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ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

«Υλοποίηση λογισμικού για τον υπολογισμό των ενεργειακών καταναλώσεων ψύξης και θέρμανσης σε μονοκατοικίες με χρήση μεθόδων ωριαίου βήματος»

«Software implementation of a simplified hourly method for the calculation of heating and cooling power consumption in domestic buildings»

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Abstract

The present thesis aims to provide a simple software tool, developed in MATLAB programming environment, able to simulate the dynamic response of residential buildings and to calculate the yearly heating and cooling demands based on the hourly method proposed in EN ISO 13790. The heating and cooling requirements in buildings are primarily dependent on weather conditions and on the physical and geometrical characteristic of the envelope, and secondly on occupant behavior.

The impact of the energy consumption in the domestic buildings sector in Europe and Greece is analyzed in the first Chapter. In the same chapter, an overview of the Greek building stock is presented. Moreover, a brief reference is made to the T.O.T.E.E. (Technical Instructions of the Technical Department of Greece) who they aims to fill the gap resulting from the lack of valid Greek Technical specifications regarding the energy study of buildings. The T.O.T.E.E. texts gives recommendations on the design, selection of materials and components, construction, installation, maintenance and use of a newly constructed or remodeled building.

The implementation of the simple hourly method of EN ISO 13790 is presented in the second chapter and insight is given for the calculation of the required parameters such as the heat transmission, the heat capacity, the gains by solar, the gains by occupants, appliances and lights, the ventilation-infiltration, the cooling and heating systems and more. The presentation of each component follows the structure that was used in order to program the method, which follows the Object Oriented Programming technique. The current implementation of the EN ISO 13790 hourly method is restricted only for single thermal zone buildings, but the way that the code is structured allows the addition of multiple thermal zones with minor modifications.

The developed software is able to predict for the thermal zone/building the hourly heating and cooling demands, the internal temperature and the hourly energy consumption by the heating/cooling systems. In addition, the primary energy consumption and CO_2 emissions are calculated, according to the T.O.T.E.E. Last but not least, a detailed analysis of the losses/gains (e.g. losses by infiltration, solar gains etc.) is also an option.

The simulation software developed for this Thesis was compared with the TRNSYS and T.E.E. K.Eν.A.K. software respectively by simulating the energy demands of a typical Single Family House in Athens, used as a benchmark building. The results of the comparison are presented in Chapter 3 and ensure the accuracy of the developed method.

In the fourth chapter, various case studies were examined using the developed software in order to determine the effect of various parameters on the final energy consumption of the benchmark building, such as different climate , different insulation thickness, different for heating and cooling profiles, different boilers and cooling systems while the fraction of the solar energy for DHW production is examined as well.

In the last chapter, the concluding remarks are summarized while recommendations for further work on the software development and usage are presented.

Περίληψη

Σκοπός της παρούσας διπλωματικής εργασίας είναι η υλοποίηση ενός υπολογιστικού προγράμματος, χρησιμοποιώντας το λογισμικό MATLAB, που είναι ικανό να προσομοιώσει τη δυναμική απόκριση των κατοικιών και να υπολογίζει την ετήσια ζήτηση σε θέρμανση και ψύξη βασιζόμενο στη απλοποιημένη μέθοδο ωριαίου βήματος του EN ISO 13790.

Η επίδραση των ενεργειακών καταναλώσεων του οικιακού τομέα σε ευρωπαϊκό και εθνικό επίπεδο αναλύονται στο πρώτο κεφάλαιο. Στο ίδιο κεφάλαιο παρουσιάζεται μια επισκόπηση του κτιριακού δυναμικού της Ελλάδας. Επίσης γίνεται μια συνοπτική αναφορά στις Τεχνικές Οδηγίες του Τεχνικού Επιμελητηρίου Ελλάδος (Τ.Ο.Τ.Ε.Ε.), οι οποίες φιλοδοξούν να καλύψουν το κενό που προέκυψε από την εώς τώρα έλλειψη έγκυρων ελληνικών τεχνικών προδιαγραφών όσον αφορά την ενεργειακή μελέτη κτιρίων. Τα κείμενα των ΤΟΤΕΕ δίνουν συστάσεις σχετικές με το σχεδιασμό, την επιλογή των υλικών και εξαρτημάτων, την κατασκευή, την εγκατάσταση, τη συντήρηση και την χρήση ενός νεόδμητου ή ριζικώς ανακαινιζόμενου κτιρίου.

Η υλοποίηση της απλοποιημένης μεθόδου ωριαίου βήματος του EN ISO 13790 παρουσιάζεται εκτεταμένα στο δεύτερο κεφάλαιο και δίνονται πληροφορίες για τον υπολογισμό των παραμέτρων που απαιτούνται από τη μέθοδο, όπως η μεταφορά θερμότητας από αγωγή και αερισμό, η θερμοχωρητικότητα των δομικών στοιχείων, τα ηλιακά κέρδη, τα κέρδη από τους ανθρώπους και τις συσκευές, τα κέρδη από τον φωτισμό, τα συστήματα θέρμανσης και ψύξης κ.α. Η παρουσίαση κάθε μεταβλητής ακολουθεί τη δομή που χρησιμοποιήθηκε και κατά τον προγραμματισμό της μεθόδου, σύμφωνα με τις αρχές του αντικειμενοστρεφή προγραμματισμού. Η υλοποίηση της ωριαίας μεθόδου του EN ISO 13790 έγινε μόνο για μία θερμική ζώνη αλλά η δομή του λογισμικού επιτρέπει την προσθήκη θερμικών ζωνών με μικρές τροποποιήσεις του κώδικα.

Το λογισμικό που αναπτύχθηκε είναι ικανό για τη υπό εξέταση θερμική ζώνη να προβλέψει την ωριαία θερμική και ψυκτική ζήτηση, την εσωτερική θερμοκρασία χώρου και την ωριαία κατανάλωση από τα συστήματα θέρμανσης και ψύξης. Ακόμη, έχει την ικανότητα να υπολογίσει την πρωτογενή ενέργεια και τις εκπομπές διοξειδίου του άνθρακα σύμφωνα με τις Τ.Ο.Τ.Ε.Ε. Ακόμη γίνεται λεπτομερώς ανάλυση των απωλειών/κερδών (π.χ. απώλειες λόγω διείσδυσης του αέρα, ηλιακά κέρδη κ.α.).

Το λογισμικό της παρούσας διπλωματικής εργασίας συγκρίνεται με τα λογισμικά TRNSYS και Τ.Ε.Ε. Κ.Εν.Α.Κ. αντίστοιχα προσομοιώνοντας τις ενεργειακές απαιτήσεις μίας μονοκατοικίας στην Αθήνα. Τα αποτελέσματα της σύγκρισης παρουσιάζονται στο τρίτο κεφάλαιο, τα οποία πιστοποιούν την ακρίβεια της μεθόδους όπου αναπτύχθηκε.

Στο τέταρτο κεφάλαιο, διαφορετικά σενάρια εξετάζονται χρησιμοποιώντας το λογισμικό όπου αναπτύχθηκε για να προσδιοριστεί η επίδραση διάφορων παραμέτρων στην τελική κατανάλωση ενέργειας του υπό μελέτη κτιρίου, όπως διαφορετικά κλιματολογικά δεδομένα, πάχη μόνωσης, ωριαία προγράμματα θέρμανσης και ψύξης, θερμικά και ψυκτικά συστήματα, αλλά και την ποσοστιαία κάλυψη της ζήτησης σε ζεστό νερό χρήσης από ηλιακή ενέργεια.

Στην τελευταία παράγραφο παρουσιάζονται συμπεράσματα και μελλοντικές συστάσεις για επέκταση και την πιθανή αξιοποίηση του λογισμικού σε ενεργειακές μελέτες.

I. Contents

II. Introduction

II.1 Global energy problems

Concerns about global warming and climate change are rising among scientists in a very high rate in the past several years. These global issues are becoming important agendas for politicians especially in developed countries to raise awareness of the consequences of global warming to public and set new regulations and standards to control the treats of global warming to earth and humanity.

The next figure shows the total global energy consumption by final sector [1], primary fuels in power allocated according to final sector electricity consumption:

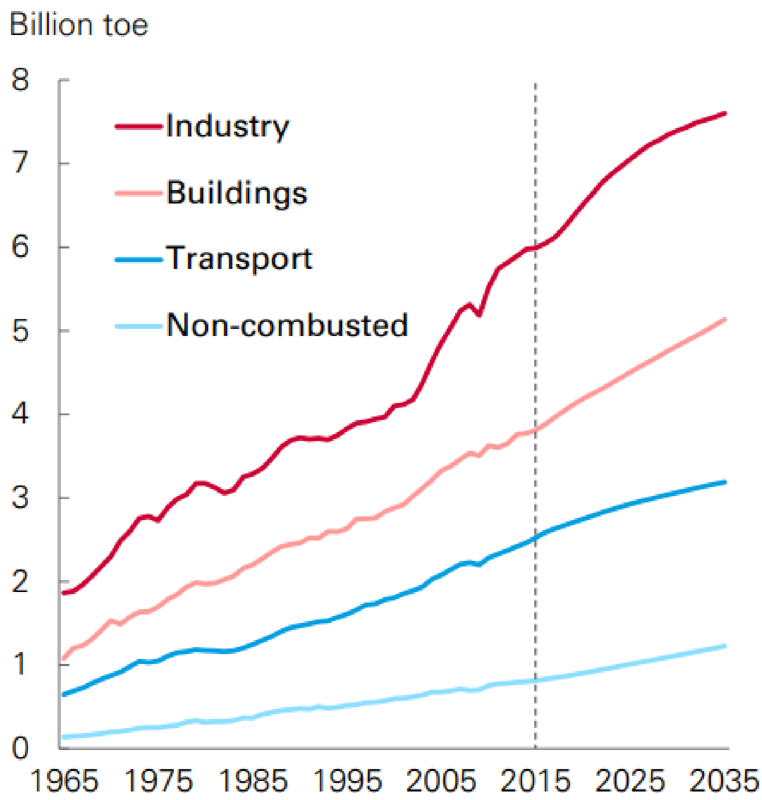

Figure 1: Total global energy consumption by final sector [1]

The increase of energy consumption in the world is driven by a combination of growing population and increasing prosperity, allowing people to live and work in greater comfort. It is obvious that in the future the energy consumption will be increased.

II.2 Domestic buildings in Europe

II.2.1 Energy consumption in domestic buildings in Europe

The reduction of energy consumption and the elimination of energy wastage are major goals of the world. Within the EU (European Union) it is committed to decrease the annual primary energy consumption of the year 2020 by 20 % to the consumption of the year 1990 [2]. Beyond this horizon, the European Commission committed in the road map towards a Low Carbon Economy to reducing energy consumption in buildings by 88% to 91% by 2050 [3]. The legislation aims to improve the energy performance of buildings in the EU, taking into account various climatic and local conditions. It sets out minimum requirements and a common methodology. It covers energy used for heating, hot water, cooling, ventilation and lighting [3].

A significant potential is given in the energy intensive consumers like buildings, especially of domestic and tertiary sector, as well as transport and industrial processes. The building sector is responsible for around 37% of the overall energy consumption in the EU [4].

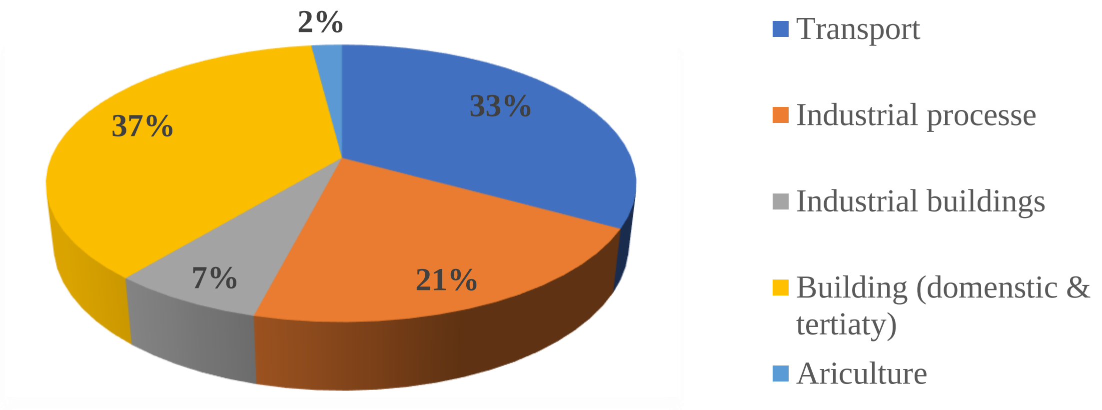

Figure 2: Energy consumers in European Union [4]

It becomes clear how significant, the study of buildings is. To achieve this goal, guidelines regarding the energy performance of buildings are proposed for the member states. Every nation is encouraged to apply a method for calculating the energy efficiency for buildings as well as to establish minimum requirements. Improving the energy performance of buildings, is a cost-effective way of fighting climate change and improving energy security, while also creating jobs. These jobs, particularly in the building sector are inherently local jobs such as assemblers, installers, etc. and Europe should not under-estimate the economic potential of investing in energy efficiency buildings.

II.2.2 Evaluation of building codes at European level

Energy efficiency in construction standards is recognized in universal as a practical and economical way to decrease energy in residential and commercial buildings. All over the world, countries are independently designing and implementing energy efficiency policies and programs in residential and commercial buildings to decrease energy waste in the new or exist buildings.

On 19 June 2018 Directive (2018/844/EU), amending the Energy Performance of Buildings Directive was published [5]. Under new and revised directive, the following requirements are established:

- EU countries will have to establish stronger long-term renovation strategies, aiming at decarbonizing the national building stocks by 2050, and with a solid financial component
- Smart technologies will be further promoted, for instance through requirements on the installation of building automation and control systems and on devices that regulate temperature at room level
- EU countries will have to express their national energy performance requirements in ways that allow cross-national comparisons
- All new buildings must be nearly zero-energy buildings by 31 December 2020 (public buildings by 31 December 2018)
- Energy performance certificates must be issued when a building is sold or rented, and they must also be included in all advertisements for the sale or rental of buildings
- EU countries must establish inspection schemes for heating and air conditioning systems or put in place measures with equivalent effect
- EU countries must set cost-optimal minimum energy performance requirements for new buildings, for the major renovation of existing buildings, and for the replacement or retrofit of building elements (heating and cooling systems, roofs, walls and so on)
- EU countries must draw up lists of national financial measures to improve the energy efficiency of buildings.

II.2.3 The Energy Performance of Buildings Directive (EPBD)

The key legislative instrument to unlock the savings potential in the building sector is the Energy Performance of Buildings Directive (EPBD), accompanied by provisions for the building sector in other Directives (specifically the Energy Efficiency Directive, Renewables Directives and Eco-design and Labelling Directive).

The EPBD regulates both ‘passive’ measures for the building design and envelope, as well as the ‘active systems’, such as for heating/cooling and lighting. Also, the EPBD introduced certificates, which indicate the Energy Performance of the building as a numeric value, allowing for benchmarking. The certificates also include a list of cost-effective energy saving measures.

After the first version, the update Directive raised the bar to a higher level by introducing the ambitious concept of nearly-zero energy consuming buildings, by including Renewable Energy systems. After 2020, this will be mandatory for all new constructions.

The end responsibility of the implementation of the EPBD is usually with a national Ministry, like Housing, or Urban Development. The actual enforcement of the EPBD is delegated to local level through regulations and directives. Depending on the selected model, the local governments could engage private sector auditors, which are officially accredited, for the final enforcement.

The EPBD mentions specifically that the energy performance of buildings should be calculated based on a methodology, which may be differentiated at national and regional level. However, that methodology should consider existing European standards.

II.3 Domestic buildings in Greece

II.3.1 Buildings in Greece

According to the results of the population-housing census of 2011 by ΕΛ.ΣΤΑΤ. (Hellenic Statistical Authority), buildings in Greece are categorized in those of exclusive use (92%) and in those of mixed uses (8%). Most of the buildings are domestic buildings counting 3.246.008 [6]. They constitute the 79.1% of all buildings in Greece. The inhabited and non-inhabited accommodation buildings are 6.384.353 in total. There is a separation in permanent residences (64.7%) and non-permanent ones (35.3%). Permanent residences are those which are used for at least six months. This distinction was made in order to allocate the household for at least 3 winter and 3 summer months [6].

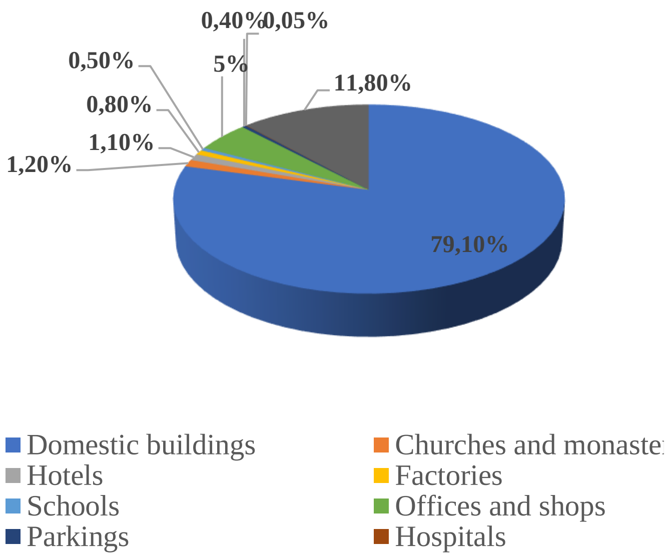

Figure 3:Buildings in Greece, 2011 [6]

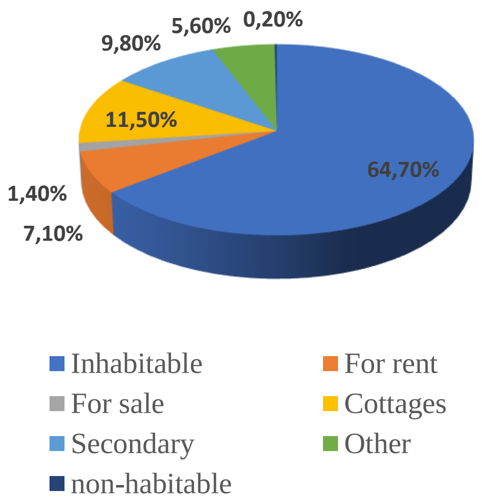

Figure 4: Domestic buildings in Greece [7]

II.3.2 Period of construction and type of insulation in domestic buildings in Greece

In 2011, the ΕΛΣΤΑΤ (Hellenic Statistical Authority), also counted the period of construction of Greek domestic buildings as part of the population-housing census. As mentioned above, the inhabited and non-inhabited accommodation buildings are 6.371.901 with 64.7% of them being permanent residences. As we can see from the next figure, most of domestic buildings were built between 1971 and 1980. Another important point is that most houses were built before 1990 which reaches the percentage of 71.58% [8].

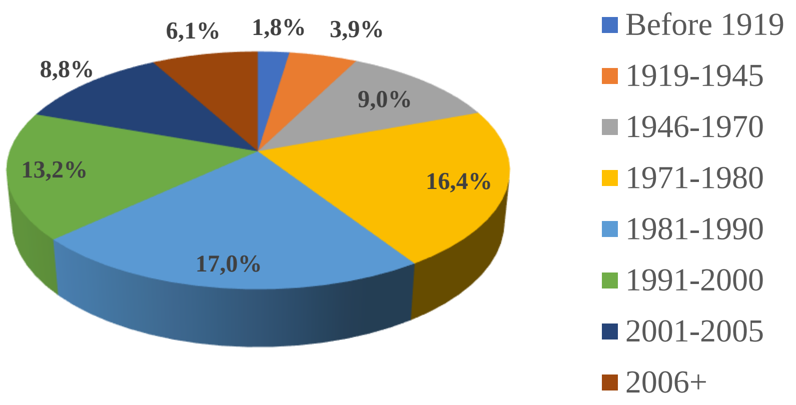

Figure 5: Percentage distribution of domestic buildings per period of time in Greece [8].

It is very important if the house has insulation or not and the insulation type. According to the next figure, it is obvious that most houses before 1990 do not have any type of insulation. As mentioned, these houses account for the bulk of Greece housing and in total of 45.6% they do not have insulation. Houses which either have no insulation or have only double glazing account for 71.5% of all houses in Greece [8]. As a result, increased energy consumption is expected in residential buildings constructed prior to 1990, which reflects to the generally increased energy consumption in the building sector of Greece.

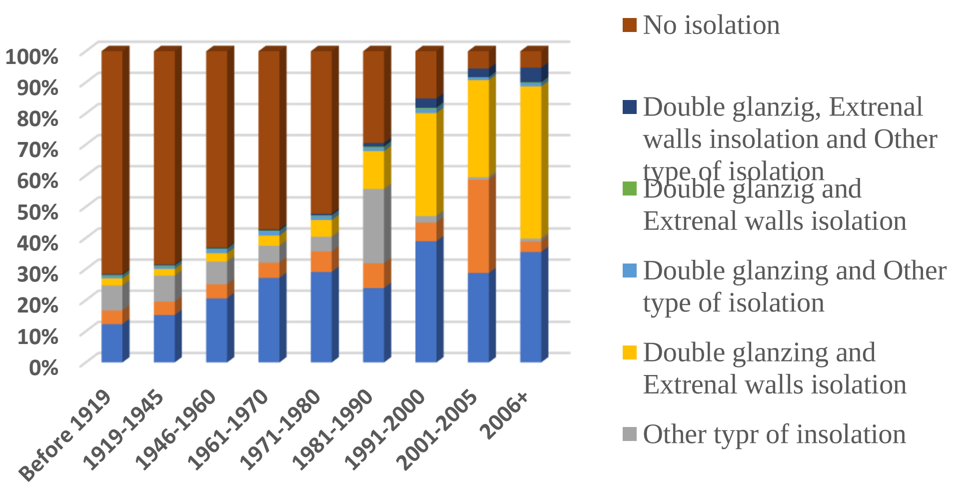

Figure 6 Type of isolation in houses per period of time in Greece [8]

II.3.3 Energy consumption in domestic building in Greece

The Greek energy consumption distribution does not differ to the EU one, presented in the previous section. The building sector is responsible for around 26% of the overall energy consumption in 2013 in Greece [9]. More specifically 15% of the overall energy consumption is only the Residential space heating [9]. Figure 3 shows the residential energy consumption in 2013.

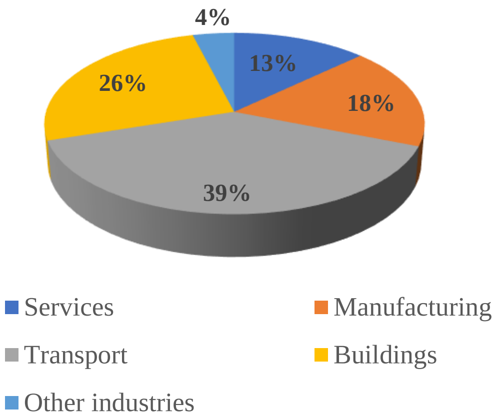

Figure 7: Largest end-uses by sector, 2013 in Greece [9]

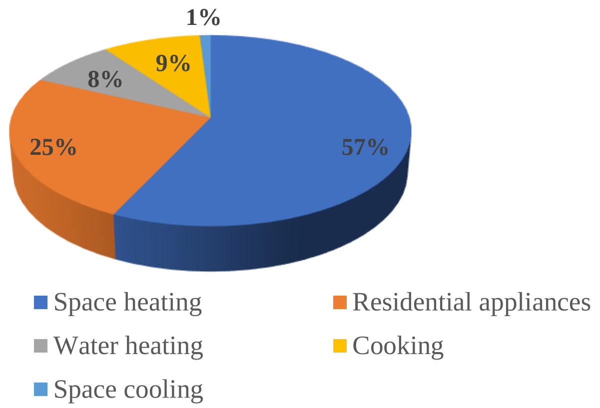

Figure 8: Residential energy consumption by end-use, 2013 in Greece [9]

It is obvious that the energy consumption in the building – and especially the residential – sector is a major issue for Greece as well as the E.U. In order to conform to the EU directives described above, the Greek government drew up the Regulation of Building's Energy Efficiency (named K.Eν.A.K.), which is analytically described in the following sections.

II.3.4 Energy study of domestic buildings in Greece

II.3.4.1 Building Energy Efficiency Regulation (K.Eν.A.K.)

K.Eν.A.K (Building Energy Efficiency Regulation) is implemented through the T.O.T.E.E. (Technical Instruction of Technical Department of Greece). With K.Eν.A.K the integrated energy planning in the building sector is institutionalized to improve the energy efficiency of buildings, in order to save energy and protect the environment. The Energy Classification of Buildings is carried out with the publication of the Π.Ε.Α. (Energy Efficiency Certificate) and is mandatory for any new lease of part of a residential building (apartment) or business space of any size, as well as for the purchase or sale of a single building or part of a building (apartment) of any size. The Π.Ε.Α. is valid for 10 years. It is noteworthy that before the publication of K.Eν.A.K there was nothing equivalent in Greece. This means that, there was no control of the energy study of the buildings in the country.

In April 2010 K.Eν.A.K was issued with the joint ministerial decision number D6 / home. 2825/2010 "Approval of Regulation of Energy Efficiency of Buildings (K.Eν.A.K) (Φ.Ε.Κ. Β΄ 407) [10]. The main points of the regulation are:

- The methodology for calculating the energy efficiency and energy classification of buildings is defined. The methodology is based on the relevant European standards that are mandatory.
- The minimum requirements (kWh/m^2) for the energy efficiency and energy classification of new and radically refurbished buildings are defined through the reference of building methodology. Under the same methodology energy buildings and existing buildings to be certified are evaluated and classified.
- The minimum specifications for the architectural design, the thermophysical characteristics of the structural elements of the building shell and the technical specifications of the electromechanical installations of the new buildings under consideration, as well as the radically renovated ones, are defined.
- The content of the M.E.A. (Energy Efficiency Study) of the buildings is defined. The M.E.A. is submitted along with other relevant studies for the issuing of a building permit.
- The form of the Π.Ε.Α. (Energy Performance Certificate) of a building, as well as the elements it will include.
- The procedure for building energy inspections as well as the inspections of boilers and heating and air-conditioning installations is defined

Minimum requirements and energy performance standards are completed when the building has all the minimum requirements described by K.Eν.A.K. Moreover, the total primary energy consumption of the building under consideration should be less than or equal to the total primary energy consumption building reference. That means, the building should be classified as energy class B or higher. The obligation to comply with is made to the extent that this is technically, operationally and economically feasible. In the case of failure to meet the minimum standards, there should be sufficient documentation when drawing up the energy efficiency study. Buildings protected by special town planning arrangements and building conditions (eg buildings of traditional settlements) are excluded [10].

K.Eν.A.K. has been updated in 27/11/2017 [11]. This is an evolution of the previous Regulation, with improvements and enrichment in individual articles, and a small increase in the requirements, for the new buildings. From that day the previous K.Eν.A.K. was cancelled and the new version must be used.

II.3.4.2 T.O.T.E.E. (Technical Instruction of Technical Department of Greece)

The T.O.T.E.E. (Technical Instructions of the Technical Department of Greece) aims to fill the gap resulting from the lack of valid Greek Technical Specifications in the construction and production sector and constitute the confirmation of the T.E.E. (Technical Department of Greece) policy to contribute to the creation of technology infrastructure in Greece.

The T.O.T.E.E. texts gives recommendations on the design, selection of materials and components, construction, installation, maintenance and use of a technical project. With these texts, the T.E.E. aims to provide concrete content and define the rules of art and science at all stages of the technical project life (design, study, construction, supervision, receipt, maintenance, use).

In texts there is a frequent reference to ΕΛΟΤ standards and, where they do not exist, to international standards (ISO, European) or recognized national standards (DIN, BS, AFNOR etc.). This, because T.O.T.E.E. believes that all Greek technicians must be conscious of using at all stages of their work the Technical Standards.

TOTEE aspire to be a daily tool for all actors (and not just Engineers) who work together to perform the project.

The first phase of the drafting of the Technical Instructions consists of ten T.O.T.E. and concerns the installations (except electrical) of the building works. At a joint meeting of representatives of the then Ministry of Public Works, the Technical Department of Greece and other institutions, the Ministry's intention was to revise the anachronistic regulation "On Plumbing Installations" of 1936. T.E.E. proposed to undertake the drafting of Technical Instructions covering on this occasion, all installations (other than electrical) of a building project.

With a contract signed between the Ministry of the Environment, Physical Planning and Public Works on 24.07.1985, the T.E.E .was commissioned to draw ten T.O.T.E.Es with funding from the Ministry of the Environment and Physical Planning and all the rights to print, reproduce and disseminate the issues.

The T.O.T.E.E of this series was compiled by three-member T.E.E. Technical Engineers working groups under the coordination and supervision of a 6-member task force. In order to solve all the problems that have been presented, the help provided by the associations of the SAO and the Governor was valuable.

The Working Groups have drawn up plans. It followed Public Dialogue and Public Crisis with comments made by Organizations, Social Agencies, Government Services and individuals and subsequently drafted this final text of the Directive. Throughout this process, the Hellenic Ministry of the Environment and Water Management (EH1) contributed with substantial monitoring of the procedures and with comments and finally gave the approval of the Ministry of Environment and Waters in the final text.

In 2017 the implementation of the Technical Instructions of the Technical Department of Greece is mandatory.

- T.O.T.E.E 20701-1/20017: Detailed national parameter specifications for calculating the energy performance of buildings and issuing the energy performance certificate (Π.Ε.Α.) [12]
- T.O.T.E.E 20701-2/20017: Thermophysical properties of building materials and control of thermal insulation of buildings [13]
- T.O.T.E.E 20701-5/20017: Weather data of Greek regions [14]
- T.O.T.E.E 20701-4/20017: Instructions and forms for energy inspections of buildings, boilers and heating installations and air-conditioning installations [15]
- T.O.T.E.E 20701-5/20017: Cogeneration of Electricity, Heat and Cooling: Installations in buildings [16]

II.3.4.3 Building reference

The determination of the minimum energy performance requirements (kWh/m^2) of a building can be measured mainly by two methods: either by reference values or through the building reference. In both cases the energy categories A+, A, B+, B, C, etc. are classified for each building use and for each climate zone.

In the case of the reference values (figure 9 on the left), the energy grading classes are defined by a range of final energy consumption (kWh/m^2) for each building use and climate zone.

In the case of the building reference (Figure 9 on the right), the building which is under study is compared to the building reference, which always occupies the category B. The final primary energy consumption (kWh/m^2) of the building reference also determines the category B, while the other categories are formed as percentages of the building reference.

