an average time of one hour per day. It also operates 2 laptops for 2 hours per day, television operates for 9 hours per day and it is estimated that they make use of the washing machine every second day. Household B also makes use of other electrical devices for household use.

On the following report, there is also recorded the energy consumption of both apartments, as also there is going to be estimated the annual energy consumption according to the estimated operating time of each system

Primary energy consumption:

Table 14

Building A			
YEAR	**FUEL**		
	Electricity (kWh)	**DIESEL (lit)-(Kwh)***	**Total (kWh)**
2015	3720	900 (9000Kwh)	12.720

The energy efficiency of the diesel oil converted to Kwh/lit is the lower calorific value Hu of the common used fuels in Greece : Diesel Oil = 42.700 kJoule/kg = 10.200 kcal/kg = 12kWh/kg = 10kWh/lit by this value relation the energy consumption of the diesel is calculated on the appendix above.

Table 15

Building B			
YEAR	FUEL		
	Electricity (kWh)	DIESEL (lit)-(Kwh)*	
2015	8950	-	

On the tables below there are estimated the electric energy consumption of each apartment.

Table 16

Building A				
Year 2015	Operating System			
	Heating	Cooling	Electric Water Heater (kWh)	Other Electrical Devices (kWh)
	-	-	350	3.370

Table 17

Building B				
Year 2015	Operating System			
	Heating (kWh)	Cooling (kWh)	Electric Water Heater(kWh)	Other Electrical Devices (kWh)
	2296	620,00	480	5.520

Regarding to the energy records of the two apartments it is worth to mention that apartment A has less electricity consumption than the second apartment because on the first apartment there is not installed electrical cooling and heating systems. The second apartment uses split units for space heating and cooling demand. It is noted that heating energy demand is bigger than cooling on the specific occasion. The occupants of apartment B, stated that they are not satisfied with the present heating system. Although they used split units for heating for an average time of four hours per day,during the winter. This can be justified due to the increased infiltrations that occur by the poor efficiency of windows and openings. The fact that both of the apartments use different heating systems, makes the comparison of energy consumption difficult . However, given the fact that the second family uses the electric space heating system at least four hours daily,combined with local heating stones in order to achieve proper internal thermal conditions indicates that the specific type of heating system is not the proper one. On the other hand, the first family stated that makes use of the oil boiler heating system about 2 or three hours daily and is satisfied with the indoor thermal conditions. Despite the fact that both of the split units have COP factor that meets the minimum requirements that are mentioned on the relative technical guidance, on the specific occasion using split units for heating seems less profitable than oil boiler system due to the increased infiltrations of the apartments. These increased thermal losses on the second occasion, emerge because the heat transfer on apartment A is based on radiation, while on the second occasion is based on convention. Infiltration,combined with convention of heat transfer caused increased thermal losses.

In order to compare the energy that is consumed for heating, on both occasions, there must be made a conversion of the oil quantity that was consumed for heating on primary energy terms. More specifically,it is calculated that the oil consumed for heating corresponds to 9000 kWh. As it can be easily noticed, the energy consumed for heating is bigger than the energy consumed for heating by split units of the second household. However the failure of split units to achieve desirable indoor temperatures on the second household has made the residents of the second apartment to believe that the optimal solution for space heating is by the installing oil boiler system. Comparing the energy consumption of the two apartments,there are noticed differences between the energy consumption of the two dwellings,especially on the use of electric devices such as TV, computers, electric oven, washing machine and lighting. The energy consumption of the second dwelling is bigger than the second one. It seems reasonable because the members of the second apartment are more and they tend to forget the devices open during a typical day. Another parameter that has affected the energy behaviour of the Greeks is the obvious results that have arisen by the financial crisis that the country has suffered since 2009. Most residents of the block complained about the increased cost of central heating system and decided to switch to alternative local solutions for heating.

Using split units for heating, on the specific occasion seems to be less cost effective in the specific study case.