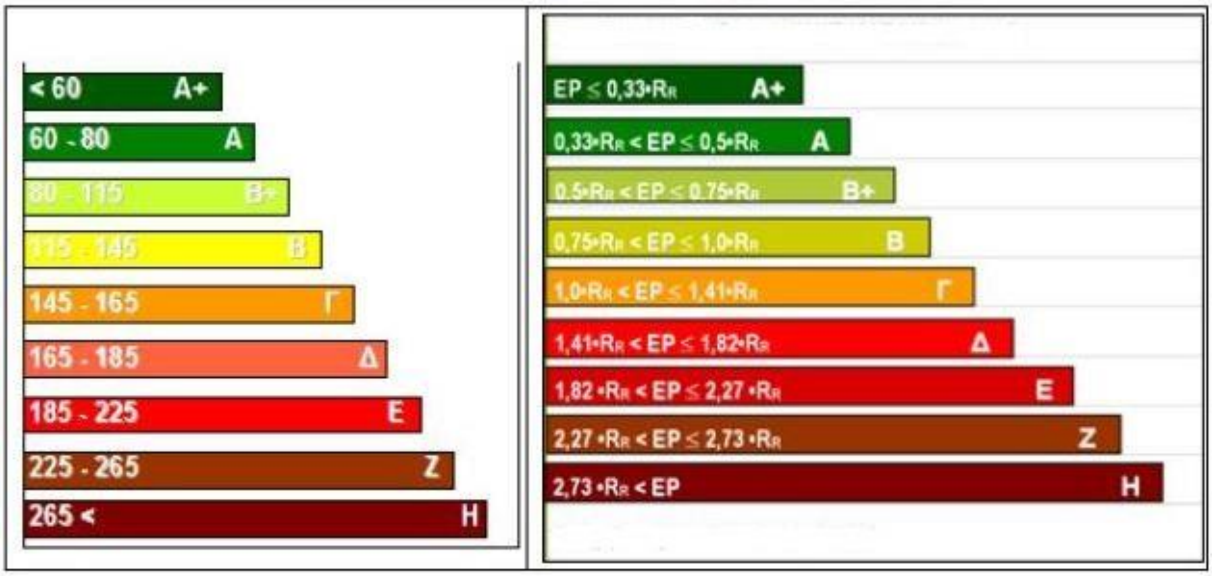

Figure 9: Representation of energy categories for reference values and building reference [10]

The definition of minimum requirements through the building reference is a method of comparing and evaluating the energy performance of the building which is under study with respect to its similar building. The building reference has the same characteristics, the same location, the same orientation, the same use and the same operating characteristics as the building under consideration. The building reference meets the minimum requirements of the K.Eν.A.K (Building Energy Efficiency Regulation) and has defined technical characteristics both in the external building blocks of the building shell and in the electromechanical installations concerning heating, cooling and air conditioning of indoor areas, hot water production and lighting.

The primary energy consumption of both buildings is estimated by means of TEE K.Eν.A.K software, which simulates the thermal performance of each building and the corresponding heating, cooling and DHW (domestic hot water) systems using the monthly method of EN ISO 13790.

II.3.4.4 Π.Ε.Α. (Energy Performance Certificates) in Greece

The houses that have received the Π.Ε.Α. (Energy Performance Certificates) since the beginning of the K.Ev.A.K (Building Energy Efficiency Regulation) are very few in number. More specifically, during the period 2011-2016 (until 31.05.16), a total of 641,662 Π.Ε.Α were issued in domestic buildings; 83% of them relate to apartment buildings or flats (535,517), while 17% relates to single-family homes [17].

Concerning the energy category in the domestic buildings, it is noted that a significant percentage of 65% is classified in the lowest energy category E-G, 32% belongs to the categories C-D, while only 3% in the categories A-B [17].

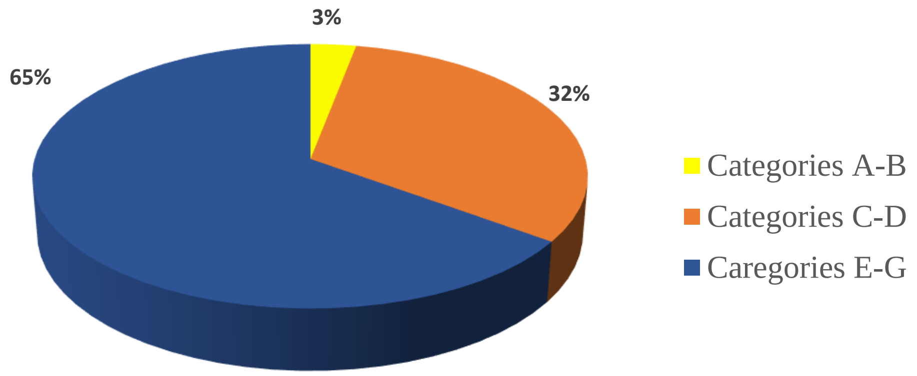

Figure 10 : Energy rating of domestic buildings that have received a Π.Ε.Α. (Energy Performance Certificates) [17]

II.3.5 Climate zones in Greece

According to K.Eν.A.K. (Building Energy Efficiency Regulation), the Greek territory is divided into four climatic zones based on the heating days. In each department, areas which are on an altitude of more than 500 meters, are incorporated in the next coldest climate zone. In zone D, all areas irrespective of altitude are included. The following table defines the counties that belong to the four climatic zones (warmest to the coldest) and their schematic representation follows on the map of Greece [12].

Climate Zone	ΝΟΜΟΙ
Zone A	Ηρακλείου, Χανιών, Ρεθύμνου, Λασιθίου, Κυκλάδων, Δωδεκανήσου, Σάμου, Μεσσηνίας, Λακωνίας, Αργολίδας, Ζακύνθου, Κεφαλληνίας & Ιθάκης, Κύθηρα & νησιά Σαρωνικού (Αττικής), Αρκαδίας (πεδινή)
Zone B	Αττικής (εκτός Κυθήρων & νησιών Σαρωνικού), Κορινθίας, Ηλείας, Αχαΐας, Αιτωλοακαρνανίας, Φθιώτιδας, Βοιωτίας, Ευβοίας, Μαγνησίας, Λέσβου, Χίου, Κέρκυρας, Λευκάδας, Θεσπρωτίας, Πρέβεζας, Άρτας
Zone C	Αρκαδίας (ορεινή), Ευρυτανίας, Ιωαννίνων, Λάρισας, Καρδίτσας, Τρικάλων, Πιερίας, Ημαθίας, Πέλλης, Θεσσαλονίκης, Κιλκίς, Χαλκιδικής, Σερρών (εκτός ΒΑ τμήματος), Καβάλας, Ξάνθης, Ροδόπης, Έβρου
Zone D	Γρεβενών, Κοζάνης, Καστοριάς, Φλώρινας, Σερρών (ΒΑ τμήμα), Δράμας

Table 1: Four climates zones in Greece [12]

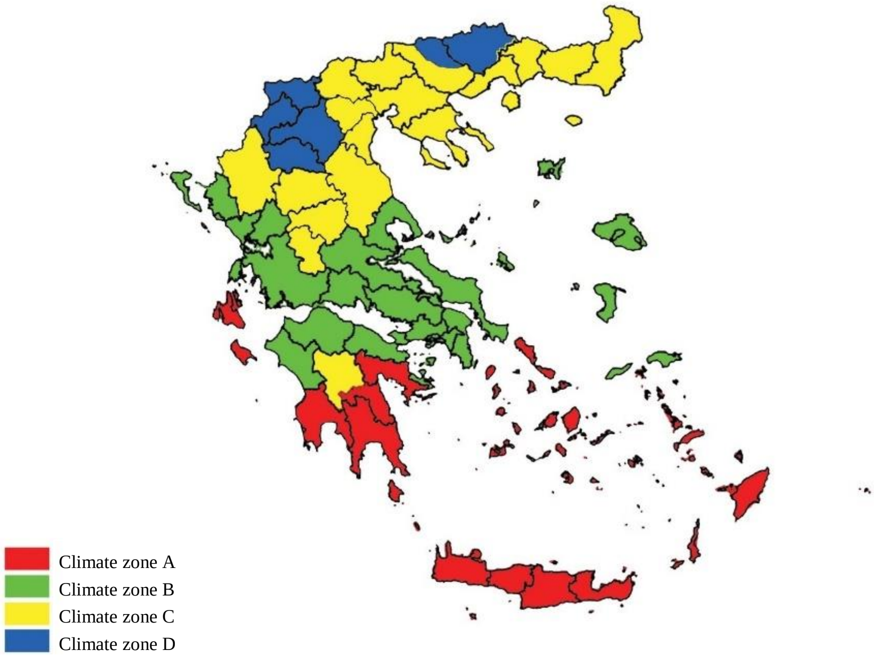

Figure 11: Four climates zones in Greece [12]

II.4 Calculation methologies

The simulation of buildings aims to the calculation heating and cooling energy demands. Simulation software allows the prediction of the effect of various changes in the building and its systems on the final energy consumption. Without building simulations software, it is not possible to know how the energy behavior will change when the construction elements are changed (e.g. by enhancing the insulation), the heating/cooling systems are upgraded or even if the control strategy of the systems is altered.

Various methodologies may be utilized in order to develop a building simulation software, which are mainly categorized by the way that the building elements can be modeled. In general, one dimensional heat flow across the building element (wall, window) is assumed and the one dimension dynamic equation of heat conduction must be solved.

Thus the response of the building elements can be calculated as the superposition of different harmonics, leading to the well-known heat Transfer Function (TF) method, which is implemented in the TRNSYS or EnergyPlus software [18]. The main drawback of such a method is that the coefficients of the Transfer Function must either be found experimentally, or calculated by from the heat transfer matrixes [19], resulting from the modeling of each layer using either a lumped parameter approach or simplified exact solutions of the heat conduction equation.

Another option is to directly use the lumped parameter modeling, for the total of the building elements of a thermal zone by splitting them into resistive and capacitive elements, based on an electrical analogous system. The order of the dynamics is imposed by the number of the capacitive elements used. Generally speaking, lumped parameter modeling for the whole thermal zone results in less complex systems, which -depending on the number of capacitive elements- can be explicitly solved by integrating a number of Ordinary Differential Equations (ODE's). In many cases, the capacitance of the building elements can be modeled using a one to three capacitive components [20], giving satisfactory results. The main restriction is imposed by the Biot number, as it is pointed out in [21]. The simple hourly method of EN ISO 13790 implements such a lumped model, using just one capacitive element for the whole building (thus neglecting the air capacitance).

II.4.1 EN ISO 13790

EN ISO 13790:2008 has been prepared by Technical Committee ISO/TC 163 "Thermal performance and energy use in the built environment" in collaboration with Technical Committee CEN/TC 89 "Thermal performance of buildings and buildings components" the secretariat of which is held by SIS.

Attention is drawn to the possibility that some of the elements of this documents may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent right.

EN ISO 13790 has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association (Mandate M/343), and supports essential requirements of EU Directive 2002/91/EC on the energy performance of buildings (EPBD). It forms part of a series of standards aimed at European harmonization of the methodology for the calculation of the energy performance of buildings. An overview of the whole set of standards is given in CEN/TR 15615.

Attention is drawn to the need for observance of EU Directives transposed into national legal requirements. Existing national regulation (with or without reference to national standards) may restrict for the time being the implementation of this European Standard.

According to the CEN/CENELEC Internal Regulations, the national standard organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

This International Standard is one of a series of calculation methods for the design and evaluation of thermal and energy performance of buildings. It presents a coherent set of calculation methods at different level of detail for the energy use of the space heating and cooling of a building and the influence of the recoverable thermal losses of technical building systems such as heating and cooling systems.

II.4.2 Use of simulations software

Nowadays it is possible to employ several software packages to evaluate building's energy performance, each of them based on a different calculation code, with different boundary conditions in terms of environmental temperature, solar radiation, wind velocity and more.

II.4.2.1 TRNSYS

TRNSYS is a transient systems simulation program with a modular structure that was designed to solve complex energy system problems by breaking the problem down int a series of smaller components [18].

TRNSYS is an open modular structure with open source code which simulates all sectors of an energy-system except the transport sector. The TRNSYS model simulates the performance of the entire energy-system by breaking it down into individual components, and it is primarily used for analyzing single-project, local, community, or island energy-systems. To create a model, the user is able to create custom components or choose from the TRNSYS standard library of components. TRNSYS is used extensively to simulate solar energy applications, conventional buildings, and even biological processes.

As stated above, the modeling of the building elements in TRNSYS is based on the Transfer Function method. Besides, the effect of radiation among the inner surfaces that enclose the air node the external surfaces to the environment is also taken into account.

II.4.2.2 EnergyPlus

EnergyPlus has its roots in both the BLAST (Building Loads Analysis and System Thermodynamics) and DOE-2 were both developed and released in the late 1970s as energy and load simulation.

Like its parent programs, EnergyPlus is an energy and thermal load simulation program. Based on a user's description of a building from the perspective of the building's physical make-up, associated mechanical systems, etc. EnergyPlus is able to calculate the heating and cooling loads necessary to maintain thermal control setpoints, conditions throughout an secondary HVAC system and coil loads, and the energy consumption of primary plant equipment as well as many other simulation details that are necessary to verify that simulation is performing as the actual building should.

Similarly to the TRNSYS software, energy plus is based on Transfer Function methods in order to model the conductivity of building elements.

II.4.3 Weather data sources for building simulation

The weather data are very important. Every year has not the same weather data with the previous year. It is very important when you compare two scenarios for the same building, to have the same weather data. Also the internal temperature has a major impact by the external temperature.

It is very different to find out weather data on an hourly basis because every location has different weather data. For this reason, T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given monthly average values and a methodology to calculate the weather data on an hourly basis in many location in Greece [14].

There are many sources that you can take weather data. Some sources are K.Eν.A.K and Meteonorm, which is used by TRNSYS, and EPSCT(Energy Performance Standard Calculation Toolkit) [22].

III. Software implementation of the hourly method of EN ISO13790

In this section a detailed overview of the method implemented in the simulation software will be presented. The software follows an objected oriented programming structure, where different calculation procedures are implemented as data objects. The software consists of the following classes:

1. Building class
2. Thermal Zone
3. Wall class
    - Thermal coefficient (U_c)
    - Shading factor (F_{sh})
    - Heat capacity (C_m)
4. Windows
    - Thermal coefficient (U_w)
    - Shading factor (F_{sh})
    - Infiltration from the windows
5. Ventilation infiltration
6. Occupancy gains
7. Lighting gains
8. Weather
    - Radiation
    - Dry bulb temperature
9. DHW system
10. Heating system (Boiler)
    - Boiler efficiency
    - Prime energy efficiency
    - Network losses
11. Cooling system
    - Cooling system efficiency
    - Prime energy efficiency
    - Network losses
12. Heating terminal units
    - Efficiency
13. Cooling terminal units
    - Efficiency

Objected oriented programming (OOP) refers to a type of computer programming (software design) in which programmers define not only the data type of a data structure, but also the types of the operations (functions) that can be applied to the data structure. In this way, the data structure becomes an object that includes both data and functions. In addition, relationships between one object and another can be created. The next figure shows the objected oriented programming structure and the classes of it.

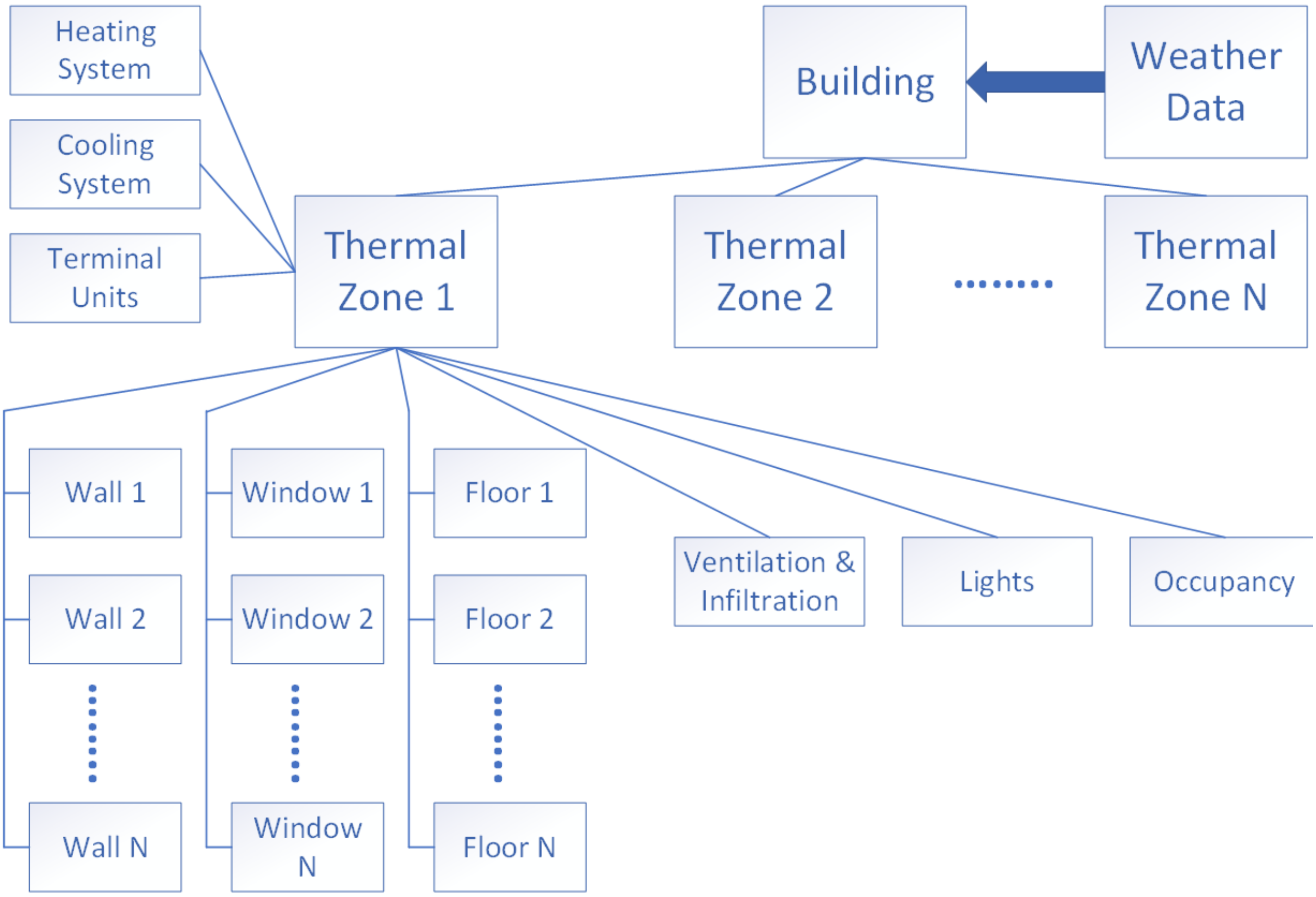

Figure 12: The objected oriented programming structure and its classes

III.1 Walls, Floors and Windows class

III.1.1 Terms and definitions

Heat transmission coefficient of the window (U_w)
is the overall heat coefficient of the window, measured in Watts per square meters Kelvin degrees.

Heat transmission coefficient of the glazing (U_g)
is the heat transmission coefficient of the window's glazing, measured in Watts per square meters Kelvin degrees.

Heat transmission coefficient of the frame (U_f)
is the heat coefficient of the window's frame, measured in Watts per square meters Kelvin degrees.

Heat transmission coefficient of the panel (U_p)
is the heat coefficient of the window's panel, measured in Watts per square meters Kelvin degrees.

Heat transmission coefficient of the opaque (U_c)
is the thermal transmittance of the opaque part, measured in Watts per square meters Kelvin degrees.

Linear heat transfer coefficient of the glazing (Ψ_g)
is the linear heat transfer coefficient of the thermal bridge at the junction of the frame, measured in Watts per square meters Kelvin degrees.

Linear heat transfer coefficient of the panel (Ψ_p)
is the linear heat transfer coefficient of the thermal bridge at the junction of the panel, measured in Watts per square meters Kelvin degrees.

Length of the linear thermal bridge at the junction of the (l_g)
is the perimeter of the glazing, measured in meters.

Surface area of the glazing (A_g)
is the surface area of the glazing, measured in square meters.

Surface area of the panel (A_p)
is the surface area of the panel, measured in square meters.

Surface area of the frame (A_f)
is the surface area of the frame, measured in square meters.

Surface area of the opaque (A_c)
is the projected area of the opaque part, measured in square meters.

Design thermal conductivity (λ)
Design thermal conductivity, measured in Watts per meter Kelvin degrees.

Thickness (d)
is the thickness of a layer, measured in meter.

Total clear-sky irradiance (E_t)
is the total clear-sky irradiance, measured in Watts per square meters.

Shading factor (F_{sh})
is the dimensionless shading factor.

Window frame factor (F_f)
is the dimensionless frame factor, ratio of the projected frame area to the overall projected area of the glazed element. Window frame factor is equal to 0.2 for heating-dominated climates and 0.3 for cooling-dominated climates [23].

Form factor (F_r)
is the dimensionless from factor between the building element and the sky determined. The values for the form factor for radiation between the element and the sky is equal to 1 for an unshaded horizontal roof and 0.5 for an unshaded vertical wall [23].

External thermal surface resistance (R_a)
is the external surface heat resistance of the element, measured in Watts per square meters Kelvin degrees.

Internal thermal surface resistance (R_i)
is the internal surface heat resistance of the element, measured in Watts per square meters Kelvin degrees.

Heat flow rate due to radiative (Φ_r)
is the extra heat flow due to thermal radiation to the sky for a specific building element, measured in Watts.

The average difference between the external air temperature and the apparent sky temperature ($\Delta\theta_{er}$)
is the average difference between the external air temperature and the apparent sky temperature, measured in Kelvin degrees. When the sky temperature is not available from climatic data, the average difference, $\Delta\theta_{er}$, between the external air temperature and the sky temperature should be taken as 9 K in sub-polar areas, 13 K in the tropics and 11 K in intermediate zones [23].

External radiative heat transfer coefficient (h_r)
is the external radiative heat transfer coefficient, measured in Watts per square meters Kelvin degrees.

Emissivity for thermal radiation of the external surface (ε)
is the emissivity for thermal radiation of the external surface, dimensionless.

Absorption coefficient of the opaque ($\alpha_{S,c}$)
is the dimensionless absorption coefficient for solar radiation of the opaque part,

Solar transmittance (g_{gl})
is the total energy transmittance of the window, dimensionless.

Floor area (A_{floor})
is the floor area per zone, measured in square meters.

Heat flow rate (Φ_{sol})
is the heat flow rate from solar heat sources in the considered building zone, measured in Watts per square meters.

Heat transfer per building element (H_{tr})
is the heat transfer by window and wall, measured in Watts per square meters Kelvin degrees.

Characteristic dimension of the plate (B')
is characteristic dimension of the plate, measured in meters.

Depth (z)
is the depth which has the wall or the floor into the ground, measured in meters.

Shading factor (F_{sh})
is the dimensionless shading factor.

Horizontal factor (F_{hor})
is the dimensionless partial shading correction factor for the horizon, it is the shading coefficient from the obstacle of the surrounding area (adjacent buildings, etc.)

Overhang factor (F_{ove})
is the dimensionless partial shading correction factor for overhangs by a horizontal cantilever or an external sunshade

Fin factor to the left side ($F_{fin,left}$)
is the dimensionless partial shading correction factor for fins.

Fin factor to the right side ($F_{fin,right}$)
is the dimensionless partial shading correction factor for fins.

Horizon angle (α)
is an average over the horizon facing the façade considered, measured in degrees.

Fin angle (β)
is the angle from the fin shading, measured in degrees.

Overhang angle (γ)
is the angle from the overhang shading, measured in degrees.

Heating and cooling period
Heating period can be assumed from 15 October until 15 April. The rest of the days are included in cooling period.

Heat capacity (C_m)
modulus of the net periodic thermal conductance divided by angular frequency, measured in Joules per Kelvin degrees.

Areal heat capacity (k_m)
heat capacity divided by area of element, measured in Joules per square meters Kelvin degrees.

Heat transfer matrix (Z)
matrix relating the complex amplitudes of temperature and heat flow rate on one side of a component to the complex amplitudes of temperature and heat flow rate on the other side.

Periodic penetration depth (δ)
Depth at which the amplitude of the temperature variations is reduced by the factor "e" (is the natural logarithms; e=2,718…) in a homogeneous material of infinite thickness subjected to sinusoidal temperature variations on its surface.

Design thermal conductivity (λ)
Design thermal conductivity, measured in Watts per meter Kelvin degrees.

Thickness (d)
is the thickness of a layer, measured in meter.

Period (ξ)
is the period of the variations, measured in seconds.

Ratio of the thickness (ξ)
is the ratio of the thickness of the layer to the penetration depth, dimensionless.

Effective mass area (A_m)
is the effective mass area, measured in square meters.

Conduction/convection coefficient (h_a)
Is the conduction/convection coefficient, measured in Watts per square meters Kelvin degrees.

Hemispherical emissivity of the first surface bounding the airspace (e_1)
Is the hemispherical emissivity of the first surface bounding the airspace, dimensionless.

Hemispherical emissivity of the second surface bounding the airspace (e_2)
Is the hemispherical emissivity of the second surface bounding the airspace, dimensionless.

Intersurface emittance (E)
Is the Intersurface emittance, dimensionless.

Radiative coefficient for a black-body surface at 10 centigrade (hr_0)
is the radiative coefficient for a black-body surface at 10 centigrade, measured in Watts per square meters Kelvin degrees.

Radiative coefficient (hr)
is the radiative coefficient, measured in Watts per square meters Kelvin degrees.

III.1.2 Heat transmission coefficient of the window (U_w)

The overall heat transmission coefficient of the window can be calculated from the next equation:

$$U_w = \frac{A_f U_f + A_g U_g + A_p U_p + l_g \Psi_g + l_p \Psi_p}{A_f + A_g + A_p} [\frac{W}{m^2 K}]$$

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for heat transmission coefficient of the glazing (U_g) [12], for heat transfer coefficient of the frame (U_f) [12], for heat transmission coefficient of the panel (U_p) [12] and for linear heat transfer coefficient of the glazing (Ψ_g) as the next tables show.

Type of glazing	**U_g [W/(m²K)]**
Single glass pane	5.70
Twin glass pane with air gap 6mm	3.30
Twin glass pane with air gap 12mm	2.80
Twin glass pane with air gap 6mm and with a low-emission membrane coating (ε=0.10)	2.60
Twin glass pane with air gap 12mm and with a low-emission membrane coating (ε=0.10)	1.80
Glass bricks	3.50

Table 2: Heat transmission coefficient of the glazing (U_g) [12]

Type of frame	**U_f [W/(m²K)]**
Metal frame without thermal switch	7
Metal frame with thermal switch	2.5
Composite frame with polyurethane	2.8
Composite frame with PVC with two chambers	2.2
Composite frame with PVC with three chambers	2
Composite frame with PVC with many chambers	1.5
Wooden frame of hardwood with average frame thickness of 5cm	2.4
Wooden frame of softwood with average frame thickness of 5cm	2
Wooden frame of hardwood with average frame thickness of 10cm	1.7
Wooden frame of softwood with average frame thickness of 10cm	1.5

Table 3: Heat transmission coefficient of the frame (U_f) [12]

Type of panel	**U_p [W/(m²K)]**
Aluminum/aluminum	3.30
Aluminum/glass	3.30
Iron/glass	3.30

Table 4: Heat transmission coefficient of the panel (U_p) [12]

Type of glazing	Ψ_g [W/(m^{2}K)]
Double or triple glazing. No low-emission coating	
Metal frame without thermal switch	0.02
Metal frame with thermal switch	0.08
Composite frame	0.06
Wooden frame	0.06
Double glazing with low-emission single sheet coating	
Metal frame without thermal switch	0.05
Metal frame with thermal switch	0.11
Composite frame	0.08
Wooden frame	0.08

Table 5: Linear heat transfer coefficient of the glazing (Ψ_g) [12]

Type of panel	Ψ_p [W/(m^{2}K)]
Aluminum/aluminum	0,245
Aluminum/glass	0,190
Iron/glass	0,160

Table 6: Linear heat transfer coefficient of the panel (Ψ_p) [12]

III.1.3 Heat transmission coefficient of the wall (U_c)

The overall heat transmission coefficient of the wall can be calculated from the next equation:

$$U_c = \frac{1}{R_i + \sum \frac{d_i}{\lambda_i} + R_\delta + R_a} [\frac{W}{m^2 K}]$$

T.O.T.E.E. (Technical Instruction of Technical Department of Greece), if the part of the wall is in the ground, then the overall heat transmission coefficient is changed according to the depth in the ground (z) [12], as the next table shows:

z(m)	U_c'[W/m^{2}K]											
	4,5	**3**	**2**	**1,5**	**1**	**0,9**	**0,8**	**0,7**	**0,6**	**0,5**	**0,4**	**0,3**
0.5	2.14	1.7	1.3	1.06	0.77	0.71	0.64	0.57	0.5	0.43	0.35	0.27
1	1.59	1.31	1.05	0.88	0.67	0.62	0.57	0.51	0.45	0.39	0.32	0.25
1.5	1.3	1.09	0.89	0.76	0.59	0.55	0.51	0.47	0.42	0.36	0.3	0.24
2	1.1	0.94	0.78	0.68	0.54	0.5	0.47	0.43	0.39	0.34	0.29	0.23
2.5	0.97	0.83	0.7	0.61	0.49	0.46	0.43	0.4	0.36	0.32	0.27	0.22
3	0.87	0.75	0.64	0.56	0.46	0.43	0.4	0.37	0.34	0.3	0.26	0.21
4.5	0.67	0.59	0.51	0.45	0.38	0.36	0.34	0.31	0.29	0.26	0.23	0.19
6	0.56	0.49	0.43	0.39	0.33	0.31	0.29	0.27	0.25	0.23	0.2	0.17
9	0.42	0.38	0.33	0.3	0.26	0.25	0.24	0.22	0.21	0.19	0.17	0.15

Table 7: Equivalent heat transmission coefficient U_c'[W/m^{2}K] of a vertical structural element of heat transmission coefficient U_c [W/m^{2}K] which extends to depth z[m] [13]

III.1.4 Heat transmission coefficient of the floor (U_f)

The overall heat transmission coefficient of the floor can be calculated from the next equation:

$$U_f = \frac{1}{R_i + \sum \frac{d_i}{\lambda_i} + R_\delta + R_a} [\frac{W}{m^2K}]$$

According to T.O.T.E.E. (Technical Instruction of Technical Department of Greece), the external surface heat resistance (Ra) is equal to 0.17 if beneath floor is an empty space and is equal to 0 if beneath the floor is ground [13].

As a characteristic dimension of the plate, B ' is defined as twice the ratio of the area of the plate, A to its exposed perimeter, Π [13]:

$$B' = 2\frac{A}{\Pi} [m]$$

In the case of a building that is on inclined ground or on terrain with different levels, the depth of the plate will be taken equal to the average of the different plate distances from the final ground level in contact with the building.

For example as shown to the next figure:

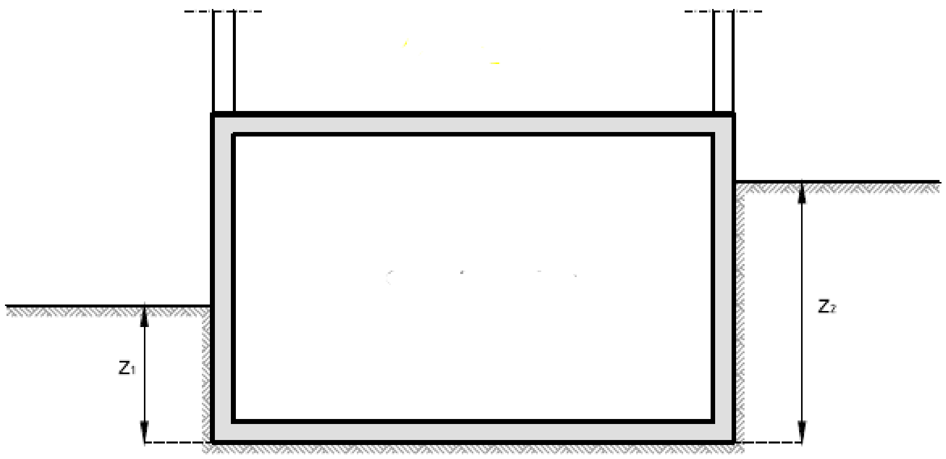

Figure 13: Indicative section of the building to determine the base of the foundation plate on the ground with different bearing levels due to the inclined ground

So the equal depth is: $z = \frac{z_1 + z_2}{2} [m]$

The overall heat transmission coefficient is changed according to the depth in the ground (z) and the characteristic dimension of the plate (B'). T.O.T.E.E. has given an equivalent het transmission coefficient (U_f') [12] as the next table shows:

U_f' [W/m^{2}K]	z(m)	Characteristic dimension of the plate (B')														
		≤2	3	4	5	6	7	8	9	10	12	14	18	22	26	≥30
4.50	0	1.21	0.98	0.83	0.73	0.64	0.58	0.53	0.49	0.45	0.4	0.36	0.3	0.25	0.22	0.2
	0.5	1.05	0.87	0.75	0.66	0.59	0.53	0.49	0.45	0.42	0.37	0.33	0.28	0.24	0.21	0.18
	1	0.92	0.78	0.68	0.6	0.54	0.49	0.45	0.42	0.39	0.35	0.31	0.6	0.23	0.2	0.18
	1.5	0.82	0.71	0.62	0.55	0.5	0.46	0.42	0.39	0.37	0.33	0.3	0.2	0.22	0.19	0.17
	2	0.74	0.65	0.57	0.52	0.47	0.43	0.4	0.37	0.35	0.31	0.28	0.24	0.21	0.18	0.17
	2.5	0.67	0.6	0.53	0.48	0.44	0.41	0.38	0.35	0.33	0.3	0.27	0.23	0.2	0.18	0.16
	3	0.62	0.55	0.5	0.45	0.42	0.39	0.36	0.34	0.32	0.28	0.26	0.22	0.19	0.17	0.1
	4	0.53	0.48	0.44	0.41	0.38	0.35	0.33	0.31	0.29	0.26	0.24	0.21	0.18	0.16	0.15
	5	0.47	0.43	0.39	0.37	0.34	0.32	0.3	0.29	0.27	0.25	0.22	0.19	0.17	0.15	0.14
	6	0.42	0.38	0.36	0.33	0.31	0.3	0.28	0.27	0.25	0.23	0.21	0.18	0.16	0.15	0.13
	9	0.32	0.3	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.19	0.18	0.16	0.14	0.13	0.12
4	0	1.17	0.96	0.81	0.71	0.63	0.57	0.52	0.48	0.45	0.39	0.35	0.29	0.25	0.22	0.2
	0.5	1.01	0.85	0.73	0.64	0.58	0.2	0.48	0.44	0.41	0.36	0.33	0.27	0.24	0.21	0.19
	1	0.89	0.76	0.66	0.59	0.53	0.48	0.45	0.41	0.39	0.34	0.31	0.26	0.22	0.2	0.18
	1.5	0.8	0.69	0.61	0.55	0.49	0.45	0.42	0.39	0.36	0.32	0.29	0.25	0.21	0.19	0.17
	2	0.72	0.63	0.56	0.51	0.46	0.43	0.39	0.37	0.35	0.31	0.28	0.24	0.2	0.18	0.16
	2.5	0.66	0.59	0.53	0.48	0.44	0.4	0.37	0.35	0.33	0.29	0.27	0.23	0.2	0.18	0.16
	3	0.61	0.54	0.49	0.45	0.41	0.38	0.36	0.33	0.31	0.28	0.26	0.22	0.19	0.17	0.15
	4	0.53	0.47	0.43	0.4	0.37	0.35	0.32	0.3	0.29	0.26	0.24	0.2	0.18	0.16	0.14
	5	0.47	0.42	0.39	0.36	0.34	0.32	0.3	0.28	0.27	0.24	0.22	0.19	0.17	0.15	0.14
	6	0.42	0.38	0.35	0.33	0.31	0.29	0.28	0.26	0.25	0.23	0.21	0.18	0.16	0.14	0.13
	9	0.32	0.3	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.19	0.18	0.16	0.14	0.13	0.12
3.5	0	1.12	0.92	0.79	0.69	0.61	0.55	0.51	0.47	0.44	0.38	0.34	0.29	0.25	0.22	0.19
	0.5	0.98	0.82	0.71	0.63	0.56	0.51	0.47	0.43	0.4	0.36	0.32	0.27	0.23	0.2	0.18
	1	0.87	0.74	0.65	0.58	0.52	0.47	0.44	0.41	0.38	0.34	0.3	0.25	0.22	0.19	0.18
	1.5	0.77	0.68	0.6	0.53	0.48	0.44	0.41	0.38	0.36	0.32	0.29	0.24	0.21	0.19	0.17
	2	0.7	0.62	0.55	0.5	0.46	0.42	0.39	0.36	0.34	0.3	0.28	0.23	0.2	0.18	0.16
	2.5	0.64	0.57	0.52	0.47	0.43	0.4	0.37	0.34	0.32	0.29	0.26	0.22	0.2	0.17	0.16
	3	0.59	0.53	0.48	0.44	0.41	0.38	0.35	0.33	0.31	0.28	0.25	0.22	0.19	0.17	0.15
	4	0.52	0.46	0.43	0.4	0.37	0.34	0.32	0.3	0.29	0.26	0.24	0.2	0.18	0.16	0.14
	5	0.46	0.41	0.38	0.36	0.33	0.31	0.3	0.28	0.27	0.24	0.22	0.19	0.17	0.15	0.14
	6	0.41	0.38	0.35	0.33	0.31	0.29	0.27	0.26	0.25	0.23	0.21	0.18	0.16	0.14	0.13
	9	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.22	0.21	0.19	0.18	0.16	0.14	0.13	0.12
3	0	1.06	0.88	0.75	0.66	0.59	0.54	0.49	0.45	0.42	0.37	0.33	0.28	0.24	0.21	0.19
	0.5	0.93	0.79	0.68	0.61	0.54	0.5	0.46	0.42	0.39	0.35	0.31	0.26	0.23	0.2	0.18
	1	0.83	0.71	0.63	0.56	0.51	0.46	0.43	0.4	0.37	0.33	0.3	0.25	0.22	0.19	0.17
	1.5	0.74	0.65	0.58	0.52	0.47	0.43	0.4	0.37	0.35	0.31	0.28	0.24	0.21	0.18	0.17
	2	0.68	0.6	0.54	0.49	0.44	0.41	0.38	0.36	0.33	0.3	0.27	0.23	0.2	0.18	0.16
	2.5	0.62	0.56	0.5	0.46	0.42	0.39	0.36	0.34	0.32	0.29	0.26	0.22	0.19	0.17	0.15
	3	0.58	0.52	0.47	0.43	0.4	0.37	0.34	0.32	0.31	0.27	0.25	0.21	0.19	0.17	0.15
	4	0.5	0.45	0.42	0.39	0.36	0.34	0.32	0.3	0.28	0.25	0.23	0.2	0.18	0.16	0.14
	5	0.45	0.41	0.38	0.35	0.33	0.31	0.29	0.28	0.26	0.24	0.22	0.19	0.17	0.15	0.14
	6	0.4	0.37	0.34	0.32	0.3	0.29	0.27	0.26	0.24	0.22	0.21	0.18	0.16	0.14	0.13
	9	0.31	0.29	0.27	0.26	0.24	0.23	0.22	0.21	0.21	0.19	0.18	0.16	0.14	0.13	0.12
2.5	0	0.99	0.83	0.71	0.63	0.57	0.51	0.47	0.44	0.41	0.36	0.32	0.27	0.23	0.21	0.18
	0.5	0.87	0.75	0.65	0.58	0.52	0.48	0.44	0.41	0.38	0.34	0.3	0.26	0.22	0.2	0.18

	1	0.78	0.68	0.6	0.54	0.49	0.45	0.41	0.38	0.36	0.32	0.29	0.24	0.21	0.19	0.17
	1.5	0.71	0.62	0.56	0.5	0.46	0.42	0.39	0.36	0.34	0.31	0.28	0.23	0.2	0.18	0.16
	2	0.65	0.58	0.52	0.47	0.43	0.4	0.37	0.35	0.33	0.29	0.26	0.22	0.2	0.17	0.16
	2.5	0.6	0.53	0.49	0.44	0.41	0.38	0.35	0.33	0.31	0.28	0.25	0.22	0.19	0.17	0.15
	3	0.56	0.5	0.46	0.42	0.39	0.36	0.34	0.32	0.3	0.27	0.24	0.21	0.18	0.16	0.15
	4	0.49	0.44	0.41	0.38	0.35	0.33	0.31	0.29	0.28	0.25	0.23	0.2	0.17	0.15	0.14
	5	0.44	0.4	0.37	0.34	0.32	0.3	0.29	0.27	0.26	0.23	0.21	0.19	0.16	0.15	0.13
	6	0.39	0.36	0.33	0.31	0.3	0.28	0.27	0.25	0.24	0.22	0.2	0.18	0.16	0.14	0.13
	9	0.3	0.28	0.27	0.25	0.24	0.23	0.22	0.21	0.2	0.19	0.17	0.15	0.14	0.13	0.11
2	**0**	0.89	0.76	0.66	0.59	0.53	0.48	0.45	0.41	0.39	0.34	0.31	0.26	0.22	0.2	0.18
	0.5	0.8	0.69	0.61	0.55	0.49	0.45	0.42	0.39	0.36	0.32	0.29	0.25	0.21	0.19	0.17
	1	0.72	0.63	0.56	0.51	0.46	0.43	0.39	0.37	0.35	0.31	0.28	0.24	0.2	0.18	0.16
	1.5	0.66	0.59	0.53	0.48	0.44	0.4	0.37	0.35	0.33	0.29	0.27	0.23	0.2	0.18	0.16
	2	0.61	0.54	0.49	0.45	0.41	0.38	0.36	0.33	0.31	0.28	0.26	0.22	0.19	0.17	0.15
	2.5	0.56	0.51	0.46	0.42	0.39	0.36	0.34	0.32	0.3	0.27	0.25	0.21	0.18	0.16	0.15
	3	0.53	0.47	0.43	0.4	0.37	0.35	0.32	0.31	0.29	0.26	0.24	0.2	0.18	0.16	0.14
	4	0.47	0.42	0.39	0.36	0.34	0.32	0.3	0.28	0.27	0.24	0.22	0.19	0.17	0.15	0.14
	5	0.42	0.38	0.35	0.33	0.31	0.29	0.28	0.26	0.25	0.23	0.21	0.18	0.16	0.14	0.13
	6	0.38	0.35	0.32	0.3	0.29	0.27	0.26	0.25	0.23	0.22	0.2	0.17	0.15	0.14	0.13
	9	0.29	0.28	0.26	0.24	0.23	0.22	0.21	0.21	0.2	0.18	0.17	0.15	0.14	0.12	0.11
1.5	**0**	0.77	0.67	0.59	0.53	0.48	0.44	0.41	0.38	0.36	0.32	0.29	0.24	0.21	0.19	0.17
	0.5	0.7	0.62	0.55	0.5	0.45	0.42	0.39	0.36	0.34	0.3	0.27	0.23	0.2	0.18	0.16
	1	0.64	0.57	0.51	0.47	0.43	0.4	0.37	0.34	0.32	0.29	0.26	0.22	0.19	0.17	0.16
	1.5	0.59	0.53	0.48	0.44	0.4	0.38	0.35	0.33	0.31	0.28	0.25	0.22	0.19	0.17	0.15
	2	0.55	0.49	0.45	0.42	0.38	0.36	0.33	0.31	0.3	0.27	0.24	0.21	0.18	0.16	0.15
	2.5	0.52	0.46	0.43	0.39	0.37	0.34	0.32	0.3	0.29	0.26	0.24	0.2	0.18	0.16	0.14
	3	0.48	0.44	0.4	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.23	0.2	0.17	0.15	0.14
	4	0.43	0.39	0.36	0.34	0.32	0.3	0.28	0.27	0.26	0.23	0.21	0.18	0.16	0.15	0.13
	5	0.39	0.36	0.33	0.31	0.29	0.28	0.26	0.25	0.24	0.22	0.2	0.18	0.16	0.14	0.13
	6	0.36	0.33	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.21	0.19	0.17	0.15	0.13	0.12
	9	0.28	0.26	0.25	0.24	0.22	0.21	0.21	0.2	0.19	0.18	0.17	0.15	0.13	0.12	0.11
1	**0**	0.61	0.54	0.49	0.45	0.41	0.38	0.36	0.33	0.31	0.28	0.26	0.22	0.19	0.17	0.15
	0.5	0.56	0.51	0.46	0.42	0.39	0.36	0.34	0.32	0.3	0.27	0.25	0.21	0.18	0.16	0.15
	1	0.53	0.47	0.43	0.4	0.37	0.35	0.32	0.31	0.29	0.26	0.24	0.2	0.18	0.16	0.14
	1.5	0.49	0.44	0.41	0.38	0.35	0.33	0.31	0.29	0.28	0.25	0.23	0.2	0.17	0.16	0.14
	2	0.47	0.42	0.39	0.36	0.34	0.32	0.3	0.28	0.27	0.24	0.22	0.19	0.17	0.15	0.14
	2.5	0.44	0.4	0.37	0.35	0.32	0.31	0.29	0.27	0.26	0.24	0.22	0.19	0.16	0.15	0.13
	3	0.42	0.38	0.35	0.33	0.31	0.29	0.28	0.26	0.25	0.23	0.21	0.18	0.16	0.14	0.13
	4	0.38	0.35	0.32	0.3	0.29	0.27	0.26	0.25	0.23	0.22	0.2	0.17	0.15	0.14	0.13
	5	0.35	0.32	0.3	0.28	0.27	0.25	0.24	0.23	0.22	0.2	0.19	0.16	0.15	0.13	0.12
	6	0.32	0.3	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.19	0.18	0.16	0.14	0.13	0.12
	9	0.26	0.24	0.23	0.22	0.21	0.2	0.19	0.19	0.18	0.17	0.16	0.14	0.13	0.12	0.11
0.9	**0**	0.57	0.51	0.46	0.43	0.39	0.37	0.34	0.32	0.3	0.25	0.21	0.21	0.18	0.17	0.15
	0.5	0.53	0.48	0.44	0.4	0.37	0.35	0.33	0.31	0.29	0.24	0.2	0.2	0.18	0.16	0.15
	1	0.5	0.45	0.41	0.38	0.36	0.33	0.31	0.29	0.28	0.23	0.2	0.2	0.17	0.16	0.14
	1.5	0.47	0.42	0.39	0.36	0.34	0.32	0.3	0.28	0.27	0.22	0.19	0.19	0.17	0.15	0.14
	2	0.44	0.4	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.22	0.19	0.19	0.17	0.15	0.13

	2.5	0.42	0.38	0.35	0.33	0.31	0.29	0.28	0.26	0.25	0.21	0.18	0.18	0.16	0.14	0.13
	3	0.4	0.37	0.34	0.32	0.3	0.28	0.27	0.26	0.24	0.2	0.18	0.18	0.16	0.14	0.13
	4	0.36	0.33	0.31	0.29	0.28	0.26	0.25	0.24	0.23	0.19	0.17	0.17	0.15	0.14	0.12
	5	0.33	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.22	0.18	0.16	0.16	0.14	0.13	0.12
	6	0.31	0.29	0.27	0.25	0.24	0.23	0.22	0.21	0.2	0.18	0.15	0.15	0.14	0.13	0.12
	9	0.25	0.24	0.22	0.21	0.2	0.19	0.19	0.18	0.18	0.15	0.14	0.14	0.12	0.11	0.1
	0	0.53	0.47	0.43	0.4	0.37	0.35	0.32	0.31	0.29	0.24	0.2	0.2	0.18	0.16	0.14
	0.5	0.49	0.44	0.41	0.38	0.35	0.33	0.31	0.29	0.28	0.23	0.2	0.2	0.17	0.16	0.14
	1	0.47	0.42	0.39	0.36	0.34	0.32	0.3	0.28	0.27	0.22	0.19	0.19	0.17	0.15	0.14
	1.5	0.44	0.4	0.37	0.35	0.32	0.31	0.29	0.27	0.26	0.22	0.19	0.19	0.16	0.15	0.13
	2	0.42	0.38	0.35	0.33	0.31	0.29	0.28	0.26	0.25	0.21	0.18	0.18	0.16	0.14	0.13
0.8	**2.5**	0.4	0.36	0.34	0.32	0.3	0.28	0.27	0.25	0.24	0.2	0.18	0.18	0.16	0.14	0.13
	3	0.38	0.35	0.32	0.3	0.29	0.27	0.26	0.25	0.23	0.2	0.17	0.17	0.15	0.14	0.13
	4	0.35	0.32	0.3	0.28	0.27	0.25	0.24	0.23	0.22	0.19	0.16	0.16	0.15	0.13	0.12
	5	0.32	0.3	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.18	0.16	0.16	0.14	0.13	0.12
	6	0.29	0.28	0.26	0.24	0.23	0.22	0.21	0.21	0.2	0.17	0.15	0.15	0.14	0.12	0.11
	9	0.24	0.23	0.22	0.21	0.2	0.19	0.18	0.18	0.17	0.15	0.14	0.14	0.12	0.11	0.1
	0	0.48	0.43	0.4	0.37	0.35	0.33	0.31	0.29	0.27	0.23	0.2	0.2	0.17	0.15	0.14
	0.5	0.45	0.41	0.38	0.36	0.33	0.31	0.29	0.28	0.26	0.22	0.19	0.19	0.17	0.15	0.14
	1	0.43	0.39	0.36	0.34	0.32	0.3	0.28	0.27	0.26	0.21	0.18	0.18	0.16	0.15	0.13
	1.5	0.41	0.37	0.34	0.32	0.31	0.29	0.27	0.26	0.25	0.21	0.18	0.18	0.16	0.14	0.13
	2	0.39	0.36	0.33	0.31	0.29	0.28	0.26	0.25	0.24	0.2	0.18	0.18	0.16	0.14	0.13
0.7	**2.5**	0.37	0.34	0.32	0.3	0.28	0.27	0.25	0.24	0.23	0.2	0.17	0.17	0.15	0.14	0.13
	3	0.35	0.33	0.3	0.29	0.27	0.26	0.25	0.24	0.22	0.19	0.17	0.17	0.15	0.13	0.12
	4	0.33	0.3	0.28	0.27	0.25	0.24	0.23	0.22	0.21	0.18	0.16	0.16	0.14	0.13	0.12
	5	0.3	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.2	0.17	0.15	0.15	0.14	0.12	0.11
	6	0.28	0.26	0.25	0.23	0.22	0.21	0.21	0.2	0.19	0.17	0.15	0.15	0.13	0.12	0.11
	9	0.23	0.22	0.21	0.2	0.19	0.18	0.18	0.17	0.17	0.15	0.13	0.13	0.12	0.11	0.1
	0	0.43	0.39	0.36	0.34	0.32	0.3	0.28	0.27	0.26	0.21	0.18	0.18	0.16	0.15	0.13
	0.5	0.41	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.25	0.21	0.18	0.18	0.16	0.14	0.13
	1	0.39	0.36	0.33	0.31	0.29	0.28	0.26	0.25	0.24	0.2	0.18	0.18	0.16	0.14	0.13
	1.5	0.37	0.34	0.32	0.3	0.28	0.27	0.26	0.24	0.23	0.2	0.17	0.17	0.15	0.14	0.13
	2	0.36	0.33	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.19	0.17	0.17	0.15	0.13	0.12
0.6	**2.5**	0.34	0.32	0.29	0.28	0.26	0.25	0.24	0.23	0.22	0.19	0.16	0.16	0.15	0.13	0.12
	3	0.33	0.3	0.28	0.27	0.25	0.24	0.23	0.22	0.21	0.18	0.16	0.16	0.14	0.13	0.12
	4	0.3	0.28	0.27	0.25	0.24	0.23	0.22	0.21	0.2	0.17	0.15	0.15	0.14	0.12	0.11
	5	0.28	0.26	0.25	0.24	0.22	0.21	0.21	0.2	0.19	0.17	0.15	0.15	0.13	0.12	0.11
	6	0.26	0.25	0.23	0.22	0.21	0.2	0.2	0.19	0.18	0.16	0.14	0.14	0.13	0.12	0.11
	9	0.22	0.21	0.2	0.19	0.18	0.18	0.17	0.16	0.16	0.14	0.13	0.13	0.12	0.11	0.1
	0	0.38	0.35	0.32	0.3	0.29	0.27	0.26	0.25	0.23	0.2	0.17	0.17	0.15	0.14	0.13
	0.5	0.36	0.33	0.31	0.29	0.28	0.26	0.25	0.24	0.23	0.19	0.17	0.17	0.15	0.14	0.12
	1	0.35	0.32	0.3	0.28	0.27	0.25	0.24	0.23	0.22	0.19	0.16	0.16	0.15	0.13	0.12
0.5	**1.5**	0.33	0.31	0.29	0.27	0.26	0.25	0.23	0.22	0.21	0.18	0.16	0.16	0.14	0.13	0.12
	2	0.32	0.3	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.18	0.16	0.16	0.14	0.13	0.12
	2.5	0.31	0.29	0.27	0.25	0.24	0.23	0.22	0.21	0.2	0.18	0.15	0.15	0.14	0.13	0.12
	3	0.29	0.28	0.26	0.24	0.23	0.22	0.21	0.21	0.2	0.17	0.15	0.15	0.14	0.12	0.11
	4	0.27	0.26	0.24	0.23	0.22	0.21	0.2	0.2	0.19	0.16	0.15	0.15	0.13	0.12	0.11

	5	0.26	0.24	0.23	0.22	0.21	0.2	0.19	0.19	0.18	0.16	0.14	0.14	0.13	0.12	0.11
	6	0.24	0.23	0.22	0.21	0.2	0.19	0.18	0.18	0.17	0.15	0.14	0.14	0.12	0.11	0.1
	9	0.2	0.2	0.19	0.18	0.17	0.17	0.16	0.15	0.15	0.13	0.12	0.12	0.11	0.1	0.1
0.4	**0**	0.32	0.3	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.19	0.18	0.16	0.14	0.13	0.12
	0.5	0.31	0.29	0.27	0.25	0.24	0.23	0.22	0.21	0.2	0.19	0.18	0.15	0.14	0.13	0.12
	1	0.29	0.28	0.26	0.24	0.23	0.22	0.21	0.21	0.2	0.18	0.17	0.15	0.14	0.12	0.11
	1.5	0.28	0.27	0.25	0.24	0.23	0.22	0.21	0.2	0.19	0.18	0.17	0.15	0.13	0.12	0.11
	2	0.27	0.26	0.24	0.23	0.22	0.21	0.2	0.2	0.19	0.18	0.16	0.15	0.13	0.12	0.11
	2.5	0.27	0.25	0.24	0.22	0.21	0.2	0.2	0.19	0.18	0.17	0.16	0.14	0.13	0.12	0.11
	3	0.26	0.24	0.23	0.22	0.21	0.2	0.19	0.19	0.18	0.17	0.16	0.14	0.13	0.12	0.11
	4	0.24	0.23	0.22	0.21	0.2	0.19	0.18	0.18	0.17	0.16	0.15	0.14	0.12	0.11	0.1
	5	0.23	0.22	0.21	0.2	0.19	0.18	0.17	0.17	0.16	0.15	0.15	0.13	0.12	0.11	0.1
	6	0.22	0.21	0.2	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.14	0.13	0.11	0.11	0.1
	9	0.19	0.18	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.13	0.11	0.11	0.1	0.09
0.3	**0**	0.25	0.24	0.23	0.21	0.2	0.2	0.19	0.18	0.18	0.17	0.16	0.14	0.13	0.11	0.11
	0.5	0.24	0.23	0.22	0.21	0.2	0.19	0.18	0.18	0.17	0.16	0.15	0.14	0.12	0.11	0.1
	1	0.24	0.22	0.21	0.2	0.19	0.19	0.18	0.17	0.17	0.16	0.15	0.13	0.12	0.11	0.1
	1.5	0.23	0.22	0.21	0.2	0.19	0.18	0.18	0.17	0.16	0.16	0.15	0.13	0.12	0.11	0.1
	2	0.22	0.21	0.2	0.19	0.19	0.18	0.17	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.1
	2.5	0.22	0.21	0.2	0.19	0.18	0.17	0.17	0.16	0.16	0.15	0.14	0.13	0.12	0.11	0.1
	3	0.21	0.2	0.19	0.18	0.18	0.17	0.16	0.16	0.15	0.15	0.14	0.12	0.11	0.1	0.1
	4	0.2	0.19	0.18	0.18	0.17	0.16	0.16	0.15	0.15	0.14	0.13	0.12	0.11	0.1	0.09
	5	0.19	0.18	0.18	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.12	0.11	0.1	0.09
	6	0.18	0.18	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.13	0.12	0.11	0.1	0.1	0.09
	9	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.11	0.1	0.1	0.09	0.08

Table 8: Eqivalent heat transmission coefficient U_f' [W/m^{2}K] of a horizontal plate in contact with ground [13]

III.1.5 Solar heat gain elements [23]

III.1.5.1 General

This subclause establishes the heat flow by solar gains, based on the effective collecting areas of the relevant building elements and corrections for solar shading by external obstacles. It also provides a correction for the thermal radiation to the sky.

The collecting areas to be taken into consideration are the glazing (including any integrated or add-on solar shading provision), the external opaque elements, the internal walls and floors of sunspaces, and walls behind a transparent covering or transparent insulation. The characteristics depend on climate, time and location dependent factors such as the sun's position and the ratio between direct and diffuse solar radiation. Consequently, the characteristics in general vary over time, both hourly and over the year. As a result, adequate mean or conservative values shall be selected that are appropriate for the purpose of the calculation (heating, cooling and/or summer comfort).

III.1.5.2 Heat flow by solar gains per building element

The heat flow by solar gains through building element *k*, $\Phi_{sol,k}$, expressed in watts, is given by the next equation:

$$\Phi_{sol,k} = E_{t,k} A_{sol,k} - F_{r,k} \Phi_{r,k} \ [W]$$

- $A_{sol,k}$[m^2]: is the effective collecting area of surface *k* with a given orientation and tilt angle, in the considered zone or space..

NOTE 1 The solar effective collecting area, A_{sol}, is equal to the area of a black body having the same solar heat gain as the surface considered.

NOTE 2 The extra heat flow due to thermal radiation to the sky is actually not a solar heat gain but included with the solar gains for convenience.

III.1.5.3 Effective solar collecting area of glazed elements

The effective solar collecting area of a glazed envelope element (e.g. a window), A_{sol}, expressed in square meters, is given by the next equation:

$$A_{sol,window} = F_{sh} g_{gl} (1 - F_f) A_g \ [m^2]$$

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for solar transmittance (g_{gl}) [12] as the next table shows.

Glass pane description	g_{gl}
Single glass pane	0.77
Double glass pane	0.68
Double glass pane, selective, low-emission coating	0.6
Double window	0.68
Glass blocks	0.27
Colorful or reflective	0.45
Opaque	0

Table 9: Solar transmittance (g_{gl}) [12]

III.1.5.4 Effective collecting area of opaque building elements

The net solar heat gains of opaque elements without transparent insulation during the heating season can be only a small portion of the total solar heat gains and are partially compensated by radiation losses from the building to clear skies. However, for dark, poorly insulated surfaces, or large areas facing the sky, the solar heat gains through opaque elements can become important.

For summer cooling or summer thermal comfort calculations, the solar heat gains through opaque building elements should not be underestimated. On the other hand, if thermal radiation losses are expected to be important, the transmission heat loss can be augmented at the same time, which is represented by a correction factor to the effect of the solar heat gains.

The effective solar collecting area of an opaque part of the building envelope (A_{sol}) expressed in square meters, is given by the next equation:

$$A_{sol,wall} = \alpha_{S,c} R_a U_c A_c \, [m^2]$$

T.O.T.E.E. has given standard values for the external thermal surface resistance (Ra) [12] and for the absorption coefficient of the opaque ($\alpha_{S,c}$) [12] as the next table shows:

	Surface description	**Absorption ($\alpha_{S,c}$)**
Vertical building blocks	Coating white, smooth surface (spatula)	0.3
	Coating light (e.g. pale gray, beige, yellow, pink or light blue)	0.4
	Medium shade coating (e.g. gray, beige, dark ocher, salmon)	0.6
	dark coating (e.g. dark olive, brown, gray)	0.8
	Obvious brickwork or masonry	0.8
	Obviously light brickwork or masonry	0.6
	Glossy metal surfaces (e.g. aluminum sheets)	0.2
	Opaque glass façade (e.g. glass-coated panels)	0.6
	Blooming (with evergreen plants)	0.7
Horizontal building elements (roofs)	Red tile	0.6
	Very dark coating roofs or rooms (asphalt)	0.9
	Dark coating of roofs or rooms (e.g. roofing with shingles, bituminous tiles)	0.8
	Light-colored coating roofs or rooms (e.g. paving slabs)	0.65

Table 10: absorption coefficient of the opaque ($\alpha_{S,c}$) [12]

Structural element	**Ra [m^2K/W]**
External walls and windows (to external air)	0.04
A wall bordered by a non-heated space	0.13
Wall in contact with ground	0
Roof, chamber (rising heat flow)	0.04
Roof bordered by unheated space (rising heat flow)	0.1
Floor over open passage (descending heat flow)	0.04
Floor over non-heated space (descending heat flow)	0.17
Floor in contact with the ground	0

Table 11: for the external thermal surface resistance (Ra) [12]

III.1.5.5 Thermal radiation to the sky

The extra heat flow due to thermal radiation to the sky for a specific building envelope element, Φ_r, expressed in watts, is given by the next equation:

$$\Phi_r = R_a U_c A_c h_r \Delta\theta_{er} \, [W]$$

where,

$h_r = 5\varepsilon [W/(m^2 K^4)]$ which corresponds to an average temperature of 10°C [23].

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for emissivity for thermal radiation of the external surface (ε) [12] as the next table shows.

Surface description	ε
Conventional building material	0.8
Glass	0.9
Smooth metal surfaces	0.2
Gravel	0.3
A planted or planted face with evergreen plants	0.8

Table 12: emissivity for thermal radiation of the external surface (ε) [12]

III.1.5.6 Heat flow by solar gains by window and wall (Φ_{sol})

So, the heat flow solar gains by window and opaque are:

$$\Phi_{r,window} = R_a U_w A_g h_r \Delta\theta_{er} \, [W]$$

$$\Phi_{r,wall} = R_a U_c A_{wall} h_r \Delta\theta_{er} \, [W]$$

$$\Phi_{sol,window} = E_t A_{sol,window} - F_r \Phi_{r,window} \, [W]$$

$$\Phi_{sol,wall} = E_t A_{sol,opaque} - F_r \Phi_{r,wall} \, [W]$$

III.1.6 Heat transfer by window and wall (H_{tr})

The heat transfer by window and opaque can be given by the next equations:

$$H_{tr,window} = \frac{\sum A_g U_w}{\sum A_{floor}} [W/(m^2 K)]$$

$$H_{tr,wall} = \frac{\sum A_{wall} U_c}{\sum A_{floor}} [W/(m^2 K)]$$

III.1.7 Area heat capacity [24]

III.1.7.1 Data required

The elements of the construction must be known. The data required to compute the dynamic thermal characteristics are:

- The detailed drawing of the product, with dimensions
- For each material used in the product:
  - the thermal conductivity, λ [W/(mK)]
  - the specific heat capacity, c [J/(kgK)]
  - the density, ρ [kg/m^3]

These values shall be the design values of the materials used.

III.1.7.2 Heat transfer matrix of a multi-layer component

III.1.7.2.1 General

The procedure in 1.3.2 (Procedure) applies to building components consisting of plane homogeneous layers. Thermal bridges usually present in such building components do not affect significantly the dynamic thermal characteristics and can hence be neglected.

The calculation of dynamic thermal characteristics of non-plane components and of components containing very important thermal bridges shall be made by solving the equation of heat transfer under periodic boundary conditions. For this purpose, the rules for modeling the component given in EN ISO 10211 [25] shall be used together with numerical methods, such as finite difference and finite element techniques.