On previous chapters there was mentioned the fact that the occupants of the first building don't use split units for space cooling needs. More specifically, they stated that natural ventilation is adequate to achieve space cooling of the apartment. On the other hand the occupants of apartment B they make excess use of the space cooling system during the summer season. This is mirrored on the energy profile of the second family and on the relative table that imprints the energy consumption of each system. There is noticed an estimated additional energy consumption of 620 kWh for each year, based on an average use of cooling system for 2 hours daily for a period of four months during the summer season, as stated by the occupants of the second apartment A.

Respectively, the second apartment consumes annually 130kWh more than apartment A for DHW uses. This is justified because family B has more members than family A. Furthermore, the annual energy consumed for lighting by family B is 100 kWh bigger that the energy consumed by family A. This difference occurs because apartment B hosts more people than apartment A and due to the differences on the daily habits of the occupants. The fact that the occupants of the second apartment tend to forget to deactivate various electric equipment, affects the energy consumption of the building. This is clearly imprinted on the difference of the energy consumption for lighting.

5. 1 Quastionairres

Indoor environmental comfort is in various occasions an objective issue. As mentioned before the factors that affect the occupant behaviour on an indoor environment are: Temperature, radiant temperature, air velocity and humidity. The human body has many ways to respond to environmental changes. Specially heat changes. In most of the cases ,occupants tend to manage heating,cooling and even lighting systems in order to achieve indoor comfort. These interactions on the aforementioned systems may influence the energy consumption of a building. In order to extract safe conclusions about the subjective conditions of an indoor environment, there must be taken under consideration in various parameters such as social beliefs and habits of the occupants,except the construction data of the building. For these reasons it is desirable to enact and share questionnaires which will provide us various information of the inspected building,as also information about the occupants behaviour.

1. Demographic Data

Gender:
Male

Female

Number Of Occupants:
One
Two
Three
Four
More than 4

Children between Occupants:
Yes
No

Operational hours of Heating Cooling Systems
Less than 2 hours
More than 4 hours
More than 6 hours

Construction Year of the building
Before 1980
Between 1980-2010
After 2010

2. Electric Apparatus Use

Using electrical appliances (tv, surge protector, etc.)? If Yes, turn off at night when you sleep?

Don't deactivate ever
Yes, deactivate always
No use
Deactivate whenever you remember

When you leave the room, how often do you turn off the lights?

Never
Always/most of the time

3. Indoor Acoustical Environments

Annoyance scale:

Very annoying
Annoying
Slightly annoying
Not annoying

Preference scale:

Please rate on the following scale how YOU would like it to be NOW:
Much quieter
Quieter
Slightly quieter
No change

Acceptability scale

Acceptable
Not acceptable
Satisfaction scale
Satisfied
Not satisfied

4. Indoor Visual Environments and Lighting

Is Natural lighting Adequate most of the Day?
No
Yes
More hours but have to light the lights of the room during the day

How many hours a day you turn on artificial lighting?
1-6 hours

6-12 hours

Visual discomfort scale:
Please rate on the following scale your visual discomfort now
Much discomfort
Discomfort

Slight discomfort
No discomfort

Preference scale:
Please rate on the following scale how you would like your visual environment to be now:
Much lighter
Lighter
Slightly lighter
No change
Slightly darker
Darker
Much darker

Acceptability scale
Acceptable
Not acceptable.
Satisfaction scale
Satisfied
Not satisfied
Sources of glare
Please indicate if you are experiencing any glare now.

5. Indoor Air Quality

Smelliness scale:
Very smelly
Smelly
Slightly smelly
Not smelly

Acceptability Scale
Acceptable
Not Acceptable

Satisfaction scale
Satisfied
Not satisfied

Sources of smells
Please indicate any sources of smell in your environment now

6. Indoor Vibration

Uncomfortable scale
Extremely uncomfortable
Very uncomfortable
Uncomfortable
Fairly uncomfortable
A little uncomfortable
Not uncomfortable

Annoyance scale:
Very annoying
Annoying
Slightly annoying
Not annoying

Acceptability scale
Acceptable
Not acceptable

Satisfaction scale
Satisfied
Not satisfied
Sources of vibration
Please indicate any sources of vibration in your environment now