III.1.7.2.2 Procedure

The procedure is as follows:

- Identify the material comprising the layers of the building component and the thickness of these layers, and determine the thermal characteristics of the materials
- Specify the period of the variations at the surfaces
- Calculate the penetration depth for the material of each layer
- Determine the elements of the heat transfer matrix for each layer
- Multiply the layer heat transfer matrices, including those of the boundary layers, in the correct order, so as to obtain the transfer matrix of the component

III.1.7.2.3 Heat transfer matrix of a homogeneous layer

The periodic penetration depth for the material of the layer, δ, is calculated from its thermal properties and the period T using the follow equation.

$$\xi = \frac{d}{\delta}$$

where,

$$\delta = \sqrt{\frac{\lambda T}{\pi \rho c}}$$

The matrix elements, Z_{mn}, are calculated as follows:

$$Z_{11} = Z_{22} = \cosh(\xi)\cos(\xi) + j\sinh(\xi)\sin(\xi)$$

$$Z_{12} = -\frac{\delta}{2\lambda}\{\sinh(\xi)\cos(\xi) + \cosh(\xi)\sin(\xi) + j[\cosh(\xi)\sin(\xi) - \sinh(\xi)\cos(\xi)]\}$$

$$Z_{21} = -\frac{\lambda}{\delta}\{\sinh(\xi)\cos(\xi) + \cosh(\xi)\sin(\xi) + j[\sinh(\xi)\cos(\xi) + \cosh(\xi)\sin(\xi)]\}$$

If the layer is air, then Z_{mn}, are calculated as follows:

$$ha = \max(\frac{0.25}{d}, 1.25)[\frac{W}{m^2K}]$$

$$e_1 = 0.9$$

$$e_2 = 0.9$$

$$hr_0 = 5,1[\frac{W}{m^2K}]$$

$$hr = Ehr_0 \left[\frac{W}{m^2K}\right]$$

$$R = \frac{1}{ha + hr}$$

$$Z_{11} = Z_{22} = 1$$

$$Z_{12} = -R$$

$$Z_{21} = 0$$

III.1.7.2.4 Heat transfer matrix plane air cavities

The specific heat capacity of such layers is neglected. Hence, if R_a, is the thermal resistance of the air layer, including convection, conduction and radiation, its heat transfer matrix is:

$$Z_a = \begin{pmatrix} 1 & -R_a \\ 0 & 1 \end{pmatrix}$$

The thermal resistance of the air layer shall be calculated in accordance with ISO 6946 [26]

III.1.7.2.4.1 Heat matrix of a building

The heat transfer matrix of the building component from surface is:

$$Z = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = Z_N Z_{N-1} ... Z_3 Z_2 Z_1$$

where Z_1. Z_2, Z_3,…, Z_N, are the heat transfer matrices of the various layers of the building component, beginning from layer 1. As a convention for building envelope components, layer 1 shall be the innermost layer.

The heat transfer matrix from environment to environment through the boundary layers, given by

$$Z_{ee} = Z_{s2}\, Z\, Z_{s1}$$

Where Z_{s1} and Z_{s2} are the heat transfer matrices of the boundary layers, given by

$$Z_s = \begin{pmatrix} 1 & -R_s \\ 0 & 1 \end{pmatrix}$$

Where R_s is the surface resistance of the boundary layer, including convection and radiation. Values of surface resistance shall be in accordance with ISO 6946

In most cases, the heat transfer matrix and the dynamic characteristics of a building component shall be calculated using the surface resistance values appropriate to the intended orientation of the component. If the orientation of the component is not known, the calculations shall be done for vertical orientation (heat flow horizontal). For certain applications where boundary layers are taken into account separately, the periodic heat capacity of the component should be calculated omitting the boundary layers.

III.1.7.2.5 Surface resistance of inside (R_i) and outside (R_a)

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for the inside surface resistance (R_i) and for the outside surface resistance (R_a) [13] as shown in the next table:

Structural element	**R_i [(m²K)/W]**	**R_a [(m²K)/W]**
External walls and windows (to outside air)	0.13	0.04
Wall adjacent to an unheated area	0.13	0.13
Wall adjacent to the ground	0.13	0.00
Cover (ascending heat flow)	0.10	0.04
Roof adjacent to an unheated area (descending heat flow)	0.10	0.10
Floor above open corrosion (sponge) (descending heat flow)	0.17	0.04
Floor above an unheated area (descending heat flow)	0.17	017
Floor adjacent to the ground	0.17	0.00

Table 13: Surfaces resistance of inside (R_i) and outside(R_a) [13]

III.1.7.3 Dynamic thermal characteristics

III.1.7.3.1 Areal heat capacities (k)

The areal heat capacities are:

$$k_1 = \frac{T}{2\pi}\left|\frac{Z_{11}-1}{Z_{12}}\right| [kJ/(m^2K)] \qquad k_2 = \frac{T}{2\pi}\left|\frac{Z_{22}-1}{Z_{12}}\right| [kJ/(m^2K)]$$

Equations apply to both external elements and to internal partitions

III.1.7.3.2 Internal heat capacity of the building (C_m)

For the simple hourly method, the internal heat capacity of the building zone, C_m, expressed in Joules per Kelvin degrees, is calculated by summing the heat capacities of all the building elements in direct thermal contact with the internal air of the zone under consideration with the follow equation:

$$C_m = \sum k_j \, x \, A_j \, [J/K]$$

III.1.7.3.3 The effective area (A_m)

$$A_m = \frac{{C_m}^2}{\sum A_j \, x \, {k_j}^2} [m^2]$$

where

- A_j is the area of the element j, expressed in square meters
- k_j is the internal heat capacity per area of the building element j, expressed in Joules per square meters Kelvin degrees

III.1.8 Shading factor (F_{sh})

The shading factor methodology is the same for the wall class and for the window class.

The building blocks of a building may be shaded externally due to the presence of external obstacles and elements of the building itself, such as overalls, side elements or even parts of the structure (eg recesses). Interior curtains (curtains, blinds) of the openings and outer shutters, which are also not considered as fixed shades, are not taken into account.

The shading factors are determined depending on the type of shade (horizontal, lateral external obstacles and shades) and their geometry. Because depending on the season the shading factors change, for each exterior surface with a certain orientation, the corresponding mean shading coefficients, one for the winter season and one for the summer season, depending on the type of shade.

Shading factor (F_{sh}) can be calculated by the next equation:

$$F_{sh} = F_{hor} F_{ove} F_{fin,left} F_{fin,right}$$

Shading factor (F_{sh}) is equal to 0 when it is night. That means when solar altitude is greater than 90º and lower than 0º.

III.1.8.1 Horizontal factor (F_{hor})

This factor determines the shading that occurs on the building's surfaces by the presence of natural obstacles (e.g. hills) or artificial (e.g. high-rise buildings). When the horizon is free, the factor is equal to one (F_{hor}=1), while for full shading is equal to zero (F_{hor}=0). T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for the horizontal factor (F_{hor}) [12] as the next table shows:

		Orientation				
Angle α (°)	**Period**	**S**	**SE and SW**	**E and W**	**SE and SW**	**N**
0	heating	1	1	1	1	1
	cooling	1	1	1	1	1
5	heating	0,98	0,97	0,96	0,98	1
	cooling	1	0,98	0,97	0,96	0,96
10	heating	0,96	0,95	0,93	0,95	1
	cooling	1	0,97	0,94	0,92	0,92
15	heating	0,91	0,89	0,86	0,92	1
	cooling	1	0,94	0,9	0,88	0,9
20	heating	0,86	0,84	0,8	0,89	1
	cooling	1	0,92	0,86	0,84	0,87
25	heating	0,73	0,73	0,72	0,87	1
	cooling	1	0,9	0,83	0,82	0,87
30	heating	0,61	0,62	0,65	0,85	1
	cooling	1	0,89	0,81	0,81	0,86
35	heating	0,53	0,54	0,61	0,84	1
	cooling	0,99	0,85	0,77	0,77	0,86
40	heating	0,44	0,47	0,57	0,83	1
	cooling	0,98	0,82	0,72	0,73	0,85
45	heating	0,4	0,44	0,55	0,82	1
	cooling	0,95	0,78	0,68	0,7	0,8
50	heating	0,36	0,4	0,53	0,81	1
	cooling	0,93	0,74	0,63	0,67	0,85
55	heating	0,34	0,38	0,52	0,81	1
	cooling	0,89	0,7	0,6	0,65	0,85
60	heating	0,32	0,37	0,51	0,81	1
	cooling	0,86	0,67	0,57	0,63	0,85
65	heating	0,32	0,36	0,5	0,81	1
	cooling	0,79	0,63	0,55	0,63	0,85
≥70	heating	0,31	0,36	0,5	0,81	1
	cooling	0,73	0,58	0,52	0,82	0,85

Table 14: Horizontal factor (F_{hor}) [12]

In the case of many natural or artificial obstacles of different height, then the upper obstacle face is the average height of all obstacles that extend in length as long as the face of the building occupies, weighted by the corresponding length of each obstacle. Similarly, if the opposite obstacles are at a different distance from the examined face then the calculation of the viewing angle of the obstacles will be based on the average distance of all obstacles that extend in length as long as the examined face occupied by the respective length every obstacle.

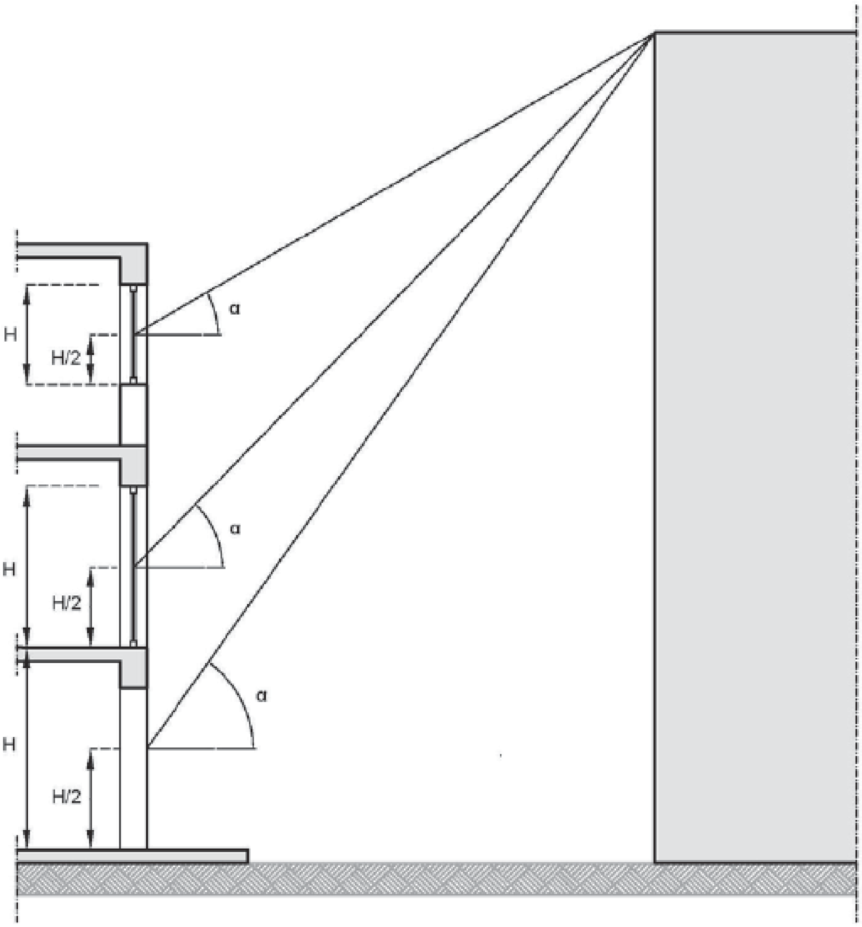

Figure 14: Horizontal angle (α) [12]

III.1.8.2 Overhang factor (F_{ove})

This factor determines the shading of the building's surface due to the presence of horizontal projections (extensions, grooves, transverse openings). In case there is no horizontal projection, the coefficient is equal to the one (F_{ov}=1), while when the shadow is full, the factor is equal to zero (F_{ov}=0). T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for the overhang factor (F_{ove}) [12] as the next table shows:

		Orientation				
Angle β (º)	**Period**	**S**	**SE and SW**	**E and W**	**SE and SW**	**N**
0	heating	1	1	1	1	1
	cooling	1	1	1	1	1
5	heating	0,97	0,97	0,97	0,97	0,96
	cooling	0,95	0,96	0,96	0,97	0,97
10	heating	0,94	0,94	0,94	0,93	0,92
	cooling	0,89	0,91	0,93	0,93	0,94
15	heating	0,91	0,91	0,91	0,9	0,89
	cooling	0,84	0,86	0,89	0,9	0,9
20	heating	0,87	0,88	0,88	0,86	0,85
	cooling	0,78	0,82	0,85	0,87	0,87
25	heating	0,84	0,84	0,85	0,83	0,81
	cooling	0,73	0,77	0,81	0,83	0,84
30	heating	0,8	0,81	0,82	0,8	0,77
	cooling	0,67	0,72	0,77	0,8	0,8
35	heating	0,76	0,77	0,78	0,76	0,74
	cooling	0,61	0,67	0,72	0,76	0,77
40	heating	0,72	0,91	0,75	0,73	0,7
	cooling	0,56	0,62	0,68	0,72	0,74
45	heating	0,68	0,69	0,7	0,69	0,66
	cooling	0,51	0,57	0,63	0,68	0,7
50	heating	0,63	0,64	0,66	0,65	0,62
	cooling	0,46	0,52	0,85	0,64	0,67
55	heating	0,57	0,58	0,62	0,61	0,59
	cooling	0,42	0,48	0,53	0,59	0,63
60	heating	0,5	0,52	0,57	0,57	0,55
	cooling	0,39	0,43	0,48	0,55	0,6
65	heating	0,42	0,45	0,5	0,53	0,51
	cooling	0,36	0,39	0,43	0,49	0,56
70	heating	0,34	0,37	0,44	0,48	0,47
	cooling	0,33	0,34	0,38	0,44	0,52
80	heating	0,17	0,21	0,29	0,38	0,4
	cooling	0,28	0,26	0,27	0,32	0,41
≥90	heating	0,1	0,12	0,17	0,27	0,33
	cooling	0,24	0,19	0,18	0,22	0,3

Table 15: Overhang factor (Fove) [12]

In the case of multiple horizontal external shades of different width, the width of the cantilever is the weighted average width of all the beams.

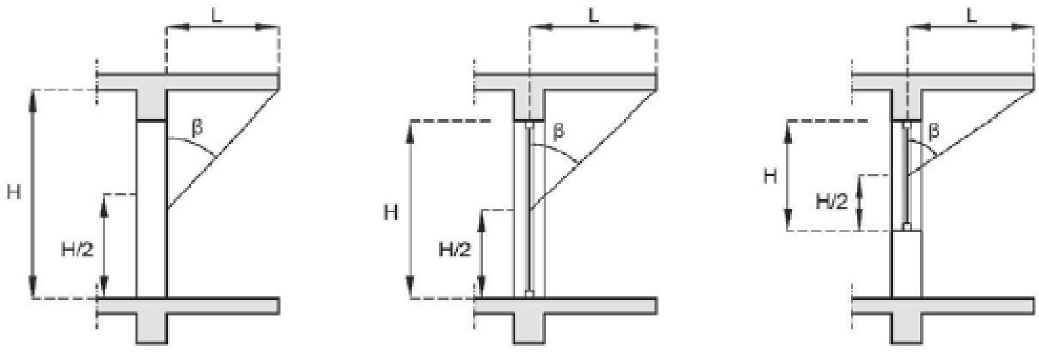

Figure 15: Fin angle (β) [12]

III.1.8.3 Fin factor (F_{fin})

The shading coefficient from lateral projections (F_{fin}) determines the shading of the building's surface due to the presence of vertical projections (lateral projections, parts of the building itself, adjacent buildings). If there is no lateral protrusion (γ=0°), the factor is equal to one (F_{fin}=1), while when the shadow is full (γ=90 °), the factor is equal to zero (F_{fin}=0). T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for the fin factor to the left side ($F_{fin,left}$) [12] and to the right side ($F_{fin,right}$) [12] as the next tables show:

		Orientation							
Angle γ_1 (°)	**Period**	**S**	**SW**	**W**	**NW**	**N**	**NE**	**E**	**SE**
0	heating	1	1	1	1	1	1	1	1
	cooling	1	1	1	1	1	1	1	1
10	heating	0,97	0,99	1	1	1	0,95	0,95	0,97
	cooling	0,97	0,97	1	1	0,97	0,96	0,99	0,99
20	heating	0,95	0,99	1	1	1	0,92	0,9	0,93
	cooling	0,95	0,94	0,99	1	0,95	0,93	0,98	0,99
30	heating	0,92	0,98	1	1	1	0,89	0,86	0,9
	cooling	0,93	0,9	0,99	1	0,93	0,89	0,96	0,98
40	heating	0,89	0,97	1	1	1	0,86	0,8	0,87
	cooling	0,91	0,86	0,98	1	0,92	0,84	0,95	0,97
50	heating	0,85	0,95	1	1	1	0,84	0,75	0,83
	cooling	0,89	0,81	0,97	1	0,92	0,79	0,93	0,96
60	heating	0,81	0,93	1	1	1	0,82	0,69	0,79
	cooling	0,88	0,76	0,96	1	0,92	0,73	0,91	0,96
≥70	heating	0,76	0,9	1	1	1	0,81	0,62	0,73
	cooling	0,86	0,71	0,94	1	0,92	0,66	0,88	0,95

Table 16: Fin factor to the left side [12]

		Orientation							
Angle γ_2 (º)	**Period**	**S**	**SW**	**W**	**NW**	**N**	**NE**	**E**	**SE**
0	heating	1	1	1	1	1	1	1	1
	cooling	1	1	1	1	1	1	1	1
10	heating	0,97	0,97	0,95	0,95	1	1	1	0,99
	cooling	0,97	0,99	0,99	0,96	0,97	1	1	0,97
20	heating	0,95	0,93	0,9	0,92	1	1	1	0,99
	cooling	0,95	0,99	0,98	0,93	0,95	1	0,99	0,94
30	heating	0,92	0,9	0,86	0,89	1	1	1	0,98
	cooling	0,93	0,98	0,96	0,89	0,93	1	0,99	0,9
40	heating	0,89	0,87	0,8	0,86	1	1	1	0,97
	cooling	0,91	0,97	0,95	0,84	0,92	1	0,98	0,86
50	heating	0,85	0,83	0,75	0,84	1	1	1	0,95
	cooling	0,89	0,96	0,93	0,79	0,92	1	0,97	0,81
60	heating	0,81	0,79	0,69	0,82	1	1	1	0,93
	cooling	0,88	0,96	0,91	0,73	0,92	1	0,96	0,76
≥70	heating	0,76	0,73	0,62	0,81	1	1	1	0,9
	cooling	0,86	0,95	0,88	0,66	0,92	1	0,94	0,71

Table 17: Fin factor to the right side [12]

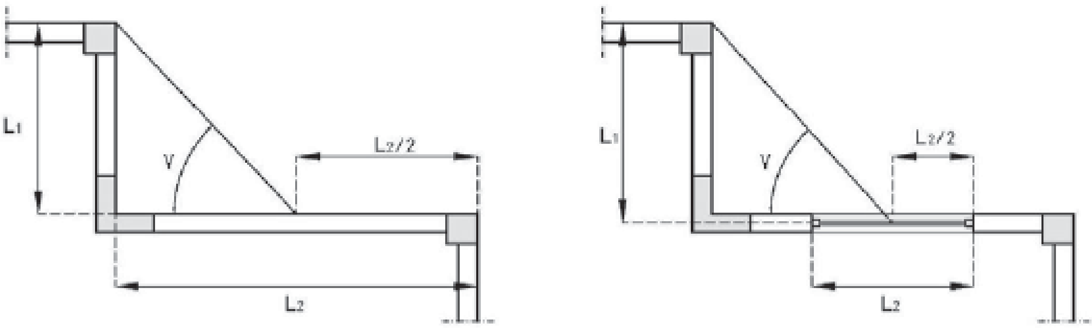

Figure 16: Overhang angle (γ) [12]

III.2 Ventilation-Infiltrarion

III.2.1 Terms and definitions

Floor area (A_f)
is the floor area per zone, measured in square meters

Required fresh air (q_{v-min})
is the required fresh air, measured in cubic meters per hour square meters.

Required fresh air per person ($q_{v-min-per-person}$)
is the required fresh air needed for a person, measured in cubic meters per hour person.

Number of occupants (Occ_{number})
is the number of persons in a zone.

Occupants schedule ($Occ_{schedule}$)
is equal to 1 if persons are at home and 0 if persons are not on 24-hour basis.

Exhaust air recirculation factor (fcntrl)
is the dimensionless factor for the reduction control of the supply of fresh air.

Ventilation port (P_{v-port})
is the air penetration from ventilation port, measured in cubic meters per hour.

Ventilation crevice ($P_{v-crevice}$)
is the air penetration due to crevices, measured in cubic meters per hour square meters.

Infiltered air flow (q_{v-inf})
is the infiltered part of the resulting air flow, measured in cubic meters per hour square meters.

Required air flow (q_{v-req})
is the required air flow, measured in cubic meters per hour square meters.

Heat recovery efficiency ($HR_{efficiency}$)
is the dimensionless heat recovery efficiency.

Total ventilation air ($q_{v-total-air}$)
is the total ventilation air, measured in cubic meters per hour square meters.

III.2.2 Infiltration

Infiltration due to the airtightness of the building or the thermal zone is effected by means of the engravings of the shell frames (joints of perimeter components, interlocking of movable window panels) or ventilation slots (for gas appliances) or chimney stoves (fireplace, oil or wood heater etc.), as well as joints of the building's opaque structural surfaces.

For airtight ventilation calculations air penetration through the structural opaque external surfaces of the building shell is considered negligible and is assumed to be zero. Ventilation vents or fireplace chimneys (fireplace, wood or oil stove, etc.) are taken, as the case may be, according to the number of windows in the building under study or for inspection.

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given a simply method and fixed values to calculate the total ventilation of the building. For more accurate, EN ISO 1575-2007 has given calculation methods for the determination of air flow rates in buildings including infiltration [27].

T.O.T.E.E. has given standard values for air penetration from ventilation port ($P_{v\text{-}port}$) [12], for air penetration due to crevice ($P_{v\text{-}crevice}$) [12] and for total ventilation of non-heated spaces ($P_{v\text{-}airtightness}$) [12] as the next tables show. If there is something which is not included in the next tables, it can be included manually.

Type of opening (glazing, doors, etc.)	**$P_{v\text{-}port}$ [m^3/h]**
Fireplace chimney, wood or oil heater chimney or other burning chamber	20
Ventilation shelves, e.g. for use of gas appliances	10
Doors with margin at the bottom>1.0cm and in contact with the outside environment	10

Table 18: Air penetration form ventilation port ($P_{v\text{-}port}$) [12]

Type of opening (glazing, doo, etc.)	$P_{v\text{-}crevice}$ [$m^3/(m^2h)$]	
	door	**glazing**
Wooden frame		
Single glazing, not airtight, recessed, seamless, opening	11.8	15.1
Without glazing (door) and without airtightness	11.8	15.1
Double-glazing, sliding, with brush, recessed	9.8	12.5
Opening pane, with double glazing, without certification	9.8	12.5
Without glazing (door) and without airtightness, without certification	9.8	12.5
Metal or synthetic frame		
Single glazing, not airtight, recessed, seamless, opening	7.4	8.7
Without glazing (door) and without airtightness	7.4	8.7
Double-glazing, sliding, with brush, recessed	5.3	6.8
Opening pane, with double glazing, without certification	5.3	6.8
Without glazing (door) and without airtightness, without certification	5.3	6.8
Metal, composite or wooden frame certified according to EN 12207		
Variability class based on overall surface of the frame: 1	7.7	7.7
2	4.1	4.1
3	1.4	1.4
4	0.5	0.5
Glass facades		
For partially opening window frames of glass facades (e.g. projected sections), only the non-fixed part is taken into account, depending on the above categories of this table.		

Table 19: air penetration due to crevice ($P_{v\text{-}crevice}$) [12]

So, the calculation of infiltration is:

$$q_{v-inf} = P_{v-port} + P_{v-crevice} A_w \, [\frac{m^3}{h}]$$

III.2.3 Required fresh air

There are two possible required fresh air, depend on people or minimum required fresh air according to T.O.T.E.E. (Technical Instruction of Technical Department of Greece) as the next tables show:

Uses of buildings or thermal zones	$q_{v\text{-}min\text{-}per\text{-}person}$ [$m^3/h/person$]	$q_{v\text{-}min}$ [$m^3/(m^2h)$]
Single-family home, block of flats (more than one apartment)	15	0.75
Corridors and other public communal auxiliary spaces	-	2.60
Bathroom	-	6.00

Table 20: Required fresh air ($q_{v\text{-}min}$) [12]

The required fresh air is the maximum of the fresh air due to people and minimum fresh air for the comfort of the people So, the required fresh air is calculated by the next equation:

$$q_{v-req} = \max(Occ_{number} Occ_{fraction} q_{v-min-per-person}, q_{v-mi})[\frac{m^3}{h}]$$

III.2.4 Total ventilation

The total ventilation is the maximum between the required fresh air ($q_{v\text{-}req}$) and the infiltration ($q_{v\text{-}inf}$). If the infiltration is less than required fresh air, then the habitants would open a window because they would need fresh air. There are two types of ventilation, Natural or Mechanical. The total ventilation can be calculated as shows:

Natural ventilation

The calculation of the total ventilation when is natural ventilation, can be calculated by the next equation:

$$q_{v-tot-air} = \max(q_{v-req}, q_{v-inf})[\frac{m^3}{h}]$$

Mechanical ventilation:

When there is a mechanical ventilation, then the required fresh air coverage by definition and the heat recovery correction is entered for the purposes of thermal calculations.

Heat recovery efficient ($HR_{efficiency}$) is given to the next table:

Type of heat recovery	**$HR_{efficiency}$**
No heat recovery	0
Heat exchange plates or pipes	0.65
Two elements system	0.60
Loading cold with air-conditioning	0.40
Heat pipes	0.60
Slowly rotating or intermittent heat exchangers	0.70

Table 21: Heat recovery system efficiency ($HR_{efficiency}$) [28]

The calculation of the total ventilation when is mechanical ventilation, can be calculated by the next equation:

$$q_{v-tot-air} = (1 - fcntrl)(1 - HR_{efficiency})\, q_{v-req} + q_{v-inf}\ [\frac{m^3}{h}]$$

III.3 Occupants and Appliances

III.3.1 Terms and definitions

Number of occupants (Occ_{number})
is the number of persons in a zone.

Occupant schedule ($Occ_{schedule}$)
is equal to 1 if persons are at home and 0 if persons are not on 24-hour basis.

Occupant density ($Occ_{density}$)
is the density of the persons, measured in cubic meters per person.

Occupant thermal power ($Occ_{themral}$)
is the metabolic rate of persons, measured in Watts per person.

Appliance schedule ($Appl_{schedule}$)
is equal to 1 if persons are at home and 0 if persons are not on 24-hour basis.

Thermal power of appliances ($Appl_{thermal}$)
is the consumption rate of appliances, measured in Watts per square meters.

Occupant gains (Occ_{gains})
are the gains from occupants, measured in Watts per square meters.

Appliance gains ($Appl_{gains}$)
are the gains from appliances, measured in Watts per square meters.

Floor area (A_f)
is the area of the floor, measured in square meters

III.3.2 Gains by occupants and appliances

Every person according to their activity, releases heat in the form of a sensible and latent load. Sensible load is due to the radiation of his body and the transfer of heat from his body to the air. The radiation/transport ratio is about 50%-50% and, of course, depends on the individual's clothing and activity. However, for simple calculations in the context of assessing the energy performance of a building, this ratio does not materially affect and usually does not fall into the calculations. The latent load is due to the breathing and sweating of every human being and is as big as the activity of the individual increases.

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for occupant density ($Occ_{density}$) [12], thermal power of occupants ($Occ_{thermal}$) [12]and appliances ($Appl_{thermal}$) [12] as shown in the next tables:

Uses of buildings or thermal zones	**$Occ_{density}$ [m^2/persons]**	**$Occ_{thermal}$ [W/person]**
Single-family home, block of flats (more than one apartment)	20	80
Corridors and other public communal auxiliary spaces	0	0
Bathroom	0	0

Table 22: Occupant density ($Qcc_{density}$) and thermal power ($Qcc_{thermal}$) [12]

Uses of buildings or thermal zones	**$Appl_{thermal}$ [W/m^2]**
Single-family home, block of flats (more than one apartment)	2
Corridors and other public communal auxiliary spaces	0
Bathroom	0

Table 23: Thermal power of appliances ($Appl_{thermal}$) [12]

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has also given standard values for occupant schedule ($Occ_{schedule}$) [12] and appliance schedule ($Appl_{schedule}$) [12] as shown in the next table:

Uses of buildings or thermal zones	**$Occ_{schedule}$ [hours per day]**	**$Appl_{schedule}$ [hours per day]**
Single-family home, block of flats (more than one apartment)	18	18
Corridors and other public communal auxiliary spaces	18	18
Bathroom	18	18

Table 24: Occupant schedule ($Occ_{schedule}$) and appliance schedule ($Appl_{schedule}$) [12]

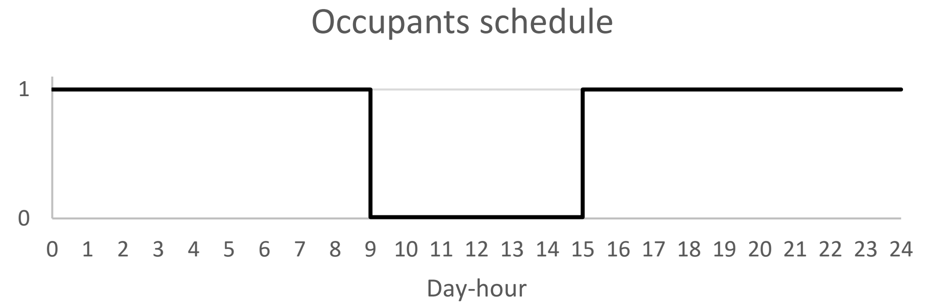

Figure 17: Occupants schedule

The gains by occupants and appliances are calculated using the follow equations:

$$Occ_{gains} = \frac{Occ_{number}Occ_{fraction}Occ_{thermal}}{Occ_{density}} xA_f \,[W]$$

$$Appl_{gains} = Appl_{fraction}Appl_{thermal}A_f \;[W]$$

III.4 Lights

III.4.1 Terms and definitions

Total gains from lights ($Light_{gains}$)
is the gains from lights, measured in Watts per square meters.

Total installed lighting power in the zone (P_n)
is the power of all lights in the zone, measured in Watts per square meters.

Lighting schedule
if lights are open then lighting schedule is 1 else is 0 on 24-hour basis.

Daylight time usage (T_D)
is the operating hours during the daylight time, measured in hours.

Non-daylight time usage (T_N)
is the operating hours during the non-daylight tie, measured in hours.

Daylight dependency factor (F_D)
is the dimensionless factor relating the usage of the total installed lighting power to daylight availability in the zone.

Occupant dependency factor (F_O)
is the dimensionless factor relating the usage of the total installed lighting power to occupant period in the zone.

Power density of a lamp
every type of lamp has it own power density, measured in Watts per square meters per 100lx.

Level of lighting
lx is the SI derived unit of illuminance and luminous emittance, measuring luminous flux per unit area. Level of lighting measured in lx.

Floor area (A_f)
is the area of the floor, measured in square meters

III.4.2 Calculating energy used for lighting

The total installed lighting power in the zone is:

$$P_n = (\text{powe density of lamp x number of lamps}) \text{ x } (\text{level of lighting}) [W/m^2]$$

The total gains from lights can be calculated as the next equation:

$$Light_{gains} = P_n \text{ x } (\text{lighting fraction}) \text{ x } F_D \text{ x } F_O \text{x} A_f \ [W]$$

III.4.3 Lighting schedule

Lights affect the internal temperature when they are on. When lights are off, there are no thermal gains. To find the thermal gains when lights are on, firstly, the total of daily lighting operation must be known.

According to T.O.T.E.E. 2017 (Technical Instruction of Technical Department of Greece) the hours that lights are on in a house are 1820 per year during the availability of natural lighting (daylight time usage) and 1680 per year during the absence of natural lighting (non-daylight time usage) [12].

Type of building	Non-daylight time usage (T_N) [hours/year]	Non-daylight time usage (T_N) [hours/year]
Domestic building	1820	1680

Table 25: Number of hours per year for daylight time and non-daylight time [12]

This is equal to 5,056 hours daylight time usage (T_D) per day and 4,603 hours non-daylight time usage (T_N) per day. The method used is hourly, so the hours per day of daylight time usage (T_D) and for non-daylight time usage (T_N) are 5 hours for both of them. Habitants are the ones who turn on and off the lights, so they have to be at home when lights are on. It is assumed that lights are on from 06:00 until 09:00 and from 18:00 until 24:00.

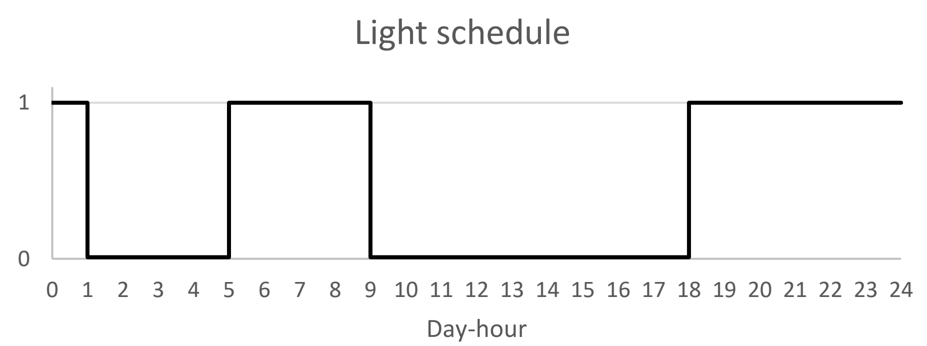

Figure 18: Light schedule

III.4.4 Type of lamp

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given ten different types of lamps [12]. If the house which is under study has a lamp which is not included in the table of T.O.T.E.E., it can be included manually. The next table shows the ten types of lamps.

Type of lamp	**Power density per 100 lx [W/m²/100 lx]**
Simple incandescent (abolished)	27
Halogen incineration	16.6
Mercury vapor (abolished)	7
High pressure sodium vapors	4.2
Compact fluorescence (including ballast)	4.5
Linear fluorescence T8 (halophospate including electromagnetic ballast)	4.2
Linear fluorescence T8 (triphosphor including electromagnetic ballast)	3.4
Linear fluorescence T5 (including electromagnetic ballast)	3.2
Metal halide vapors (including electromagnetic ballast)	5.2
Led with built-in driver	2.5

Table 26: Type of lamp [12]

The table refers to one lamp. If there are more lamps of a single type, the power density is multiplied by with the total number of lamps.

III.4.5 Light factors

III.4.5.1 Daylight dependency factor (F_D)

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for daylight dependency factor (F_D) [12]. Standard values of the natural light affect the factor due to the use of control automation with natural light sensors and control of dimmable luminaires. If the house which is under study has a different light sensor or control than T.O.T.E.E., it can be included manually. The next table shows the daylight dependency factor (F_D) from T.O.T.E.E

Control automation devices for the use of natural lighting	**F_D**
Manual lighting control for all building uses	1.0
Automatic lighting control (with natural light sensor)	0.7

Table 27: Daylight dependency factor (F_D) [12]

III.4.5.2 Occupant dependency factor (F_O)

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for occupant dependency factor (F_O) [12]. Standard values are separate in System without sensors for presence or absence detection and systems with presence or motion detection sensors. The next table shows the occupant dependency factor (F_O) from T.O.T.E.E.

Systems without sensors for presence or absence detection	F_O
Manual switch (touch/quencher (σβέσης))	1.00
Manual switch (touch/quaencher) in temporary accomodation outside communal areas	0.70
Systems with presence or motion detection sensors	**F_O**
Auto ignition and extinguishing	0.80
Manual ignition/Automatic ignition	0.75

Table 28: Occupant dependency factor (F_O) [12]

III.5 Weather data

III.5.1 Terms and definitions

Direct Normal Irradiance (DNI)

is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. Typically, you can maximize the amount of irradiance annually received by a surface by keeping it normal to incoming radiation. This quantity is of particular interest to concentrating solar thermal installations and installations that track the position of the sun. Direct normal irradiance is taken from EPSCT (Energy Performance Standard Calculation Toolkit) [29]. Direct normal irradiance is measured in Watts hours per square meters.

Diffuse Horizontal Irradiance (DHI)

is the amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun but has been scattered by molecules and particles in the atmosphere. Basically, it is the illumination that comes from clouds and the blue sky. Diffuse horizontal is taken from EPSCT (Energy Performance Standard Calculation Toolkit) [29]. Diffuse horizontal is measured in Watts hours per square meters.

Dry-bulb temperature (DBT)

is the temperature of air measured by a thermometer freely exposed to the air, but shielded from radiation and moisture. *DBT* is the temperature that is usually thought of as air temperature, and it is the true thermodynamic temperature. It indicates the amount of heat in the air and is directly proportional to the mean kinetic energy of the air molecules. Dry bulb temperature is taken from EPSCT (Energy Performance Standard Calculation Toolkit) [29]. Dry bulb temperature is measured in Celsius degrees.

Solar declination (δ)

is the angle between the earth/sun line and the equatorial, measured degrees.

Day (n)

is the day of the year, is 1 for the 1st January and 365 for the 31st December.

Solar altitude (β)
is the angle between the horizontal plane and a line emanating from the sun. Its value ranges from 0° when the sun is the horizontal and 90° if the sun is directly overhead. Negative values correspond to night times. Solar altitude is measured in degrees.

Equation of time (ET)
the earth's orbital velocity varies throughout the year as determined by a solar time sundial, varies somewhere from the mean time kept by a clock running at a uniform rate. This variation is called the equation of time (ET) which is measured in minutes.

Solar azimuth angle (φ)
is the angular displacement from south of the projection, on the horizontal plane, of the earth/sun line, measured in degrees.

Hour angle (ω)
is the angle defined as the angular distance on the celestial sphere measured westward along the celestial equator from the meridian to the hour circle passing through a point, measured in degrees.

Incidence angle (θ)
is the angle between the line normal to the irradiated surface and the earth-sun line, measured in degrees.

Zenith angle (Z)
is the angle between the sun and the center of the sun's disc, measured in degrees

Tilt angle (Σ)
is the angle between the surface and the horizontal plane, its value lies between 0 and 180° (0° for horizontal and 90° for vertical, measured in degrees.

Surface azimuth angle (ψ)
is defined as the displacement from south of the projection, on the horizontal plane, of the normal to the surface. Measured in degrees.

Orientation	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Surface azimuth (ψ)	180°	-135°	-90°	-45°	0°	45°	90°	135°

Table 29: Surface Orientations and Azimuths, measured from South [30]

Day degree (Γ)
is the conversation of the day (n) into degrees (0-360), measured in degrees.

Latitude (Lat)
is geography coordinate that specifies the north-south position of a point on the Earth's surface.

Apparent solar time (AST)
is a calculation of the passage of the time based on the position of the sun in the sky, measured in decimal hours.

Local standard time (LST)
is the local standard time, measured in decimal hours.

Longitude of local standard time meridian (LSM)
is the longitude of local standard time meridian, negative in western hemisphere, measured in degrees.

Longitude of site (LON)
is the longitude of site, measured in degrees.

Ground Reflectance (R_g)
is the dimensionless factor of ground reflectance, often taken to be 0.2 for the typical mixture of ground surfaces.

Foreground Surface	**R_g**
Water (near normal incidences)	0.07
Coniferous forest (winter)	0.07
Asphalt new	0.05
Asphalt weathered	0.10
Bituminous and gravel roof	0.13
Dry bare ground	0.2
Weathered concrete	0.2 to 0.3
Green grass	0.26
Dry grassland	0.2 to 0.3
Desert sand	0.4
Light building surfaces	0.6
Snow-covered surfaces (Typical center)	0.2
Snow-covered surfaces (Typical urban site)	0.4
Snow-covered surfaces (Typical rural site)	0.5
Snow-covered surfaces (Isolated rural site)	0.7

Table 30: Ground Reflectance of Foreground Surfaces [31]

Total clear-sky irradiance (E_t)
is the sum of three components ($E_{t.b}$, $E_{t,d}$, $E_{t,r}$), measured in Watts per square meters.

The beam component ($E_{t,b}$)
is originating from the solar disc, measured in Watts per square meters.

The diffuse component ($E_{t,d}$)
is originating from the sky dome, measured in Watts per square meters.

The ground-reflected component ($E_{t,r}$)
is originating from the ground in front of the receiving surface, measured in Watts per square meters.

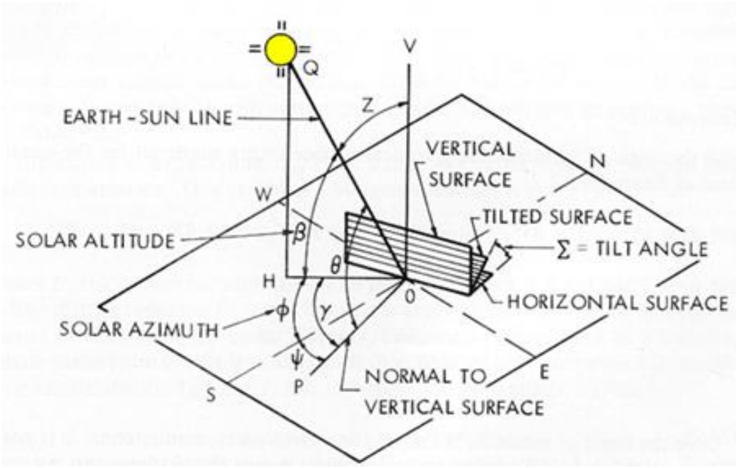

Figure 19: Solar Angles for Vertical and Horizontal Surfaces [32]

III.5.2 External temperature

External temperature is equal to Dry-bulb temperature (DBT). Dry bulb temperature is taken from EPSCT (Energy Performance Standard Calculation Toolkit) [29]. Dry bulb temperature is measured in Celsius degrees.

III.5.3 Calculation direct normal irradiance and diffuse horizontal irradiance

The calculation of direct normal irradiance and diffuse horizontal irradiance can be calculated as follow as ASHRAE [30]:

$$\delta = 23.45 \sin(360 \frac{n+284}{365})$$

$$\Gamma = 360 \frac{n-1}{365}$$

$$ET = 2.2918[0.0075 + 0.1868\cos(\Gamma) - 3.2077\sin(\Gamma) - 1.4615\cos(2\Gamma) - 4.8089\sin(2\Gamma)]$$

$$AST = LST + ET/360 + (LON - LSM)/15$$

$$\omega = 15(AST - 12)$$

$$\begin{aligned}\cos(\theta) = {} & \sin(\delta)\sin(\varphi)\cos(\Sigma) - \sin(\delta)\cos(\varphi)\sin(\Sigma)\cos(\psi) \\ & + \cos(\delta)\cos(\varphi)\cos(\Sigma)\cos(\omega) + \cos(\delta)\cos(\varphi)\cos(\Sigma)\cos(\omega) \\ & + \cos(\delta)\sin(\varphi)\sin(\Sigma)\cos(\psi)\cos(\omega) + \cos(\delta)\sin(\Sigma)\sin(\psi)\sin(\omega)\end{aligned}$$

$$\cos(Z) = \sin(\delta)\sin(\varphi) + \cos(\delta)\cos(\varphi)\cos(\omega)$$

Beam irradiance is calculated as the next equation:

$E_{t,b} = DNI\cos(\theta)$ this relationship is valid when cos(θ)>0; otherwise, $E_{t,b}$=0

Diffuse irradiance is:

$$Y = \max(0.45, 0.55 + 0.437\cos(\theta) + 0.313\cos^2(\theta)$$

$$\text{if } \Sigma \le 90^o \text{ then } E_{t,d} = DHI(Y\sin(\Sigma) + \cos(\Sigma))$$

$$\text{if } \Sigma > 90^o \text{ then } E_{t,d} = DHIxY\sin(\Sigma)$$

Irradiance due to ground reflection :

$$E_{t,r} = (DNI\cos(Z) + DHI)\,R_g\,\frac{1-\cos(\Sigma)}{2}$$

Total clear-sky irradiances is the sum of the irradiance du to ground reflection,: the beam irradiance and the diffuse irradiance:

$$E_t = E_{t,b} + E_{t,d} + E_{t,r}\,[\frac{W}{m^2}]$$

III.6 Domestic hot water and solar water heating

III.6.1 Terms and definitions

Solar collector area (A_c)
is the solar collector area, measured in square meters.

Floor area (A_f)
is the floor area per zone, measured in square meters

Number of occupants (Occ_{number})
is the number of persons in a zone.

Occupant schedule ($Occ_{schedule}$)
is equal to 1 if persons are at home and 0 if persons are not on 24-hour basis.

Tilt angle (Σ)
is the angle between the collector and the horizontal plane, its value lies between 0 and 180^o (0^o for horizontal and 90^o for vertical, measured in degrees.

Final water temperature (θ_f)
is the final water temperature of the water, measured in Celsius.

Water temperature (θ_w)
is the average monthly water mains temperature, measured in Celsius.

Hot water demand ($Demand_{water}$)
is the daily hot water demand, measured in liters per person day.

Circulation system ($System_{circ}$)
Is the type of circulation system.

Solar energy utilization factor ($Solar_{factor}$)

is the solar energy utilization factor for domestic hot water production.. It depends on the type of the collector and the tilt angle of the collector.

System efficiency ($System_{efficiency}$)
is the system efficiency, depends on circulation system..

Domestic hot water energy (DHW_{energy})
is the domestic hot water energy according to demand hot water, measured in kilowatt hour per day

Solar energy ($Solar_{energy}$)
is the energy from the sun to the collector, measured in kilowatt hour

Energy need to hot the demand water (DHW_{need})
is the energy need to hot the demand water, measured in kilowatt hour

III.6.2 Energy need for domestic hot water

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given standard values for final water temperature (θ_f) [12], water temperature (θ_w) [12], hot water demand ($Demand_{water}$) [12] and solar energy utilization factor ($Solar_{factor}$) [12].

final water temperature: $\theta_f = 45^o C$

Climate zones	J	F	M	A	M	J	J	A	S	O	N	D
A	13.0	12.8	13.8	16.3	19.9	23.8	26.2	26.2	24.9	21.7	18.1	14.8
B	10.4	10.1	11.7	14.8	18.9	23.1	25.6	25.8	23.5	19.7	15.5	12.2
C	6.5	7.3	9.4	13.2	17.6	21.9	24.3	24.6	22.0	17.7	12.7	8.6
D	4.2	5.0	7.5	11.5	15.7	19.8	22.2	22.7	20.2	15.9	10.8	6.6

Table 31: the average monthly water mains temperature (θ_w), measured in Celsius [12]

Uses of buildings or thermal zones	$Demand_{water}$ [l/person/day]
Single-family home, block of flats (more than one apartment)	50

Table 32: the daily hot water demand ($Demand_{water}$) [12]

Cities	Type of solar collector								
	Flat plate			Selective			Evacuated tube		
	Tilt angle (Σ)								
	15°	45°	65°<	15°	45°	65°<	15°	45°	65°<
Alexandroupoli	0.318	0.325	0.329	0.341	0.353	0.350	0.360	0.367	0.369
Athens	0.338	0.344	0.351	0.359	0.369	0.369	0.374	0.381	0.383

Heraklion	0.333	0.339	0.343	0.355	0.364	0.361	0.370	0.375	0.378
Kastoria	0.307	0.314	0.316	0.333	0.344	0.340	0.356	0.363	0.363
Larisa	0.327	0.334	0.341	0.350	0.360	0.360	0.369	0.376	0.378
Lemnos	0.319	0.327	0.331	0.343	0.354	0.352	0.360	0.368	0.370
Naxos	0.332	0.340	0.344	0.355	0.365	0.363	0.372	0.378	0.381
Patra	0.335	0.342	0.348	0.357	0.366	0.366	0.373	0.381	0.382
Thessaloniki	0.325	0.332	0.337	0.348	0.358	0.358	0.368	0.375	0.376
Tripoli	0.317	0.324	0.327	0.340	0.349	0.347	0.363	0.369	0.370

Table 33: the solar energy utilization factor for domestic hot water production ($Solar_{factor}$) [12]

System efficiency ($System_{efficiency}$) is given by EN 2916 [28] as the next table shows:

Type of circulation system	**Distribution system efficiency**
all taps within 3m from heat generation	1.0
taps more than 3m from heat generation	0.8
circulation system or unknown	0.6

Table 34: System efficiency [28]

So, energy need to hot the demand water can be calculated as:

$$DHW_{energy} = \frac{4.18 Demand_{water}(\theta_f - \theta_w) Occ_{number}}{1000x3.6} [\frac{kWh}{day}]$$

$$Solar_{energy} = \frac{Radiation(orientation, \Sigma) A_s Solar_{factor}}{1000} [kWh]$$

$$DHW_{need} = \max(\frac{DHW_{energy} Occ_{fraction}}{\sum Occ_{fraction}} - Solar_{energy}, 0)[kWh]$$

III.7 Boiler-burner efficiency

III.7.1 Terms and definitions

Seasonal boiler-burner efficiency ($\eta_{sK\Theta}$)
is the seasonal boiler-burner efficiency.

Conversion factor for seasonal performance (ΣΜΘΔ)
is the conversion factor for the seasonal performance.

Energy efficiency of the seasonal space heating ($\eta_{sA\Theta}$)
is the conversion factor for the seasonal performance.

Boiler-burner efficiency (η_{gen})
is the overall efficiency of the boiler-burner.

Nominal power (P_n)
is the nominal power of the boiler-burner, measured in Watts.

Maximum thermal capacity (P_{gen})
is the maximum thermal capacity of the unit heating of the building, measured in Watts.

Building area (A)
is the area of all surfaces facing the thermal zone, measured in square meters.

Maximum allowed heat transmission coefficient (U_m)
is the maximum allowed transmission coefficient which is depended on the climate zone, measured in Watts per square meters Kelvin degrees..

Temperature difference (ΔT)
is the temperature difference for the system dimensioning which is depended on the climate zone, measured in Celsius degrees.

Number of occupants (Occ_{number})
is the number of persons in a zone.

Minimum required fresh air (q_{v-min})
is the minimum required fresh air, measured in cubic meters per hour square meters.

Required fresh air per person ($q_{v-min-per-person}$)
is the required fresh air needed for a person, measured in cubic meters per hour person.

Floor area (A_f)
is the area of the floor, measured in square meters

Required fresh air (V)
is the real efficiency of the boiler-burner, measured in cubic meters per hour.

Real efficiency of the boiler-burner (η_{gm})
is the real efficiency of the boiler-burner.

Conversion factor to seasonal performance (η_{g0})
is the conversion factor to seasonal performance.

Oversize factor (η_{g1})
is the oversize factor of the boiler-burner.

Efficiency of insulation (η_{g2})
is the efficiency of the insulation.

Over dimensioning (Y)
is the over dimensioning which take the value 1 for boiler without over-dimensioning, 1.5 for boiler with over dimensioning 50% and so on.

III.7.2 Calculate the boiler-burner efficiency

The designer uses the assigned rated power and seasonal space heating efficiency of the boiler-burner unit indicated in the heating unit design study according to the manufacturer's technical specifications, which are listed in the product dossier under Energy Labeling Regulation 811/2013 of the EU.

The seasonal boiler-burner efficiency ($\eta_{sK\Theta}$) can be calculated as follow if it does not have energy label:

$$\eta_{sK\Theta} = \Sigma M\Theta\Delta(\eta_{sA\Theta} + 3\%)$$

The energy efficiency of the seasonal space heating ($\eta_{sA\Theta}$) according to T.O.T.E.E. (Technical Instruction of Technical Department of Greece) is as the next table shows [12]:

Type of fuel	**ΣΜΘ**
Heating oil	1.07
Natural gas	1.11
Liquid gas	1.09
Pellets A1 or A2 or B with M10 moisture and briquette A1 with moisture M12	1.09
Briquette A2 or B with moisture M15	1.10
Fire wood A1 with moisture M15	1.11
Fire wood A1 with moisture M25	1.12
Olive cake pellets with moisture M10	1.08
Olive cake pellets with moisture M10	1.09

Table 35: conversion factor for the seasonal performance [12]

T.O.T.E.E. has also given table for the maximum boiler-burner efficiency (η_{gen}) if there is not any other energy paper [12]:

The maximum thermal capacity (P_{gen}) can be calculated as follow:

$$P_{gen} = (AxU_m 1.5 + \frac{\dot{V}}{3})\Delta T[W]$$

where,

$$\dot{V} = \max(Occ_{number} q_{v-min-per-person}, q_{v-min} A_f)[\frac{m^3}{h}]$$

Climate zone	U_m[W/m²K]	ΔT(°C)
A	1.55	18
B	1.20	20
C	0.95	23
D		28

Table 36: The maximum heat transmission coefficient (U_m) and temperature difference (ΔT) [12]

If the building has been built before 1980 then $U_m = 3.5[\frac{W}{m^2K}]$

If the boiler-burner has energy label the seasonal boiler-burner efficiency ($\eta_{sK\Theta}$) can be calculated as follow:

$$\eta_{\Sigma K\Theta} = \eta_{gm}\eta_{g0}$$

where,

	Conversion factor to seasonal performance (η_{g0})			
Nominal power P_n[W]	**≤25**	**>25 & ≤100**	**>100 & ≤400**	**>400**
Boiler without elements (*)	0.82	0.84	0.87	0.90
Typical boiler (*)	0.85	0.88	0.91	0.92
Low temperature boiler	0.91	0.935	0.965	0.965
Condensation boiler	0.95	0.96	0.977	0.977
* also used in the case of biomass boiler				

Table 37: Conversion factor to seasonal performance (η_{g0}) [12]

So the boiler-burner seasonal efficiency is equal to:

$$\eta_{gen} = \eta_{sK\Theta}\eta_{g1}\eta_{g2}$$

where,

$$\eta_{g2} = aY + b$$

	Oversize factor of the boiler-burner (η_{g1})					
P_n/P_{gen}	**100%**	**125%**	**150%**	**200%**	**400%**	**500%**
Boiler without elements (*)	1	0.97	0.94	0.90	0.76	0.70
Typical boiler (*)	1	0.97	0.94	0.91	0.77	0.72
Low temperature boiler	1	0.985	0.97	0.94	0.84	0.80
Condensation boiler	1	0.988	0.975	0.95	0.85	0.82
Certified biomass boiler (manual or automatic feed)	1	0.975	0.955	0.91	0.78	0.74

Table 38: oversize factor of the boiler-burner (η_g) [12]

Insulation status	Boiler type	a	b
Good	All	0.0	1.0
Okay	Without elements, biomass	-0.0145	0.975
	Low temperature	-0.017	0.99
	Condensation	-0.015	1.00
Bad	Without elements, biomass	-0.026	0.95
	Low temperature	-0.027	0.99
	Condensation	-0.034	1.00

Table 39: Coefficients for calculating the insulation status coefficient of boiler-burner (η_{g2}) [12]

III.8 Cooling unit performance

III.8.1 Terms and definitions

Nominal power (P_n)
is the nominal power of the boiler-burner, measured in Watts.

Average seasonal efficiency index (SEER)
is the average seasonal efficiency index.

Nominal efficiency index (EER)
is the nominal efficiency index.

III.8.2 Calculate the average seasonal efficiecny index

Each cooling production unit has a rated cooling efficiency, EER (energy efficiency ratio or index), according to the manufacturer's technical specifications from the unit's certification. However, the actual operating performance of a cooling unit varies and depends on the cooling period (depending on the climate zone), the operating time of the building and, by extension, the cooling system, the indoor summer operating conditions, the automation devices compensating thermostats), the correct dimensioning of the unit and so on. For the energy performance calculations of the building it is required to determine the mean (seasonal) energy efficiency index (SEER) of the cooling unit.

For chillers and heat pumps used for cooling, performance is determined by the SEER at rated operating conditions (for cooling) as given in the manufacturer's technical specifications or calculated from the nominal index energy efficiency (EER). It is clarified that the performance of the refrigeration systems is contracted on the basis of the SEER indicators.

The SEER value is determined in specific ambient and coolant return temperature conditions. The performance of heat exchangers and heat pumps also depends on the heat source they use for their operation and may be air, ground, groundwater and surface water, seawater, engine exhausts, solar power and so on.

There are two type of heat pumps-coolers according to T.O.T.E.E. (Technical Instruction of Technical Department of Greece) [12]:

- Local or semi-central units direct air-cooled cooling
- Heat pumps-chillers with water cooled medium

III.8.2.1 Local or semi-central units direct air-cooled cooling

For air-cooled chillers/air cooled chillers complying with the Eco-design Regulation and accompanied by Energy Label, in accordance with EU Energy Labeling Regulation 626/2011, the Seasonal Energy Efficiency Rating of the $SEER_{ΕΣ}$ unit is considered in the medium climate. Average Seasonal Energy Efficiency Index, SEER, of the energy pump with energy labeling is equal to [12]:

$$SEER = 0.60\,SEER_{ΕΣ}$$

For air-cooled chillers for which no data are available, the SEER for the energy performance calculations of the building under construction or inspection shall be taken [12]:

- 1.70 for systems installed before 1990
- 2.2 for systems installed between 1990 and 2000
- 25 for systems installed after 2001
- If the energy inspector does not have any information about the cooling unit and in addition can not document the year of its installation, then it will take as it is installed before 1990

III.8.2.2 Heat pumps-chillers with water cooled medium

For heat pumps and/or coolers with total cooling capacity of less than 100 kW, because SEER (average seasonal efficiency index) is not easy to estimate, the energy performance calculations of the headquarters building conditioning is taken during the study or inspection as final cooling performance rated EER efficiency index for nominal operating temperature conditions outside air of 35°C and temperature of cooling medium supplied 7°C according to European Standard EN 14511:2007 as given by the manufacturer and listed in the technical specifications and/or in the refrigeration unit. Correspondingly, in the case of geothermal heat pumps as an EER efficiency index is obtained during the calculations the value given in geogrid temperature conditions 15°C and a cooling medium temperature of 7°C.

For water-cooled heat pumps-water coolers for which no data are available, the SEER for the energy performance calculations of the building under construction or inspection shall be taken [12]:

- 1.70 for systems installed before 1990
- 2.2 for systems installed between 1990 and 2000
- 25 for systems installed after 2001
- If the energy inspector does not have any information about the cooling unit and in addition cannot document the year of its installation, then it will take as it is installed before 1990

III.9 Terminal units

III.9.1 Terms and definitions

Terminal unit efficiency ($N_{em,t}$)
is the efficiency of the terminal unit.

Transmission efficiency (η_{em})
is the transmission efficiency.

Radiation factor (f_{rad})
is the factor for the radiation efficiency of the terminal units and depends on the height of the space heated.

Intermittent factor (f_{im})
is the factor intermittent operation in the sense of temperature-reduction in space of the building.

Hydraulic factor (f_{hydr})
is the factor for the hydraulic balance of the network of terminal units.

III.9.2 Heating terminal units

Conventional heating units for technical heating systems are: radiators, underfloor heating systems, in-wall systems and fancoil units. According to ΕΛΟΤ EN 15316.2.1:2008 the terminal unit efficiency ($N_{em,t}$) of the heating units (heat emission) of the following relationship [12]:

$$N_{em,t} = \frac{\eta_{em}}{f_{rad} f_{im} f_{hydr}}$$

where,

For heating terminal units	f_{rad}
With high smaller than 4m	1.00
With high bigger than 4m	0.95
With air circulation	1.00

Table 40: The factor for the radiation efficiency of the terminal units (f_{rad}) [12]

For the heating units	f_{im}
Continuous operation	1.00
Intermittent operation (*)	0.97
* with automatic mode control at the terminal unit	

Table 41: The factor intermittent operation in the sense of temperature reduction in space of building (f_{im}) [12]

For the heating units	f_{hydr}
With a hydraulically balanced system	1.00
with non-equilibrium systems	1.03

Table 42: the factor for the hydraulic balance of the network of terminal units (f_{hydr}) [12]

For heating terminal units Type of terminal unit	η_{em}
Immediate performance on an internal wall (90-70)^{o}C	0.85
Immediate performance on an internal wall (70-50)^{o}C	0.89
Immediate performance on an internal wall (50-35)^{o}C	0.91
Direct performance on an external wall (90-70) ^{o}C	0.89
Direct performance on an external wall (70-50) ^{o}C	0.93
Direct performance on an external wall (50-35) ^{o}C	0.95
Underfloor heating system	0.90
Indoor heating system	0.87
Ceiling heating system	0.85
Local electrical units in an internal wall	0.91
Local electrical units in an external wall	0.94

Table 43 the transmission efficiency (η_{em}) [12]

In case of obvious failures and poor maintenance (damaged parts, corrosion, leakage, etc.) of the terminal units, the output of terminal units is reduced by 10%.

If the cooling unit is air condition, then the transmission efficiency (η_{gen}).

III.9.3 Cooling terminal units

Conventional cooling units for technical cooling systems are: fancoil units, direct exhaust systems internal units, air terminals (airway nozzles), floor and in-line cooling systems and a chilled roof [12]:

$$N_{em,t} = \frac{\eta_{em}}{f_{im} f_{hydr}}$$

where,

For the heating units	f_{im}
Continuous operation	1.00
Intermittent operation (*)	0.97
* with automatic mode control at the terminal unit	

Table 44: The factor intermittent operation in the sense of temperature reduction in space of building (f_m) [12]

For the cooling units	f_{hydr}
With a hydraulically balanced system	1.00
with non-equilibrium systems	1.03

Table 45: the factor for the hydraulic balance of the network of terminal units (f_{hydr}) [12]

For cooling terminal units	η_{em}
Type of terminal unit	
Direct Systems: e.g. fan-coils, floor or ceiling units, local exhaust systems, indoor air circulation terminals, etc.	0.85
Embedded Terminal Units: e.g. interior, floor, chilled ceilings	0.89
Local heat pumps	0.91

Table 46: The transmission efficiency (η_{em}) [12]

In case of obvious failures and poor maintenance (damaged parts, corrosion, leakage, etc.) of the terminal units, the output of terminal units is reduced by 10%.

III.10 Losses of distribution networks

In order to estimate the actual energy consumption for the heating and/or cooling and/or air conditioning of a building, account shall also be taken of the heat/coolant losses from the distribution networks (heat and/or coolant) and from the inlet and outlet air conditioning air. The degree of thermal/cooling performance of a distribution network is determined by the magnitude of losses in the distribution network, which depend on:

- the thermal insulation of the distribution network
- the length and cross-section of the distribution network
- the temperature of the water (or other medium) in the grid
- the transit area of the distribution network (heated, non-heated, external environment, etc.)
- network age and damage to insulation, etc.

In ΕΛΟΤ ΕΝ 153162-3:2008, a detailed methodology is provided for calculating the thermal losses of a heating and/or cooling distribution network of the building and/or the thermal zone. This methodology is quite detailed and time-consuming, since it is necessary to precisely determine the geometry of the distribution network (length, cross sections, etc.) local resistance (valves, expansion, contractions, counters, etc.) quality and geometry thermal insulation (thickness, coefficient of thermal conductivity, etc.), the temperature of the heat/coolant, the operating time of the system (intermittent or continuous operation, thermostatically controlled etc.) of the temperature of the piping passages, the quality of the pipelines (roughness, thermal transmittance etc.) and other technical characteristics. In most cases of buildings and especially those with old technical heating/cooling/air conditionings systems, these data are difficult to record and accurately or even approximate.