7. Predicted Mean Vote and Predicted Percentage Dissatisfied

Sensation scale:
Please rate on the following scale how you feel now:
+3. Hot
+2. Warm
+1. Slightly warm
0. Neutral
-1. Slightly cool
-2. Cool
-3. Cold

Uncomfortable scale:
Very uncomfortable
Uncomfortable
Slightly uncomfortable
Not uncomfortable

Stickiness scale:

Very sticky
Sticky
Slightly sticky
Not sticky

Preference scale:
Please rate on the following scale how you would like to be now:
Much warmer
Warmer
Slightly warmer
No change
Slightly cooler
Cooler
Much cooler

Draughtiness scale:
Very draughty
Draughty
Slightly draughty
Not draughty

Dryness scale
Very dry
Dry
Slightly dry
Not dry

Satisfaction scale
Satisfied
Not satisfied

Acceptability scale
Acceptable
Not acceptable

8. Occupant energy behaviour

If you knew the monthly energy consumption, will affect you?

Yes
No

Chapter 6
Conclusions

This case study examines the difference on the energy consumption between two apartments with similar technical properties. More specifically,there is concluded that the energy consumption of a building is affected to a great extend by the habits and the energy behaviour of a residence. Additionally ,it is noticed that the energy consumption of various energy systems (lighting systems and electric apparatus) can be increased by 30%. On the specific occasion there cannot be a clear conclusion on which system is more efficient as the proper heating system.. However, by the post occupant evaluation that was conducted on the two households,it is concluded that oil boiler system offered more ideal indoor temperature during winter. The difference that occurs in the operation time of the two heating systems can be created either due to the rebound effect or due to the increased infiltrations combined with the type of heating system. Furthermore,occupant behaviour on the specific occasion is an important determinant of the required energy for space heating and cooling systems and can be affected by a string of variables such as lifestyle,motivation and interaction between the occupants.

Generally energy consumed for space heating and cooling systems is influenced by the use of heating and ventilation systems, as also by the use of other appliances.

It is commonly accepted that occupant behaviour can affect the energy behaviour of a structure and can be influenced by a number of different determinants. The most important determinant that affects the behaviour of the second apartment is the lack of energy saving perception among the family members. This is verified by the post evaluation analysis and the results of the questionnaires that were distributed to the occupants. The results indicate that family of the second apartment makes more reckless use of electrical appliances

The belief that type of temperature control and ventilation influences occupant behaviour is confirmed in the specific case study. The occupants of apartment B ventilate more rarely and mostly rely on mechanical instead of natural cooling.

In the specific case study, there have been made various assumptions due to the difficulties that emerged during the evaluation. The time of use of each system is estimated by the residents during the post occupant evaluation,due to the lack of energy data recording system that would provide more accurate indications of the consumed energy of each system.The most important factor that affects the energy consumption of an apartment is the sense of ideal indoor conditions that satisfies each family. The first family does not use cooling system because they consider that ideal indoor conditions can be achieved by natural ventilation of the apartment while the second family makes use of the cooling system during the summer. It is noticed that the occupants of second dwelling tend to ventilate less. Therefore,there can be made the assumption that this behaviour is interrelated with the excess use of the space cooling system during the summer season.

This finding might be related to the rebound effect of occupant behaviour. Furthermore, the rebound effect may also be responsible for higher temperature settings and preferences during winter. These assumptions may be right for the specific occasion. The second family stated that they also make excess use of the heating system during winter.

The financial crisis has affected the energy behaviour of a large proportion of the population. It is noticed that they turn to individual solutions for heating as also to other comfort curtailments on their daily routine.

The only way to extract energy consumption data of buildings is through questionnaires and post occupancy evaluation. However, the aforementioned methods do not consist of objective criteria because they are mainly based on subjective factors and they can often be inaccurate. Upgrading the conventional energy grid to smart grid and installation of smart meters will offer detailed energy data record and will provide safer and more accurate conclusions

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