In order to simplify the calculations of the energy efficiency of the building and based on the methodology of ΕΛΟΤ ΕΝ 15316.2.3: 2008, the percentage of losses of the distribution networks was estimated. In the next table typical values are given for the rate losses of central heating/cooling distribution systems in relation to the installed capacity of the plant, the type of insulation of pipelines and the passageways. The rate of losses refers to the total heat or cooling energy that the grid transports. These values are taken for the calculations of the building's energy efficiency.

Losses from distribution grids also include losses from long-distance central air-conditioning units ducts. When air vents pass through indoor areas, their thermal losses are relatively low due to the low temperature difference and consequently are not considered for the energy performance calculations of the building.

Thermal or cooling power distribution network	**Indoor passage and/or 20% outdoor passage**				**More than 20% outdoor passage**		
	Insulation of building reference [1]	Insulation equal to the radius of the pipes [2]	Insufficient insulation [3]	Without insulation	Insulation of building reference [1]	Insulation equal to the radius of the pipes [2]	Insufficient insulation [3] or Without insulation
[kW]	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**
Distribution networks with high temperature of working fluid (≥60°C)							
20-100	5.5	4.5	11.0	14.0	8.0	6.5	17.0
Distribution networks with low temperature of working fluid (<60°C)							
20-100	3.5	3.0	8.0	9.0	4.5	3.7	11.0
Cooling distribution networks							
20-100	2.0	1.5	3.0	4.5	2.5	2.0	6.7
[1] For insulation pipes according to the requirements of the next table [2] For insulation with a thickness equal to the radius of the pipe [3] Insufficient insulation of the network or branch due to damage. Connections and valve without insulation							

Table 47: Percentage of heat/cooling losses (%) of the central heating and /or cooling distribution network in relation to the total heat/cooling power transferred by the grid [12]

Thermal insulation thickness with equivalent λ=0.040 [W/mK] to 20°C			
By crossing in the inside		**By crossing in the outside**	
Pipe diameter	Insulation thickness	Pipe diameter	Insulation thickness
For pipes of technical heating, cooling, air conditioning systems			
from 1/2″ until 3/4″	9mm	from 1/2″ until 2″	19mm
from 1″ until 1 1/2″	11mm	from 2″ until 4″	21mm
from 2″ until 3″	13mm	greater than 4″	25mm
greater than 3″	19mm		
For pipes			
Regardless of diameter	9mm	Regardless of diameter	13mm

Table 48: Thermal insulation thickness for the insulation pipes according to the requirements of the building reference [12]

For local heat and/or cooling systems, such as domestic or outdoor boilers or local heat pumps, where there is no distribution network, distribution losses are considered to be zero for the building under study/inspection and for the home reference building has local heat pumps.

If the cooling unit is air condition, then the losses are 0%.

III.11 Ground temperature

III.11.1 Terms and definitions

Ground temperature (T_g)
is the energy from the sun to the collector, measured in Celsius degrees.

Depth (z)
is the depth which has the wall or the floor into the ground, measured in meters.

Average ground temperature (T_m)
is the average ground temperature of the year, measured in Celsius degrees.

Day of the year (n)
is the day of the year (1-365 or 366).

The annual variation of the ground temperature (A_s)
is the annual variation in the surface temperature of the ground, measured in Celsius degrees.

Ground diffusion coefficient (α)
is diffusion coefficient of the ground, measured in square meters per day.

Day of the year with minimum ground temperature (n_o)
is day of the year which the ground temperature is minimum.

III.11.2 Calculate the ground temperature

A key parameter for exploiting the thermal properties of the soil is its temperature at different depths. Ideally, this ground temperature at different depths should be measured. In practice, however, very few meteorological stations measure the surface temperature of the ground, while even fewer carry out in-depth measurements.

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given an equation to calculate the ground temperature (T_g) [14]:

$$T_g = T_m - A_s \exp[-z(\frac{\pi}{365\alpha})^{1/2}]\cos[(\frac{2\pi}{365})(n - n_o - \frac{z}{2}(\frac{365}{\pi\alpha})^{1/2})][^{o}C]$$

Where,

$$\alpha = \frac{k}{\rho x c_p}[\frac{m^2}{day}]$$

According to T.O.T.E.E. the average ground temperature of the year (T_m) can be assumed to be equal to average external temperature (T_{db}) [14]. Moreover the day of the year with minimum ground temperature (n_o) according to T.O.T.E.E. is equal to the 30 of January, that means n_o=30 [14].

III.12 Automatic control

The use of automatic control devices results in a significant reduction in energy consumption per end-use (heating, cooling, etc.). Automatic control devices may be local or central. The local controls are capable of controlling and regulating the operation of a single system such as a pump (via inverter) to regulate the operating speed of some loads, a radiator (via a thermostatic valve) or the distribution network (via thermostat compensation for temperature adjustment of the working fluid) or a luminaire (with local presence sensor) etc. Correspondingly, BEMS (Building Energy Management Systems) are used for the complete control of a space heating and/or space cooling and/or air conditioning and/or lighting heating plant and so on.

In case the heating, cooling, air conditioning, hot water, lighting, etc. (centralized or local), the energy required to meet the required loads per end-use is reduced and this reduction has to be determined in the calculation. Conversely, when there is no automatic control device, the energy meet the required loads are increased. The percentage of reduction or increase in energy required is calculated on the basis of the correction factor (f_{BAC}), reduction or increase, of energy per end-use, heating , cooling, ventilation, etc. According to ΕΛΟΤ EN 15232:2007 [33], two correction factors are proposed, one for the correction of the required thermal and/or refrigerant load and one for the correction of the final electrical consumption of the auxiliary system. The value of the correction factor is determined on the type of the automatic control devices and the number of electrical and mechanical building installations of the building being controlled.

In ΕΛΟΤ EN 15232:2007 [33], four categories of automatic control devices. A, B, C and D, are defined. In order to be classified as an automatic control device belonging to category C, it should meet all individual provisions automation or better than those listed in the next table, and concern heating/cooling units, ventilation units, distribution network, terminal units, etc., if they are in the building and automation is necessary. If all the conditions (individual automatic devices) of a category are not met then it is assumed that the total automation device of the building or thermal zone belongs to the previous category.

Description of control devices by category	Category
Thermal inertial heating, cooling and cooling systems (heaters, under floor heating, chilled ceilings). 1. Automatic independent control of the operation of terminal units per zone and operating space. Thermostat and/or thermostatic valves exist per operating space and ON-OFF control per zone. 2. Automatic temperature adjustment of the distribution network to the heat/cool loads with demand correction, by application of devices such as: temperature compensation system or variable temperature heating/cooling generation unit supply to the distribution network according to the thermal/refrigerant load of the individual spaces and the external temperature. 3. Automatic hydraulic adjustment of pumps according to thermal/refringent load. 4. In the case of a sequence between different heating / cooling units, the priority is based on the efficiency of the production units (nominal thermal / refrigerant load and degree of efficiency). **Other systems for the production, distribution and transmission of heating / cooling (fancoils, air systems).** 1. Integrated device for automatic control of the operation of terminal units at the level of autonomous spaces per property (per functional area) with user presence control (motion detection systems etc.). Exceptions are uses with a continuous presence such as all public, health and welfare, commerce, and communal and auxiliary areas of all uses. 2. Automatic temperature adjustment of the distribution network to the heat/cool loads with demand-based correction, by application of devices such as: temperature compensation system or variable temperature heating/cooling generation unit supply to the distribution network according to the thermal/refrigerant load of the individual spaces and the external temperature. 3. Automatic hydraulic adjustment of pumps according to thermal/refringent load. 4. In the case of a sequence between different heating / cooling units, the priority is based on the efficiency of the production units (nominal thermal / refrigerant load and degree of efficiency).	**A**
Thermal inertial heating, cooling and cooling systems (heaters, under floor	**B**

heating, chilled ceilings). 1. Automatic independent control of the operation of the terminal units per operating space. Thermostat and/or thermostatic valves exist per operating space, etc. 2. Automatic temperature adjustment of the distribution network to the heat/coolant loads, using devices such as: temperature compensation system or heat/cool units with variable temperature supply to the distribution network according to the external temperature. 3. Automatic hydraulic adjustment of pumps according to thermal/refringent load. 4. In case of a sequence between different heating/cooling units, the priority is based on the loads and the efficiency of the production units (nominal heat/coolant load). **Other systems for the production, distribution and transmission of heating / cooling (fancoils, air systems).** 1. Independent automatic control of the operation of the terminal units at the level of autonomous spaces per property (per functional area). Thermostat exists per operating space, etc. 2. Automatic temperature adjustment of the distribution network to the heat/refrigerant loads with demand-based correction by application of devices such as: temperature compensation system or variable-temperature heating/cooling production unit supply to the distribution network according to the external temperature. 3. Automatic hydraulic adjustment of pumps according to thermal / refrigerant load. 4. In case of a sequence between different heating/cooling units, the priority is based on the loads and the efficiency of the production units (nominal heat/coolant load).	
Thermal inertial heating, cooling and cooling systems (heaters, under floor heating, chilled ceilings). 1. Automatic central control of plant operation via thermostat or timer. 2. Automatic temperature adjustment of the distribution network to the heat/coolant loads, using devices such as: temperature compensation system or heat-cooling/cooling unit with variable temperature supply to the distribution network according to the external temperature. 3. Automatic control ON / OFF of pumps operation via thermostat or timer. 4. In the case of a sequence between different heating/cooling units, priority is based only on thermal/refrigerant loads. **Other systems for the production, distribution and transmission of heating / cooling (fancoils, air systems).** 1. Automatic central control of plant operation via thermostat or timer 2. Automatic temperature adjustment of the distribution network to	**C**

heat/coolant loads with correction according to the demand, by application of devices such as: temperature compensation system or variable temperature heating/cooling production unit supply to the distribution network according to the external temperature. 3. Automatic control ON / OFF of pumps operation via thermostat or timer. 4. In the case of a sequence between different heating/cooling units, priority is based only on thermal/refrigerant loads.	
Thermal inertial heating, cooling and cooling systems (heaters, under floor heating, chilled ceilings). 1. Control of terminal and distribution network operation is manual without room thermostats. 2. The control of the distribution network circulators is manual or without a timetable, without any feedback from the demand for heat/coolant load. 3. The heating/cooling production unit operates at a constant working fluid temperature to the distribution network. 4. In the case of a sequence between different heating/cooling units, the priority is not checked. **Other systems for the production, distribution and transmission of heating / cooling (fancoils, air systems).** 1. Control of terminal and distribution network operation is manual without room thermostats. 2. The control of the distribution network circulators is manual or without a timetable, without any feedback from the demand for heat/coolant load. 3. The heating/cooling production unit operates at a constant working fluid temperature to the distribution network. 4. In the case of a sequence between different heating/cooling units, the priority is not checked.	**D**

Table 49: Categories of control and automation devices [12]

The correction factor for heating and cooling for each climate zone show in the next table:

Uses of buildings or thermal zones	**Correction factor of heating ($f_{BAC,h}$) and cooling ($f_{BAC,c}$)**			
	A	**B**	**C**	**D**
Single-family home, block of flats (more than one apartment)	0.81	0.88	1.00	1.09
	Correction factor of auxiliary systems ($f_{BAC,e}$)			
Single-family home, block of flats (more than one apartment)	0.92	0.93	1.00	1.08

Table 50: Coefficients for the correction (reduction or increase) of energy consumption for heating /cooling ($f_{BAC,h}$ and $f_{BAC,c}$) and of electrical energy consumption of auxiliary heating/cooling systems ($f_{BAC,el}$), using automated control devices [12]

III.13 Primary energy and emissions (CO_2)

Prime energy is an energy from found in nature that has not been subjected to any human engineered conversion process. It is energy contained in raw fuels, and other forms of energy received as input to a system. Primary energy can be non-renewable or renewable.

Prime energy sources are transformed in energy conversion processes to more convenient forms of energy that can directly be used by society, such as electrical energy, refined fuels, or synthetic fuels such as hydrogen fuel.

Carbon dioxide (CO_2) enters the atmosphere through burning fossil fuels (coal, natural gas and oil), solid waste, trees and wood products, and also as a result of certain chemical reactions (e.g. manufacture of cement). Carbon dioxide is removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle [34].

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) has given values for the conversion factor of the final energy consumption of the building into prime energy as follow:

Energy source	**Conversion factor to primary energy**	**Emitted pollutants per unit of energy [kgCO_2/kWh]**
Natural gas	1.05	0.196
Heating oil	1.10	0.264
Electricity	2.90	0.989
Liquified gas	1.05	0.238
Biomass	1.00	-

Table 51: Conversion factor of the final energy consumption of the building into prime energy [12]

The next figure shows the procedure of the energy, from primary energy to heating/cooling space energy:

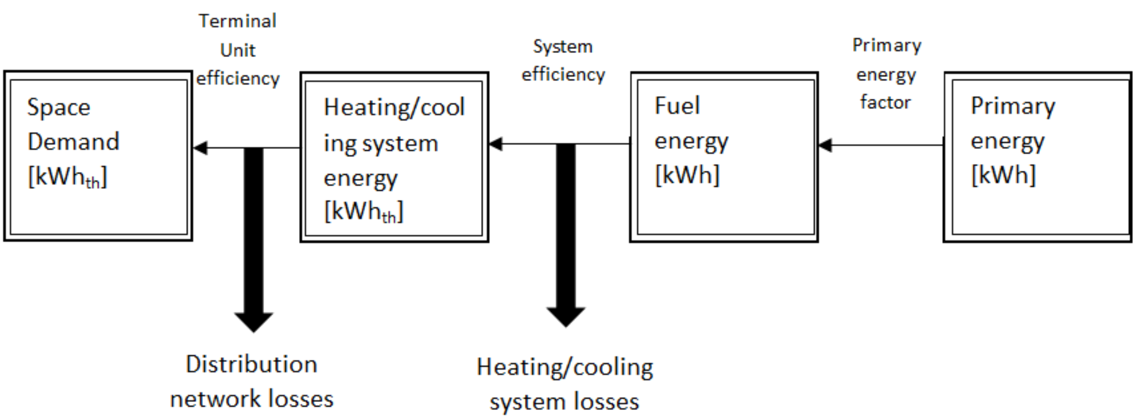

Figure 20: The procedure of the energy

IV. Development of methodology ISO 13790 in code

IV.1Simple hourly method of ISO 13790

IV.1.1 Terms and definitions

Heating set-point temperature ($\theta_{int,H,set}$)
is the set-point temperature for heating of the building zone, measured in Celsius degrees.

Cooling set-point temperature ($\theta_{int,C,set}$)
is the set-point temperature for cooling of the building zone, measured in Celsius degrees.

Coupling conductance between the air node and surface node ($H_{tr,is}$)
is the coupling conductance between the air node, θ_{air}, and the surface node, θ_s, measured in Watts per square meters Kelvin degrees.

Heat transfer coefficient between the air node and surface node (h_{is})
is the heat transfer coefficient between the air node, θ_{air}, and the surface node, θ_s, with fixed value of h_{is}=3.45 W/(m^{2}K) [23].

Ratio between thermal internal surfaces area and the floor area (Λ_{at})
is the dimensionless ratio between thermal internal surfaces area and the floor area; Λ_{at} can be assumed to be equal to 4.5 [23].

Thermal transmission coefficients of opaque building elements (H_{wall})
is the thermal transmission coefficients of opaque building elements which is split into $H_{tr,em}$ and $H_{tr,ms}$, measured in Watts per square meters Kelvin degrees.

Thermal transmission coefficients of window (H_{widow})
is the thermal transmission coefficients of window, measured in Watts per square meters Kelvin degrees.

Coupling conductance between the thermal mass node and surface node ($H_{tr,ms}$)
is the coupling conductance between the thermal mass node, θ_m, and the surface node, θ_s, measured in Watts per square meters Kelvin degrees.

Heat transfer coefficient between the thermal mass node and surface node (h_{ms})
is the heat transfer coefficient between the thermal mass node, θ_m, and the surface node, θ_s, with fixed value h_{ms}=9,1 [23].

Coupling conductance between the thermal mass node and the external node ($H_{tr,em}$)
is the coupling conductance between the thermal mass node, θ_m, and the external node, θ_e, measured in Watts per square meters Kelvin degrees.

Effective mass area (A_m)
is the effective mass area, measured in square meters.

Floor area (A_f)
is the floor area, measured in square meters.

Total area of all surfaces facing the building zone (A_{tot})
is the area of all surfaces facing the building zone, equal to Λ_{at} x A_f, measured in square meters.

Ventilation heat transfer (H_{ve})
is the thermal transmission coefficients of ventilation, measured in Watts per square meters Kelvin degrees.

Heat capacity of air per volume ($\rho_a c_a$)
is the heat capacity of air per volume, which is equal to 1200J/(m^3·K) [23].

Total ventilation air ($q_{v\text{-}total\text{-}air}$)
is the total ventilation air, measured in cubic meters per hour square meters.

Total gains ($gains_{total}$)
are the total gains from internal heat sources, measured in Watts per square meters.

Occupant gains (Occ_{gains})
are the gains from occupants, measured in Watts per square meters.

Appliance gains ($Appl_{gains}$)
are the gains from appliances, measured in Watts per square meters.

Total gains from lights ($Light_{gains}$)
are the gains from lights, measured in Watts per square meters.

Heat flow from internal heat sources (Φ_{int})
is the heat flow from internal heat sources, measured in Watts per square meters.

Heat flow rate from solar (Φ_{sol})
is the heat flow rate from solar heat sources in the considered building zone, measured in Watts per square meters.

Heat flow from thermal mass node (Φ_m)
is the heat flow from the thermal mass node, θ_m,, measured in Watts per square meters.

Heat flow from surface node (Φ_{st})
is the heat flow from the surface node, θ_s,, measured in Watts per square meters.

Heating or cooling need ($\Phi_{HC,nd}$)
is the heating or cooling need to reach the required set-point, is positive for heating and negative for cooling, measured in Watts per square meters.

Supply temperature (θ_{sup})
is the supply temperature of the ventilation air which is equal to the external temperature, θ_e, measured in Celsius degrees.

Thermal mass temperature ($\theta_{m,t}$)
is the temperature from the thermal mass, measured in Celsius degrees

Heat capacity (C_m)
modulus of the net periodic thermal conductance divided by angular frequency, measured in Joules per Kelvin degrees.

External temperature (θ_e)
is the external temperature which is equal to Dry-bulb temperature (T_{db}) or ground temperature (θ_g), depends on where is the external surface of the opaque, measured in Celsius degrees.

Ground temperature (θ_g)
is the temperature from ground, measured in Celsius degrees.

Internal surface temperature (θ_s)
is the temperature from the internal surfaces, measured in Celsius degrees.

Air temperature (θ_{air})
is the internal temperature of the building, measured in Celsius degrees.

Actual internal temperature ($\theta_{air,ac}$)
is the actual internal temperature, measured in Celsius degrees.

Operative temperature (θ_{op})
is the operative temperature, measured in Celsius degrees.

Ground temperature (θ_g)
is the energy from the sun to the collector, measured in Celsius degrees.

Annual energy needs for space heating ($Q_{H,nd}$)
are the annual energy needs for space heating the building under study requires, measured in Watts per square meters.

Annual energy needs for space cooling ($Q_{C,nd}$)
are the annual energy needs for space cooling the building under study requires, measured in Watts per square meters.

Terminal unit efficiency ($N_{em,t}$)
is the efficiency of the terminal unit.

Boiler-burner efficiency (η_{gen})
is the overall efficiency of the boiler-burner.

Average seasonal efficiency index (SEER)
is the average seasonal efficiency index.

Correction factor (f_{BAC})
is the correction factor of energy consumption which depends on automatic controls.

Subscripts:

0: when there is no required cooling or heating.

10: when there is required cooling or heating, taking cooling or heating power of 10 W/m^2

ac: are the actual variables.

un: is the unrestricted variables.

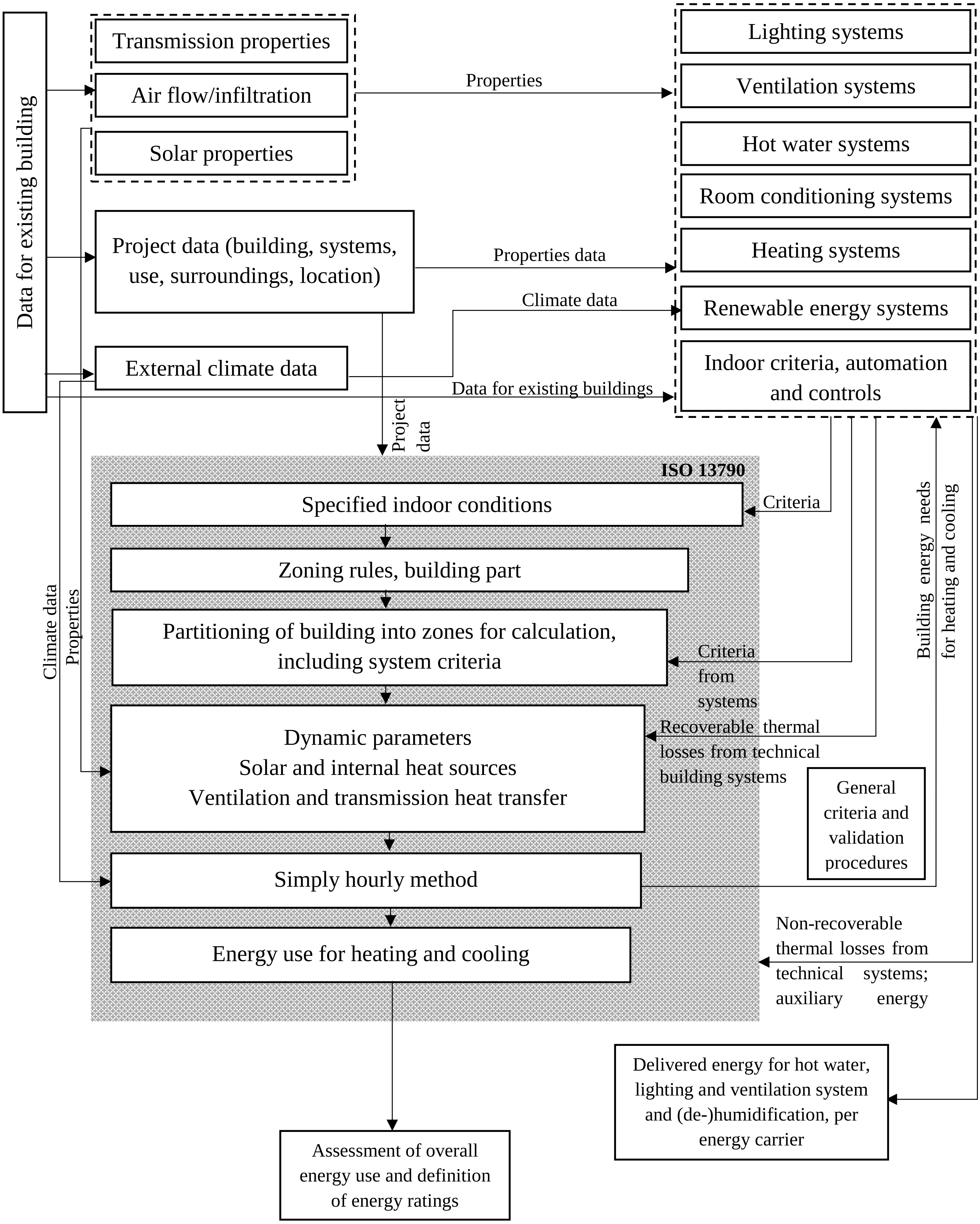

Figure 21: Flow chart of calculation procedure and links with other standards

Upon figure gives an outline of the calculation procedure and its links with other energy performance-related standards.

IV.1.2 Simple hourly method of EN ISO 13790

IV.1.2.1 Introduction

The simple hourly method presents a simplification of a dynamic situation with a chosen limited amount of equations with the intention to reduce the amount of input data as much as possible. It is possible to integrate new development easily as the physical behavior of the building can be implemented directly. The simple hourly method is based on a 5 resistance- 1capacitance (5R-1C) model, depicted in the next figure.

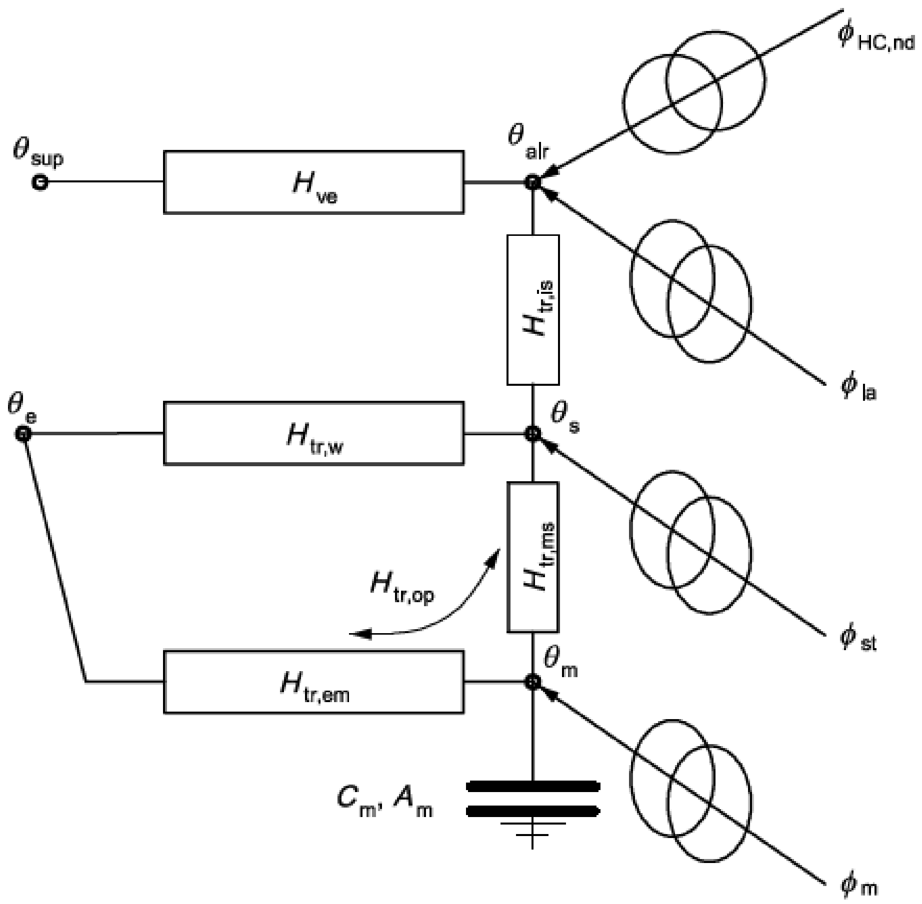

Figure 22: RC network heat flows

The heating or cooling power ($\Phi_{HC,nd}$) is supplied to or extracted from the internal air node (θ_{air}) to maintain a certain set-point indoor air temperature: $\theta_{int,H,set}$ for heating or $\theta_{int,C,set}$ for cooling.

The heat flow rates due to internal heat sources (Φ_{int}) and due to solar heat sources (Φ_{sol}) are split into three parts. These are: Φ_{ia}, Φ_{st} and Φ_m connected to the indoor air (θ_{air}), the internal surface (θ_s) and the thermal mass (θ_m) temperature nodes, respectively.

The heat transfer coefficient by ventilation (H_{ve}) is connected to the supply air temperature (θ_{sup}) and the internal air temperature. For the purposes of the energy performance certification of buildings where energy needs for heating or cooling ($\Phi_{HC,nd}$) should obtain energy requirements of HVAC and room system mutually, the supply air temperature (θ_{sup}) is equal to the external air temperature (θ_e).

$H_{tr,window}$ is the transmission heat transfer coefficient for windows, taken as having zero thermal mass. The transmission heat transfer coefficient for opaque elements ($H_{tr,wall}$) is split into the external ($H_{tr,em}$) and the internal ($H_{tr,ms}$) part, connected to the single thermal capacity (C_m), representing the building (zone) thermal mass. The internal air node (θ_{air}) and the internal surface node (θ_s) are connected though the coupling conductance.

IV.1.2.2 Main variables

The coupling conductance, $H_{tr,is}$, can be calculated by the next equation:

$$H_{tr,is} = h_{is}A[W/K] \quad \text{where, } A_t = \Lambda_{at}\sum A_f\,[m^2]$$

The split of the transmission heat transfer coefficient for opaque elements $H_{tr,wall}$ into $H_{tr,em}$ and $H_{tr,ms}$:

$$H_{tr,ms} = \frac{h_{ms}A_m}{\sum A_f}[W/m^2K]$$

$$H_{tr,em,wall} = \frac{1}{\frac{1}{H_{tr,wall}} - \frac{1}{H_{tr,ms}}}[W/m^2K] \qquad \text{or } H_{tr,em,floor} = \frac{1}{\frac{1}{H_{tr,floor}} - \frac{1}{H_{tr,ms}}}[W/m^2K]$$

The value for the overall ventilation heat transfer coefficient, $H_{ve,adj}$, can be calculated by the next equation:

$$H_{ve} = \frac{\rho_a c_a}{3600} q_{v-total-air}\,[W/m^2K]$$

IV.1.2.3 Calculation of heat flows from internal and solar heat sources

The heat flow rates from internal heat sources Φ_{int} and solar heat sources Φ_{sol} can be calculated by the next equations:

$$\Phi_{int} = gains_{total} = Occ_{gains} + Appl_{gains} + Light_{gains} \text{ [W]}$$

$$\Phi_{sol} = \Phi_{sol,window} + \Phi_{sol,wall} \text{ [W]}$$

The heat flow rates from internal and solar heat sources Φ_{int} and Φ_{sol}, expressed in watts, are split between the air node, θ_{air}, and the internal nodes, θ_{int}, θ_m, as follows:

$$\Phi_{ia} = 0,5\Phi_{int} \text{ [W]} \qquad \text{(C.1)}$$

$$\Phi_m = \frac{A_m}{A_t}(0,5\Phi_{int} + \Phi_{sol}) \text{[W]} \qquad \text{(C.2)}$$

where,

$$A_t = \Lambda_{at} \sum A_f \text{ [m}^2\text{]}$$

$$\Phi_{st} = (1 - \frac{A_m}{A_t} - \frac{H_{tr,window}}{9,1A_t})(0,5\Phi_{int} + \Phi_{sol}) \text{[W]} \qquad \text{(C.3)}$$

IV.1.2.4 Determination of the air and operative temperatures for a given value of $\Phi_{HC,nd}$

The solution model is based on a Crank-Nicholson scheme considering a time step of one hour. The temperatures are the average over one hour except for $\theta_{m,t}$ and $\theta_{m,t-1}$ which are instantaneous values at time *t* and *t-1*

For the given step $\theta_{m,t}$, expressed in degrees centigrade, is calculated at the end of the time step from the previous value $\theta_{m,t-1}$ by:

$$\theta_{m,t} = \frac{\theta_{m,t-1}[\frac{C_m}{A_f 3600} - 0,5(H_{tr,3} + H_{tr,em,wall} + H_{tr,em,floor})] + \Phi_{mtot}}{\frac{C_m}{A_f 3600} + 0,5(H_{tr,3} + H_{tr,em,wall} + H_{tr,em,floor})} [^oC] \qquad \text{(C.4)}$$

with

$$\Phi_{mtot} = \Phi_m + H_{tr,em,wall}\theta_e + H_{tr,em,floor}\theta_g + \frac{H_{tr,3}[\Phi_{st} + H_{tr,window}\theta_e + \frac{H_{tr,1}(\Phi_{ia} + \Phi_{HC,nd})}{H_{ve}} + \theta_{sup}]}{H_{tr,2}} \text{[W]} \qquad \text{(C5)}$$

For the considered time step, the average values of nodes temperatures are given by:

$$\theta_m = \frac{\theta_{m,t} + \theta_{m,t-1}}{2} [^o C] \quad \text{(C9)}$$

$$\theta_s = \frac{H_{tr,ms}\theta_m + \Phi_{st} + H_{tr,window}\theta_e + H_{tr,1}(\theta_{sup} + \frac{\Phi_{ia} + \Phi_{HC,nd}}{H_{ve}})}{H_{tr,ms} + H_{tr,window} + H_{tr,1}} [^o C] \quad \text{(C10)}$$

$$\theta_{air} = \frac{H_{tr,is}\theta_s + H_{ve}\theta_{sup} + \Phi_{ia} + \Phi_{HC,nd}}{H_{tr,is} + H_{ve}} [^o C] \quad \text{(C11)}$$

and the operative temperature by

$$\theta_{op} = 0.3\theta_{air} + 0.7\theta_s [^o C] \quad \text{(C12)}$$

NOTE This is an approximation. The operative temperature is a weighted average of the air and mean radiant temperatures, weighted by the internal surface convective (3/8) and radiative coefficients (5/8). The value of θ_s is a mix between air and mean radiant temperature.

IV.1.2.5 Calculation of internal temperature and required heating or cooling power

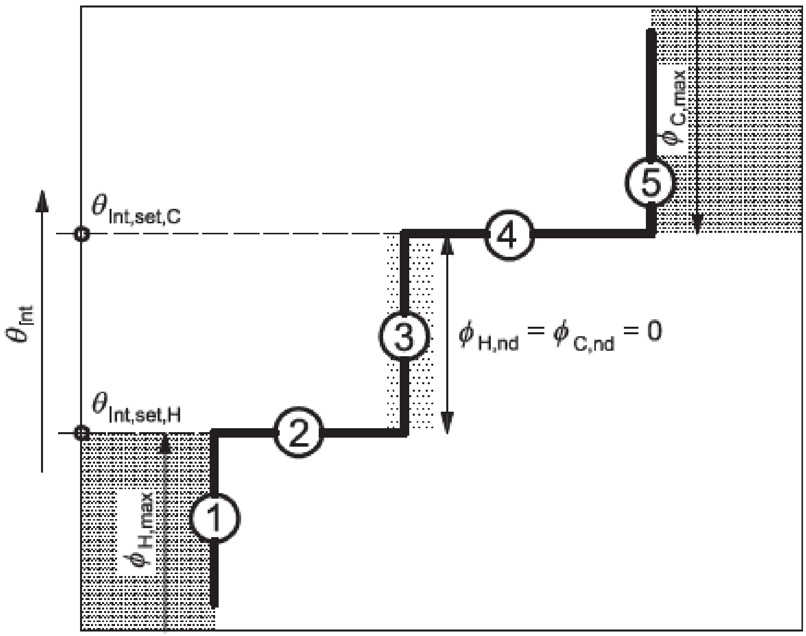

Figure 23: Building zone temperature behavior versus system behavior

For each hour, the RC network enables the calculation of the internal temperature for any amount of heating or cooling need, $\Phi_{HC,nd}$. The resolution scheme is such that the internal temperature is determined as a linear function of $\Phi_{HC,nd}$.

For a given hour, the building zone behavior line is known by applying equations described in Clause C.3 for two values of $\Phi_{HC,nd}$.

The heating and cooling power delivered to the building zone can be represented on the same graph by the $\theta_{in,H,set}$ and $\theta_{in,C,set}$ temperatures and the maximum available heating and cooling power (which can vary for each hour)

The resulting indoor temperature and heating and cooling needs are derived from the intersection of the two curves.

Five situations can occur:

1) The building zone requires heating and the heating power is not sufficient to obtain the set-point. The heating need is limited to the maximum available heating power and the calculated internal temperature is lower than the heating set-point $\theta_{in,H,set}$. This usually happens in the boost period.

2) The building zone requires heating and the heating power is sufficient. The internal temperature is equal to $\theta_{in,H,set}$ and the calculated heating need is lower than its maximum value.

3) The building zone requires neither heating nor cooling (free floating conditions). No heating or cooling is applied, and the internal temperature is calculated.

4) The building zone requires cooling and the cooling power is sufficient. The internal temperature is equal to $\theta_{in,C,set}$ and the calculated cooling need is lower than its maximum value.

5) The building zone requires cooling and the cooling power is not sufficient. The cooling need is limited to the maximum available cooling power. The calculated internal temperature is higher than the cooling setpoint $\theta_{in,C,set}$.

T.O.T.E.E. (Technical Instruction of Technical Department of Greece) [12] identified the cooling and heating set points and the number of hours that are apply as follow:

Category of building	**$\theta_{in,C,set}$ [°C]**	**$\theta_{in,C,set}$ [°C]**	**Working hours**	**Operation days per week**	**Operation period in months**
f**or a single-family home, block of flats (more than one apartment)**	26	20	18	7	12

The schedule of the temperature set points is equal to schedule of the occupants because the heating/cooling system are working when the habitants are home.

IV.1.3 Calculated heating and cooling needed

IV.1.3.1 Initialization of variables

The Simple hourly method of EN ISO 13790 is based on the previous hour, so initialization is needed for some variables.

$$\theta_{m,t} = \theta_{int,H,set} [^oC]$$

$$\Phi_{C,nd,ac_0} = 0[W]$$

$$\Phi_{HC,nd_{10}} = 0[W]$$

IV.1.3.2 Calculation procedure

The procedure in this subclause is based on the air temperature, θ_{air}, as set-point temperature. To use the operative temperature as set-point, the operative temperature shall be calculated (see Equation C.11) and the procedure given in this subclause shall be adapted accordingly.

The procedure calculates the actual internal temperature, $\theta_{air,ac}$, and the actual heating or cooling power, $\Phi_{HC,nd,ac}$. In all cases, the value of $\theta_{m,t}$ [see Equation (C.8)] is also calculated and stored, as it is used for the following time step.

Step 1: Check if cooling or heating is needed (case 3 of Figure C.2).

Take $\Phi_{HC,nd} = 0[W]\theta$ and apply Equations (C.7) to (C.11).

Name the resulting θ_{air} as $\theta_{air,0}$ ($\theta_{air,0}$ is the air temperature in free floating conditions).

If $\theta_{int,H,set} \leq \theta_{air,0} \leq \theta_{int,C,set}$, no heating or cooling is required so that $\Phi_{HC,nd,ac} = 0[W]$, $\Phi_{HC,use} = 0[W]$ $\theta_{air,ac} = \theta_{air,0} [^oC]$ and $\theta_{air,set} = \theta_{air,0} [^oC]$ and no further calculations are needed.

If not: apply step 2.

Step 2: Choose the set-point and calculate the heating or cooling need.

If $\theta_{air,0} > \theta_{int,C,set}$ take $\theta_{air,set} = \theta_{int,C,set} [^oC]$

If $\theta_{air,0} < \theta_{int,H,set}$ take $\theta_{air,set} = \theta_{int,H,set} [^oC]$

NOTE 1 Conditions might have to be added to separate the set-pos (hysteresis), to prevent oscillations.

2) The scheme could be modified to take into account a maximum heating or cooling power depending on internal temperature.

Apply Equations (C.7) to (C.11) taking $\Phi_{HC,nd} = \Phi_{HC,nd,10} [W]$ with $\Phi_{HC,nd,10} = 10A_f [W]$.

Name the resulting θ_{air} as θ_{air10} (θ_{air10} is the air temperature obtained for a heating power of 10).

Calculate $\Phi_{HC,nd,un}$ (unrestricted heating or cooling need to reach the required set-point temperature; $\Phi_{HC,nd,un}$ is positive for heating and negative for cooling).

$$\Phi_{HC,nd,un} = \frac{\Phi_{HC,nd10}(\theta_{air,set} - \theta_{air,0})}{\theta_{air,10} - \theta_{air,0}} [W] \qquad (C.13)$$

Step 3: Check if the available cooling or heating power is sufficient (case 2 or case 4 of Figure C.2).

If $\Phi_{HC,nd}$ is between $\Phi_{H,max}$ (maximum heating power) and $\Phi_{C,max}$ (maximum cooling power):

$$\Phi_{HC,nd,ac} = \Phi_{HC,nd,un} [W]$$

$$\Phi_{HC,use} = \Phi_{HC,nd,un} [W]$$

$$\theta_{air,ac} = \theta_{air,set} [^{o}C]$$

$$\theta_{s} = \frac{H_{tr,ms}\theta_{m} + \Phi_{st} + H_{tr,window}\theta_{e} + H_{tr,1}(\theta_{sup} + \frac{\Phi_{ia} + \Phi_{HC,nd,ac}}{H_{ve}})}{H_{tr,ms} + H_{tr,window} + H_{tr,1}} [^{o}C] \qquad (C10)$$

$$\theta_{air,ac} = \frac{H_{tr,is}\theta_{s} + H_{ve}\theta_{sup} + \Phi_{ia} + \Phi_{HC,nd,ac}}{H_{tr,is} + H_{ve}} [^{o}C]$$

and the calculation is completed.

If not: apply step 4.

Step 4: Calculate the internal temperature (case 1 or case 5 of Figure C.2).

If $\Phi_{HC,nd,un}$ is positive, take $\Phi_{HC,nd,ac} = \Phi_{H.max} [W] \text{and} \Phi_{HC,use} = \Phi_{H,max} [W]$.

If $\Phi_{HC,nd,un}$ is negative, take $\Phi_{HC,nd,ac} = \Phi_{C.max} [W] \text{and} \Phi_{HC,use} = \Phi_{C,max} [W]$.

Calculate $\theta_{air,ac}$ by using Equations (C.5) to (C.9).

NOTE 2 In this case, the set-point temperature is not attained.

So,

Heating needed is $\Phi_{H,nd,ac} = \max(0, \Phi_{HC,nd,un}) [W]$

Cooling needed is $\Phi_{C,nd,ac} = -\min(0, \Phi_{HC,nd,un}) [W]$

Heating used is $\Phi_{H,use} = \frac{\max(0, \Phi_{HC,use}) f_{BAC}}{N_{emT}(1 - losses_{boiler})\eta_{gen}} ([W]$

Cooling used is $\Phi_{C,use} = -\frac{\min(0, \Phi_{HC,use}) f_{BAC}}{N_{emT}(1 - losses_{coolingSystem})SEER} [W]$

Internal temperature is $\theta_{int} = \theta_{air,ac} [^{o}C]$

IV.1.3.3 Annual heating and cooling needed

The annual energy heating needs that the building under study requires:

$$Q_{H,nd} = \sum \frac{\Phi_{H,nd,ac}}{1000 A_f} \; [\frac{kWh}{m^2}]$$

The annual energy cooling needs that the building under study requires:

$$Q_{C,nd} = \sum \frac{\Phi_{C,nd,ac}}{1000 A_f} \; [\frac{kWh}{m^2}]$$

The annual energy heating that the building under study uses:

$$Q_{H,use} = \sum \frac{\Phi_{H,use}}{1000 A_f} [\frac{kWh}{m^2}]$$

The annual energy cooling that the building under study uses:

$$Q_{C,use} = \sum \frac{\Phi_{C,use}}{1000 A_f} \; [\frac{kWh}{m^2}]$$

V. Validation with different building simulation software

V.1 The Benchmark Building

In order to assess the accuracy of the results provided by simplified model developed in the current thesis, a case study was carried out and the obtained results were compared with corresponding results from T.E.E. K.Eν.A.K. software and TRNSYS.

The building used for the benchmarking among the different simulation software (next called Benchmark Building) was built between 1980 and 2000. For more details about the construction of the house, see Annex A

V.2 Comparison with T.E.E. K.Eν.A.K. software

The calculation results of the developed software were compared with the T.E.E. K.Eν.A.K software. Since the operating conditions of the heating and cooling systems in both cases must agree, a 18h heating schedule and 24h cooling schedule were supposed for the Benchmark Build, as explained in detail in the following sub section

V.2.1 Intermittent operation considerations for T.E.E. K.Eν.A.K. software

The software of T.E.E. K.Eν.A.K. uses the EN ISO 13790 monthly method for the calculation of heating and cooling power consumption. According to T.O.T.E.E. (Technical Instruction of Technical Department of Greece) [12], in the case of buildings with a discontinuous operation, less than 24 hours a day and/or less than 7 days a week, the intermittent operation according to ΕΛΟΤ EN 13790:2009 is taken into account for energy efficiency calculations of buildings. Because the breakdown criteria set out in paragraph 13.2.1.2. of the ISO 13790 have not been determined and verified at national level, the calculation of the non-dimensional reduction coefficient for an intermittent heating and cooling period, as described in paragraph 13.2.2. of the ISO 13790.

According to the paragraph 13.2.2. of the ISO 13790, the energy need for cooling, $Q_{C,nd,interm}$, expressed in megajoules, is calculated as given by the next equation:

$$Q_{C,nd,interm} = \alpha_{C,red} Q_{C,cont} \text{ [MJ]}$$

where

- $Q_{C,nd,cont}$ is the energy need for cooling when the cooling set point temperature is not changed during the day (cooling set point for 24 hours per day) expressed in megajoules
- $\alpha_{C,red}$ is the dimensionless reduction factor for intermittent cooling

The dimensionless reduction factor for intermittent cooling, $\alpha_{C,red}$, is calculated as given by the next equation:

$$\alpha_{C,red} = 1 - b_{C,red} \frac{\tau_{C,0}}{\tau} \gamma_C (1 - f_{C,day})$$

With minimum value: $\alpha_{C,red}=f_{C,day}$ and maximum value $\alpha_{C,red}=1$

$f_{C,day}$ is the fraction of the number of days in the week with, at least during daytime, normal cooling set-point (no reduced set-point or switch-off).

According to T.O.T.E.E. [12], for a single-family home, block of flats (more than one apartment), the cooling is working 7 days per week. So, the fraction $f_{C,day}$ is equal to. That means that the energy need for cooling is equal to the cooling energy need when the cooling set point temperature is not changed during the day (cooling set point for 24 hours per day).

So, the T.E.E. K.Eν.A.K. software calculate the cooling need with cooling set point ($\theta_{int.C.set}=26^oC$) for 24 hours per day.

For the heating need, the $\alpha_{H,red}$ is not equal to 1 [23], so T.E.E. K.Eν.A.K. software calculate the heating need for 18 hours per day, as the thesis' software does, according to K.Eν.A.K. [12]. The same operating schedule was assumed for the case ran in the Thesis' simulation software.

V.2.2 Comparison results

As stated above, the major difference between the T.E.E. K.Eν.A.K. software and the Thesis' software is that former uses a simplified monthly simulation in contrast with the latter; which uses an hourly time step. Furthermore, for the calculation of heating and cooling loads, T.E.E. K.Eν.A.K. software uses specific periods for heating and cooling depending on the climate:

- For the climate zone A and B the thermal period is between November 1 and April 15 and the cooling period is between May 15 and September 15
- For the climate zone C and D the thermal period is between October 15 and April 30 and the cooling period is between June 1 and August 31

The monthly energy demand for cooling and heating for both software are shown in the next table:

	T.E.E. K.Evν.A.K. software		Thesis' software	
Month	**Heating demand [kWh/m²]**	**Cooling demand [kWh/m²]**	**Heating demand [kWh/m²]**	**Cooling demand [kWh/m²]**
January	26.9	0	19.57	0
February	21.2	0	19.52	0
March	16.5	0	15.18	0
April	2.6	0	5.94	0
May	0	2.1	0.60	1.53
June	0	15	0	11.92
July	0	24.6	0	19.37
August	0	21.8	0	19.82
September	0	3.3	0	8.46
October	0	0	0.37	0.56
November	10.3	0	8.80	0
December	21.9	0	19.21	0
Total	99.4	66.8	89.19	61.66

Table 52: Monthly energy demand for cooling and heating according to T.E.E. K.Evν.A.K. software and Thesis' software

As the above table shows, the Thesis' software and the T.E.E. K.Evν.A.K.software predictions in terms of the energy need for heating/cooling differ a bit (7-10% deviation on annual basis).

The next figures show the monthly energy demand for heating/cooling and the average external temperature per month as calculated from Thesis' software and T.E.E. K.Evν.A.K. software. Dashed lines refer to the external temperature and the solid lines to the heating demand.

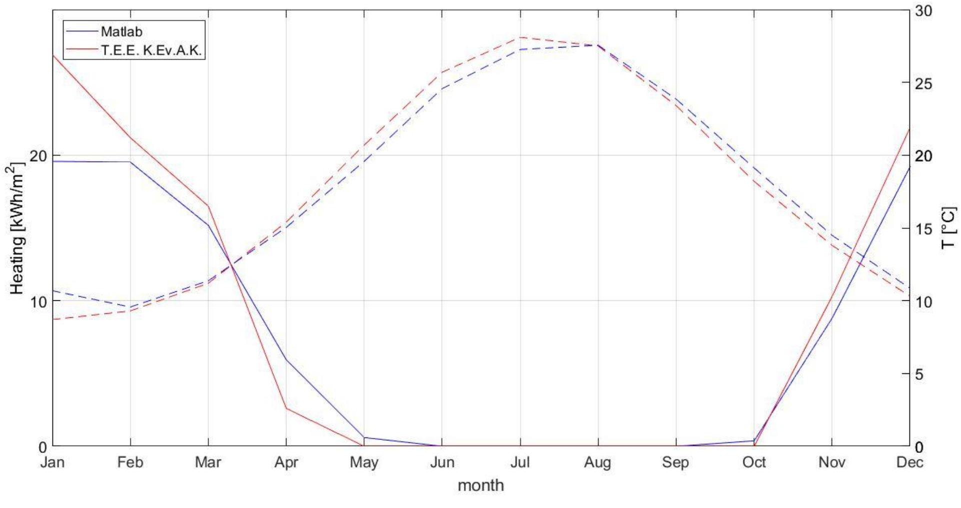

Figure 24: Monthly energy demand for heating according to T.E.E. K.Evν.A.K. and Thesis software

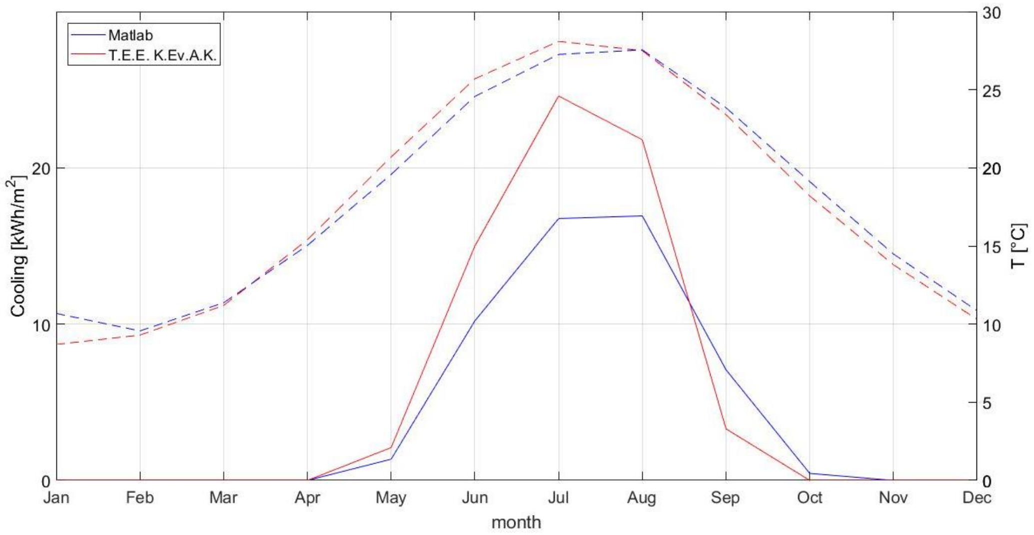

Figure 25 Monthly energy demand for cooling according to T.E.E. K.Ev.A.K. and Thesis software

In some months, due to averaging of the weather data, the energy need for cooling obtained by two methods, distinguish a lot. This is rational, since the weather data inputs of each software differ. As a result, in order to make a more fair comparison, the external Dry Bulb Temperature data provided in the Thesis software were modified in order to match the monthly average values provided by T.O.T.E.E. 3 [35] for Athens (New Philadelpheia weather station), by superposing the difference between the monthly average values dived by the hours of each month on the hourly temperature data used as input in the Thesis software.

The next table and figures show the monthly energy demand for cooling and heating, for the calibrated external temperature hourly data. Dashed line is for the external temperature and the solid line is for heating demand.

	T.E.E. K.Ev.A.K. software		**Thesis' software**	
Month	**Heating demand [kWh/m²]**	**Cooling demand [kWh/m²]**	**Heating demand [kWh/m²]**	**Cooling demand [kWh/m²]**
January	26.9	0	25.02	0
February	21.2	0	20.2	0
March	16.5	0	15.62	0
April	2.6	0	5.38	0.02
May	0	2.1	0.3	2.82
June	0	15	0	14.63
July	0	24.6	0	21.72
August	0	21.8	0	19.83
September	0	3.3	0	7.45
October	0	0	0.99	0.31
November	10.3	0	10.41	0
December	21.9	0	20.72	0
Total	99.4	66.8	98.64	66.78

Table 53: Monthly energy demand for cooling and heating according to T.E.E. K.Ev.A.K. and Thesis' software with the same average monthly temperature

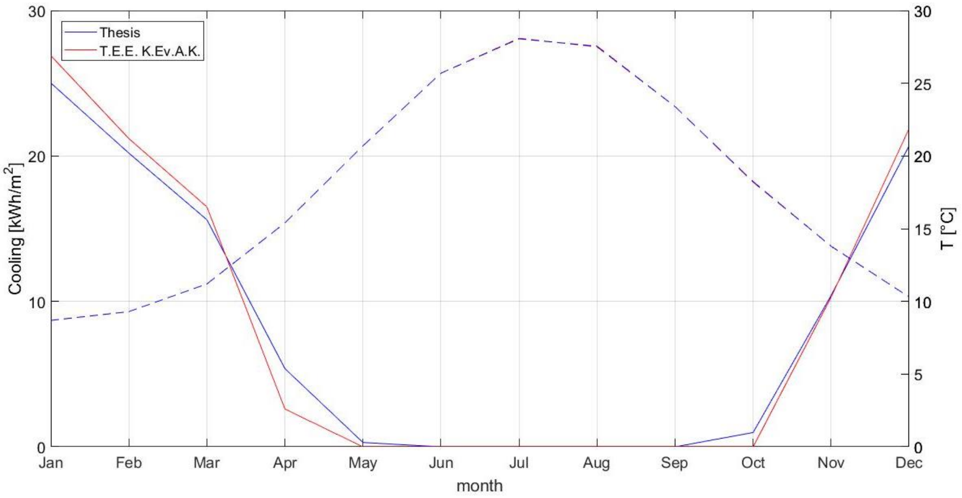

Figure 26: Monthly energy demand for heating according to T.E.E. K.Eν.A.K. and Thesis software with the same average monthly temperature.

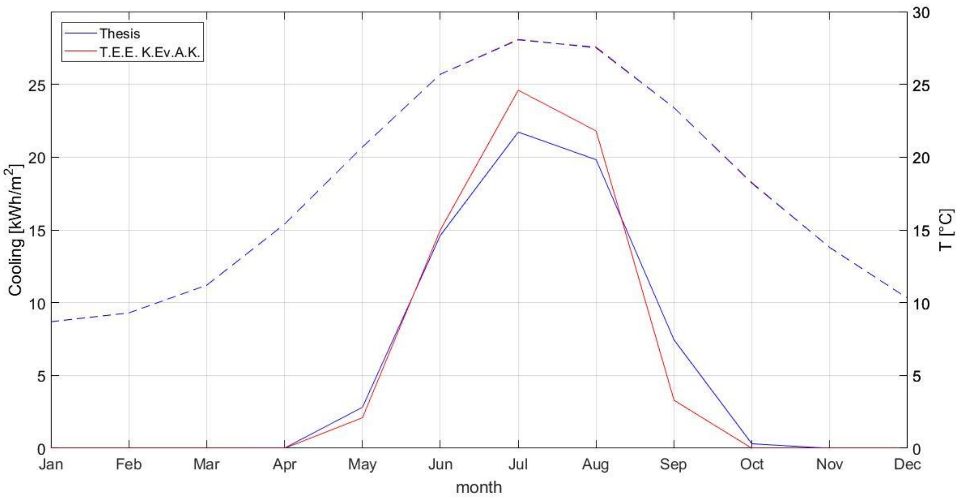

Figure 27: Monthly energy demand for cooling according to T.E.E. K.Eν.A.K. and Thesis' software with the same average monthly temperature

As above figures show, with the calibrate of external temperature, the T.E.E. K.Eν.A.K. and the Thesis' software predict the same energy need for heating/cooling (difference on annual basis 1%). The differences can be attributed to the period heating and cooling that the T.E.E. K.Eν.A.K. software is used and because of the difference in radiation data which are not available from T.O.T.E.E.. It becomes obvious the Thesis' software results validity.

V.3 Comparison with TRNSYS

Both of TRNSYS software and Thesis' software use the hourly simplified method. In order to have a more accurate intercomparison, the software of Thesis uses the same weather data as TRNSYS software. The comparison between TRNSYS' and thesis' software has been implemented for the house described Annex A, but with the quantity of windows equal to 1. Following the figure of the house as it has been designed by TRNSYS.

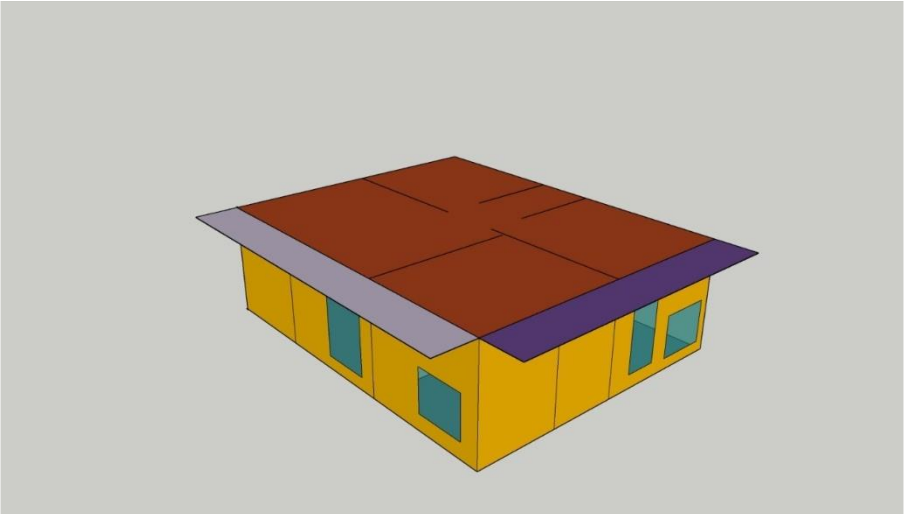

Figure 28: The under studied house as designed by TRNSYS

The monthly energy demands calculated for cooling and heating using each software are shown in the next table:

	TRNSYS' software		**Thesis' software**	
Month	**Heating demand [kWh/m^2]**	**Cooling demand [kWh/m^2]**	**Heating demand [kWh/m^2]**	**Cooling demand [kWh/m^2]**
January	20.05	0	20.47	0
February	17.80	0	17.66	0
March	14.76	0	15.03	0
April	4.73	0	6.22	0
May	0.17	0.03	0.84	0.48
June	0	3.32	0	3.89
July	0	10.40	0	9.69
August	0	10.82	0	9.57
September	0	4.01	0	3.34
October	0.77	0.4	1.64	0.11
November	6.56	0	7.87	0
December	15.76	0	15.90	0
Total	80.60	28.62	85.63	27.10

Table 54 Monthly energy demand for cooling and heating according to TRNSYS' and Thesis' software

The next figure shows the cumulative heating and cooling energy demand over a year as calculated from both software. Dashed line is for the cooling demand and the solid line is for heating demand.

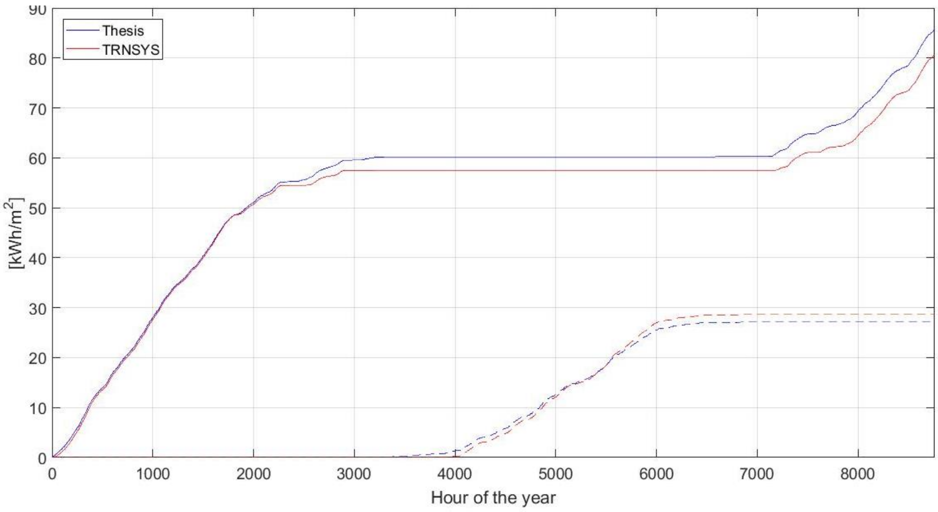

Figure 29 The heating and cooling energy demand over the year according to TRNSYS' and Thesis' simulation

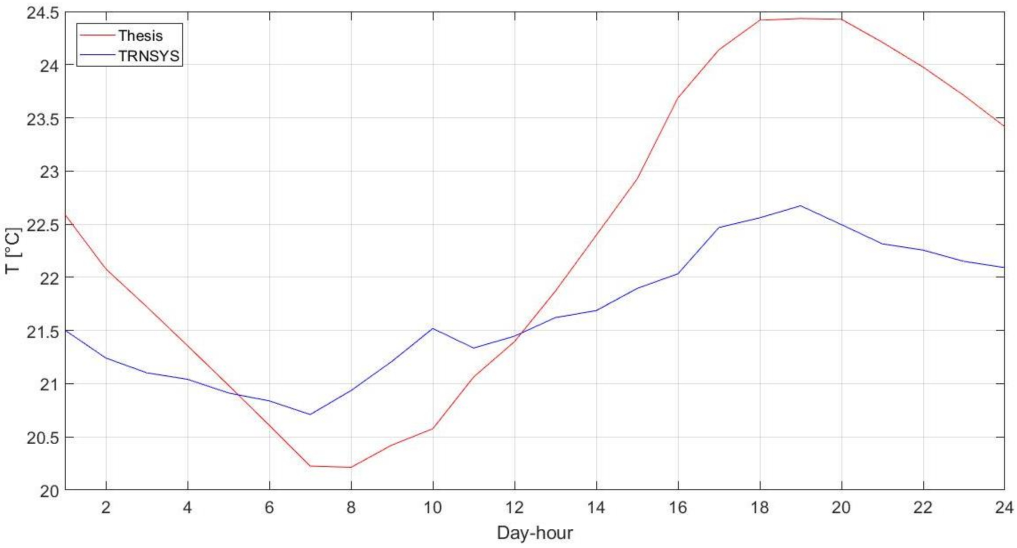

Figure 30: Internal temperature for the April 10

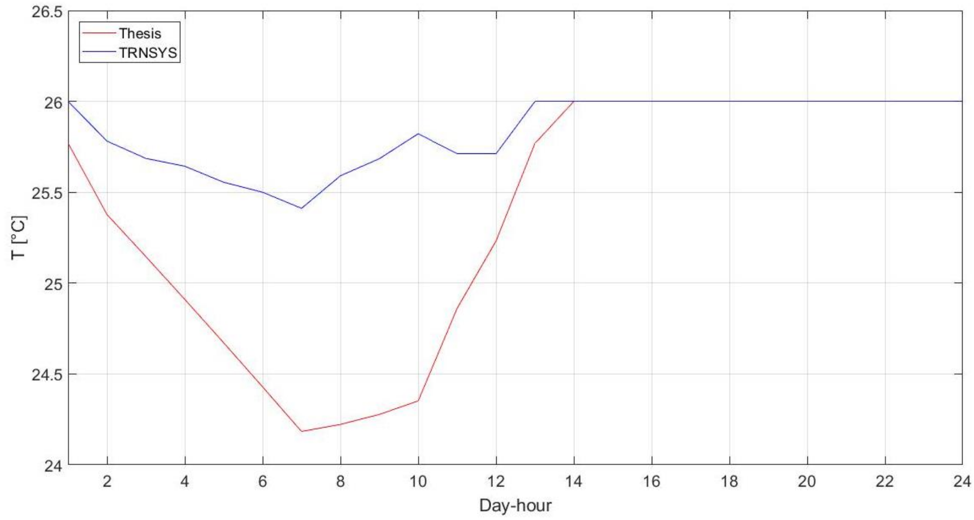

Figure 31: Internal temperature for the September 13

As the above figure show, the variation of the internal temperature of the TRNSYS and Thesis is similar .Wherefore the internal temperatures pursue the same variation, so the TRANSYS and Thesis heat transfers follow the same variation.

Since TRNSYS provide much more detailed results, it is possible to compare the contribution of each thermal gain type in the annual energy balance of the building. It is obvious that the superposition of all the gains must be equal to zero over a year. The gains are categorized as follows:

- **Heating**: Heating input from the heating system
- **Gains**: Internal gains form lights and occupants
- **Solar gains**: Solar gains from radiation
- **Cooling**: Cooling input from the cooling system
- **Ventilation**: Heat transfer by ventilation-infiltration
- **Transmittance**: Heat transfer by transmittance

The next figure depicts the energy balance graph:

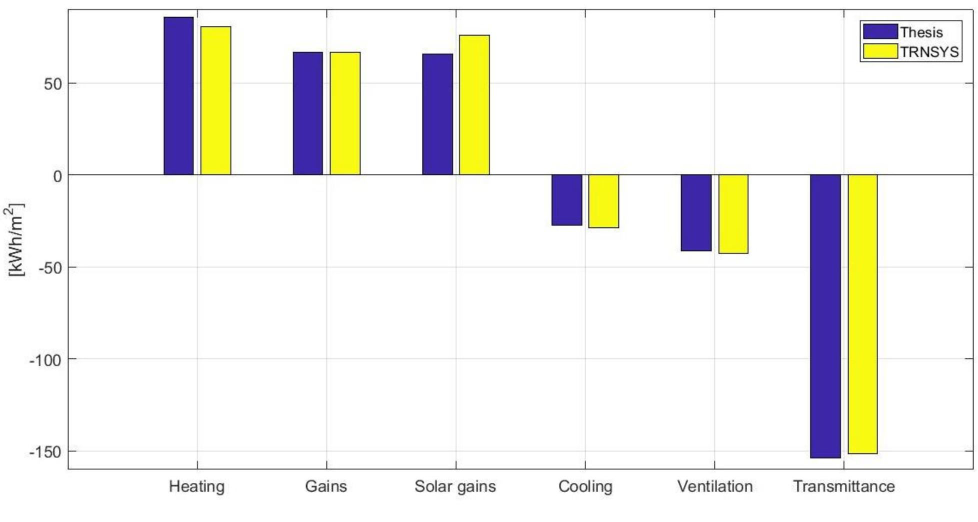

Figure 32: Heat balance comparative diagram for TRNSYS' and Thesis' software

The next table shows the heat balance:

	TRNSYS' software	Thesis' software
Heating energy demand [kWh/m^2]	80.60	85.63
Cooling energy demand [kWh/m^2]	28.62	27.10
Gains by solar [kWh/m^2]	75.73	65.78
Gains by not solar [kWh/m^2]	66.42	66.43
Heat transfer by transmission [kWh/m^2]	151.24	153.55
Heat transfer by ventilation [kWh/m^2]	42.90	41.09

Table 55: TRNSYS and Thesis results

As the above table shows, TRNSYS and Thesis' software predict similar energy need for heating/cooling (differences on annual basis 5-6%). The difference is due to the solar gains, because the inputs in TRNSYS software are not exactly the same as Thesis software. The building which simulated in TRNSYS software was already developed by the laboratory. The differences on annual basis are almost the same, this is why both software use the same weather data and hourly time step. Moreover, the above diagram shows us that the rest of the results of the two software are almost identical. In this way the Thesis' software has been successfully compared to the results of TRNSYS.

VI. Case studies using the developed software

Since the validity of the results obtained by the developed software was ensured, different case studies were carried out using the Thesis software, in order to determine the impact of several factors in the energy consumption for heating and cooling of a Single Family House in Greece. The studied house is the same as the one described in Annex A, while the factors examined are the:

- **Climate**: focusing on the results of the same building in the two most populated cities of Greece, namely Athens and Thessaloniki.
- **Insulation**: focusing on the effect of the insulation thickness in the roof and the walls
- **Operating schedule**: focusing on the effect of various heating and cooling schedules on the energy savings
- **Heating system**: focusing on the prime energy for different fuels for heating and for different cooling type
- **Domestic hot water**: focusing on the energy consumption for the domestic hot water with the boiler and the solar collector

VI.1 Comparison between Athens and Thessaloniki

The same house is being considered as the one described in Annex A. Thessaloniki is northern than Athens, so the average external temperature is less than the average temperature of the Athens and it is expected to has more heating and less cooling demand. The calculated monthly energy demands for cooling and heating for Athens and Thessaloniki are included in the following table:

	Athens		**Thessaloniki**	
Month	**Heating demand [kWh/m^2]**	**Cooling demand [kWh/m^2]**	**Heating demand [kWh/m^2]**	**Cooling demand [kWh/m^2]**
January	19.57	0	33.69	0
February	19.52	0	27.54	0
March	15.18	0	21.24	0
April	5.94	0	10.44	0
May	0.60	1.36	1.91	1.56
June	0	10.21	0.04	7.14
July	0	16.76	0	13.06
August	0	16.93	0	11.74
September	0	7.07	0	2.83
October	0.37	0.45	5.91	0.02
November	8.80	0	17.73	0
December	19.21	0	30.19	0
Total	89.20	52.78	148.69	36.35

Figure 33: Monthly energy demand for cooling and heating for Athens and Thessaloniki

Following the monthly energy uses for cooling and heating for Athens and Thessaloniki:

	Athens		Thessaloniki	
Month	**Heating use [kWh/m^2]**	**Cooling use [kWh/m^2]**	**Heating use [kWh/m^2]**	**Cooling use [kWh/m^2]**
January	21.25	0	36.56	0
February	21.19	0	29.90	0
March	16.48	0	23.06	0
April	6.45	0	11.33	0
May	0.65	0.51	2.07	0.59
June	0	3.75	0.04	2.70
July	0	6.18	0	4.87
August	0	6.12	0	4.37
September	0	2.68	0	1.07
October	0.41	0.17	6.41	0
November	9.56	0	19.24	0
December	20.86	0	32.77	0
Total	96.84	19.42	161.39	13.61

Figure 34: Monthly energy uses for cooling and heating for Athens and Thessaloniki

	Athens	**Thessaloniki**
Heating energy peak [W/m^2]	82.87	113.07
Cooling energy peak [W/m^2]	130.55	101.29

Table 56: Hourly heating and cooling energy peak

	Athens	**Thessaloniki**
Heating energy demand [kWh/m^2]	89.20	148.69
Cooling energy demand [kWh/m^2]	52.78	36.35
Gains by solar [kWh/m^2]	98.65	94.44
Gains by not solar [kWh/m^2]	66.43	66.43
Heat transfer by transmission [kWh/m^2]	118.59	166.40
Heat transfer by ventilation [kWh/m^2]	74.88	103.70

Figure 35: Athens and Thessaloniki results

The next figure shows the heating and cooling energy demand over the year from both software:

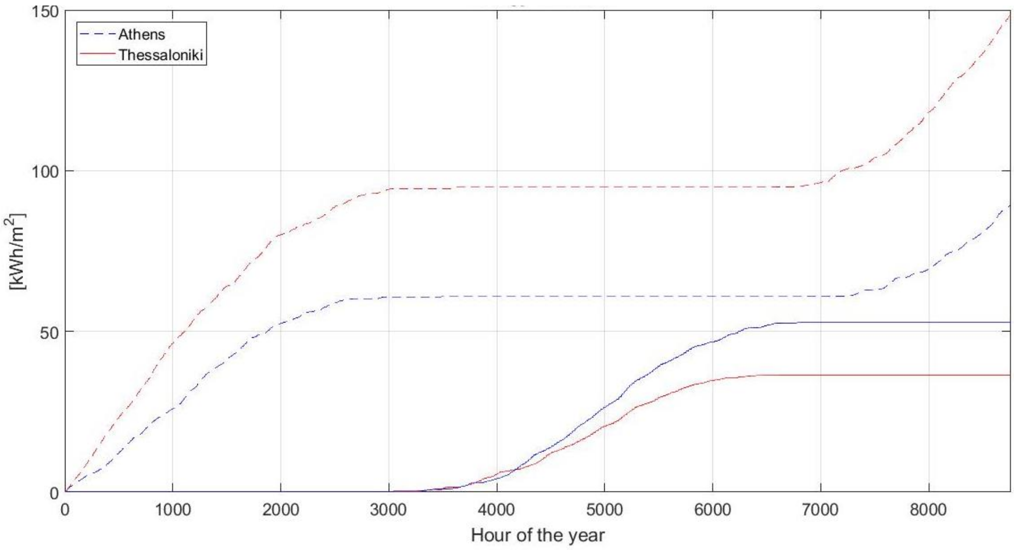

Figure 36: The heating and cooling energy demand over the year for the Athens and Thessaloniki

Following the heat balance between the Athens and the Thessaloniki. The energy balance is equal to zero for both of the location.

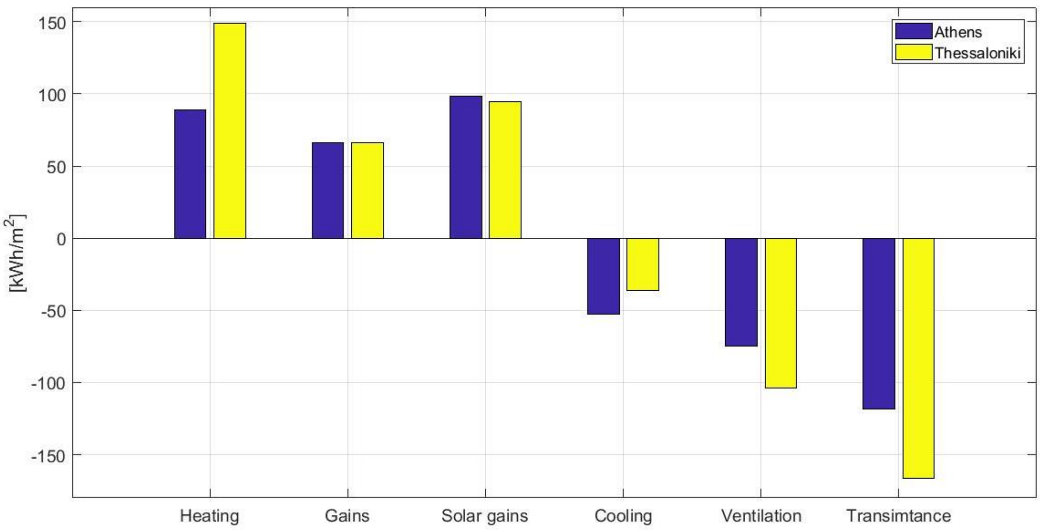

Figure 37: Heat balance comparative diagram for Athens and Thessaloniki

As it was expected, Thessaloniki needs more energy for heating (66.7%) but less energy for cooling (-29%) than Athens. Moreover, the solar gains are almost the same, Athens has slightly more than Thessaloniki. The difference is due to the ventilation and transmittance losses, so the difference between the two cities can be attributed to the external Dry Bulb Temperature. The Thesis' software has the capability to be used for more Greek cities, provided that hourly weather data are available.

VI.2 Different thickness of insulation

In this chapter it will be examined the perspective to change the existing insulation, which is 6 cm for roof and 4 cm for the walls. So, the following scenarios were examined, in both Athens and Thessaloniki:

- no insulation on the roof and the walls
- no insulation on the roof and 3 cm insulation on the walls
- 3 cm insulation on the roof and no insulation on the wall
- 3 cm insulation on the roof and on the wall
- 6 cm insulation on the roof and 4 cm on the wall (which is the case for the Benchmark Building), and
- 6 cm insulation on the rood and on the walls

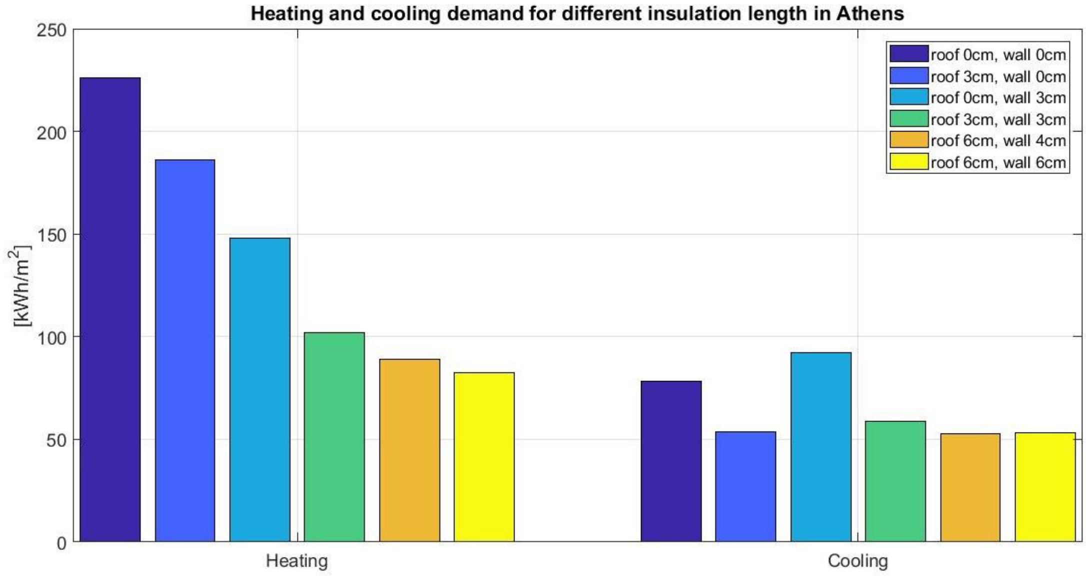

Figure 38: Heating and cooling demand for different insulation length in Athens

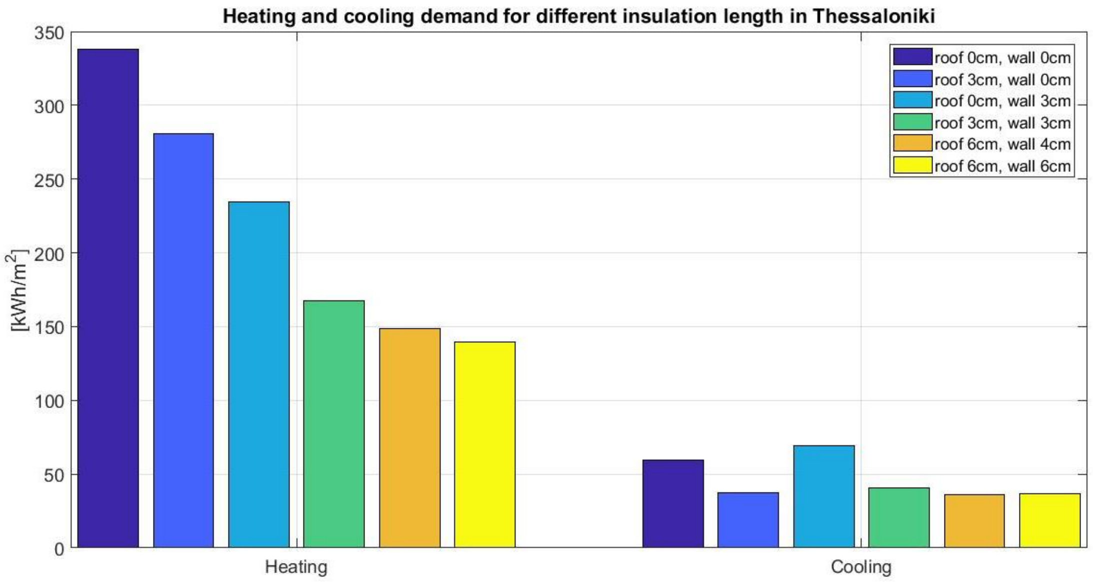

Figure 39: Heating and cooling demand for different insulation length in Thessaloniki

As the above figures show, the insulation has a major impact to the heating and cooling needs. It is obvious that the thicker the insulation the house would have, the less heating the energy demand, in both locations. Moreover, it is better to insulate the walls of the house rather than the roof for the heating period and to insulate the roof of the house for the cooling demand. The insulation thickness as it grows, the impact become smaller. The heating demand does not decrease much more if the house is insulated more than 3 cm. Because the insulation is expensive, furthermore study should be done (economic and technical) to find out the optimal scenario. The key conclusion extracted from the aforementioned figures is that even though the climatic conditions change, the behavior for different thickness of insulation do not alter, hence the insulation influence on the building's thermal needs is independent from the climatic conditions (at least for the variation between Athens and Thessaloniki).

VI.3 Different profile for heating and cooling

In this chapter it will be examined the perspective to change the hourly profile for heating in Athens and Thessaloniki. The following scenarios are examined:

- All day. :the heating temperatures set points are activated all day
- 16 hours: the heating temperatures set points are activated between 7:00 and 23:00
- 9 hours: the heating temperatures set points are activated between 07:00 and 10:00, and between 17:00 and 23:00

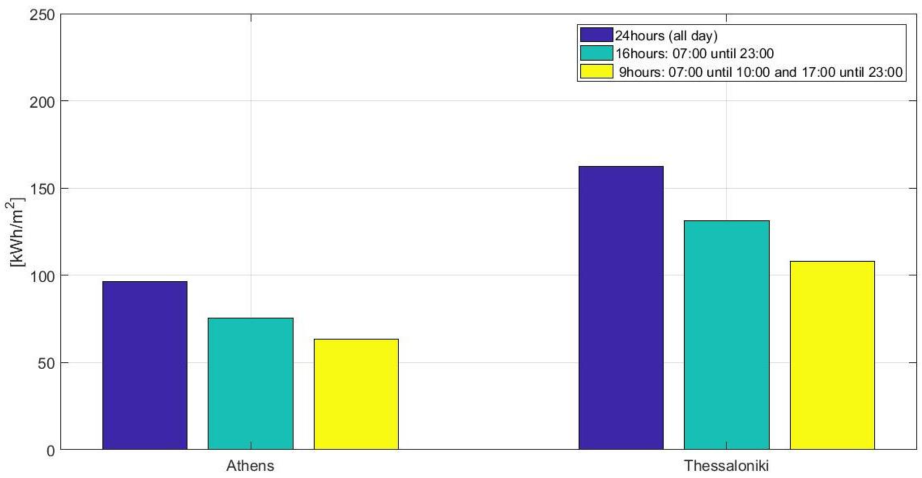

Figure 40: Heating demand energy for different heating profile

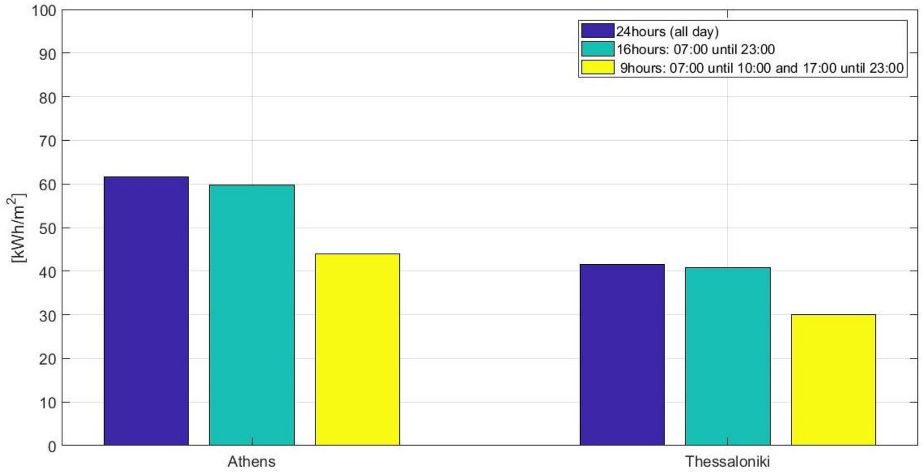

Figure 41: Cooling demand energy for different cooling profile

It is obvious that the less hours of the day the heating temperature set point is activated, the less heating energy demand is. Especially in Thessaloniki, which has lower average temperature than in Athens For the 16 hours schedule, the annual heating demand is 19.2% (Thessaloniki) and 21,5% (Athens) less than 24 hours schedule. Also, for the 9 hours schedule, the annual heating demand is less than the annual heating demand of 24 hours schedule (33.6% in Thessaloniki and 34.06% in Athens). It is very important to know how to use your heating system. The cooling energy demand is decreasing as the hours of the day the cooling temperature set point are decreasing. The difference between the 24 hours schedule and the 16 hours schedule is similar, but the 9 hours schedule has major different from the 24 hour schedule More specific, the annual cooling demand for 9 hours schedule is 27.69% (Thessaloniki) and 28.87% (Athens) less than the 24 hours schedule. With Thesis' software, the heating demand can be accurately calculated and the habitants can find out what hours of the day should use the heating system

The follow table shows the maximum and minimum internal temperature for the scenario of 16hours and 9hours:

	Athens	**Thessaloniki**
T_{min} (16 hours) [^oC]	12.4	8.74
T_{min} (9 hours) [^oC]	11.68	8.22
T_{max} (16 hours) [^oC]	28.84	27.36
T_{max} (9 hours) [^oC]	34.89	32.94

Table 57: Annual minimum and maximum internal temperature for the scenarios of 16 hours and 9 hours

VI.4 Different boilers and cooling systems

In this chapter, the impact in the primary energy consumption of different boilers (depending on the fuel) and cooling systems will be examined for both Athens and Thessaloniki. The following scenario will are examined:

- For heating and DHW (domestic hot water) (10kW)
  - Natural gas
  - Heating oil
  - Biomass
- For cooling
  - 2 split units air condition (5kW each, construction after 2001)
  - A central chiller with Fan Coils as terminal units (10kW after 2001)

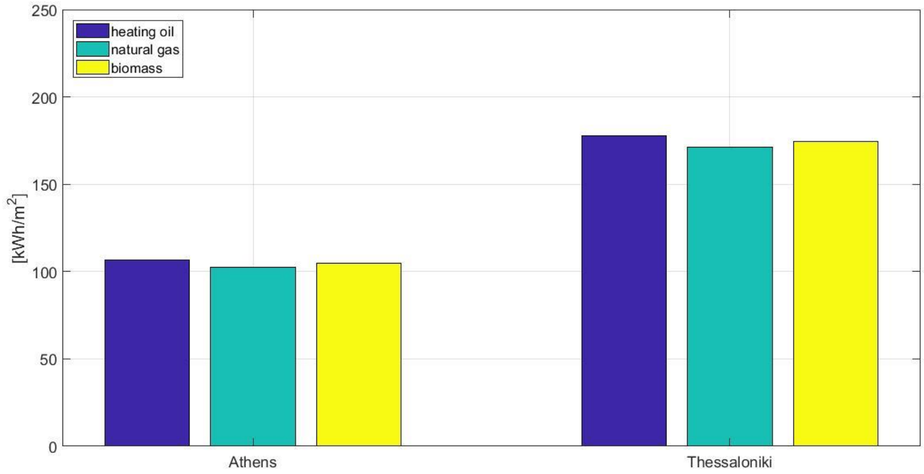

Figure 42: Prime energy for different boilers (depending on the fuel)

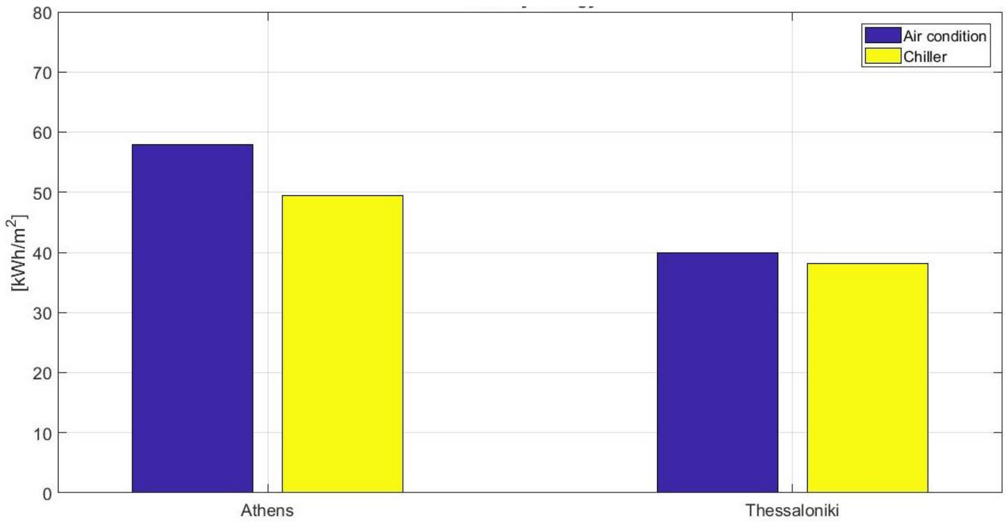

Figure 43: Prime energy for different cooling systems

The three different fuel for heating system have no major different in terms of primary energy consumption. The natural gas is slightly better and follows the biomass.

Besides, the chiller is much more effective compared to the solution of split units (air conditioners), primarily due to the higher value of SEER. Taking account of the fact that air conditioners are not the best solution in terms of thermal comfort, central cooling systems are much more preferable.

VI.5 Energy consumption for DHW (domestic hot water)

In this chapter, the split of energy consumption for DHW is examined. The DHW can be heated by three different systems with the follow preference:

- Solar collector with collector area $3m^2$
- Boiler with nominal power 10kW
- Electrical resistance

It is preferable the DHW to heated by solar collector because the energy is renewable. The follow figure shows the use of the above systems for heating the DHW in Athens and Thessaloniki:

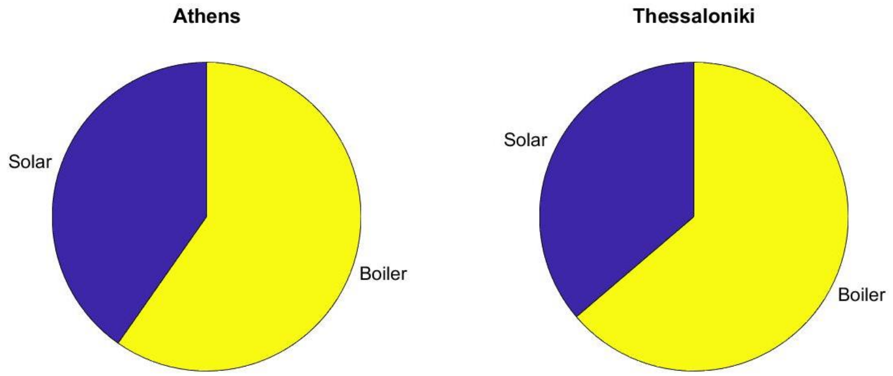

Figure 44: From which system the domestic hot water is heated

The annual energy consumption for DHW in Athens is 66.17 kWh/m^2 and in Thessaloniki is 68.11 kWh/m^2. The percentage from solar collector use in Athens is 40.29% and in Thessaloniki is 36.23%. There is no major different between the two locations. This is because, as mention above, the annual solar gains are similar. It comes to conclusion that the radiation is the same all over the Greece.

VII. Conclusions and future work recommendations

The building sector is responsible for around 37% of the overall energy consumption in the European Union.. It becomes clear how significant, the study of buildings is. Every nation is encouraged to apply a method for calculating the energy efficiency for buildings as well as to establish the minimum requirements. Besides, Europe should not under-estimate the economic potential of investing in energy efficiency buildings. Following the aforementioned trend, European Council conducted a key legislative tool to unlock the savings potential in the building sector, which is the Energy Performance of Buildings Directive (EPBD).In Greece, K.Eν.A.K provides the norms and technical guidelines in order to ensure the energy efficiency of new and renovated buildings K.Eν.A.K is categorized the buildings according to their energy performance and issues the Π.Ε.Α. (Energy Performance Certificates), which certifies the energy class of a building, compared to the expected consumption of the reference one, by simulating both buildings and the installed systems using T.E.E. K.Eν.A.K. software.

As a result the existence of a simulation software is now crucial for the prediction of the heating and cooling energy consumption, heating and cooling systems behavior and benchmarking between different options for modifying the building or its systems. Many software have been developed like TRNSYS, EnergyPlus and T.E.E. K.Eν.A.K.

EN ISO 13790 propose two simplified methods for the calculation of the energy consumption, the monthly and hourly method, The hourly method is based on a lumped parameter 5R-1C model for the whole thermal zone and generally provides more accurate results and the opportunity to forecast the loads in hourly base. In addition with the hourly method, one is able to find the peak of heating and cooling demand for an hour and dimensioning the heating and cooling systems. Moreover, the hourly method is able to evaluate transient phenomena like internal temperature, heat transfer. In addition, it is possible to study different control strategies or simulate the response of energy storage devices (e.g. sensible or latent thermal storage systems). This is the reason why this method was finally chosen to be implemented in the thesis software.

The developed software has the ability to predict

- the hourly heating and cooling demand
- the hourly heating and cooling uses to cover of demands
- the solar gains, the gains from lights, appliances and persons , the heat transfer by transmittance the heat transfer by ventilation
- the hourly peak of the heating and cooling energy demand
- the primary energy

In this thesis completed the follow tasks:

- Implementation of the simplified hourly method according to EN ISO 13790
- Expandable code was programmed in MATLAB environment following objected oriented programming, making it easy to be expanded at a later time
- The EN ISO 13790 presents a method for the calculation of heating and cooling demand and several inputs are required for its implementation. The inputs are incorporated from the T.O.T.E.E. standards with its tabulates, calculation methods, fixed units etc.
- The challenges of developing the methodology of EN ISO13790 can be attributed to the requirement of a lot of input data, including material properties, shading coefficients, weather data etc. and the integration of tabulated data from T.O.T.E.E.
- The correct use of assumptions because of the complexity of some variables. The simplifications from the T.O.T.E.E. were taken into account for the reduction but also the accurate of the methodology.

The developed software has been successfully compared with TRNSYS and T.E.E. K.Eν.A.K. software. The comparison result proved that the software was accurate with similar results to the others software.

Since the validity of the results obtained by the developed software was ensured, different case studies were carried out using the developed software and several inferences were captured such as:

- The impact of climate data in the heating and cooling demands. The external temperature has a major impact in the energy demand due to the heat transfer by ventilation-infiltration and transmittance. Moreover, the solar gains are similar independent from the location in Greece.
- Even though the climatic conditions change, the behavior for different thickness of insulation do not alter, hence the insulation influence on the building’s thermal needs is independent from the climatic conditions
- Heating and cooling profiles are cable to change the yearly energy demand. The scenario that all day the heating and cooling set points has the biggest annual energy demand. It is perforable to activate set points between 07:00 and 10:00, and between 17:00 and 23:00 than all day.
- He natural gas and heating oil have not a major difference in terms of primary energy consumption, even though the natural gas boiler is slightly better. On the other hand, biomass boilers are associated with greater values of primary energy consumption because of its bad boiler efficiency.
- For cooling demand, the chiller is much more effective compared to the solution of split units (air conditioners), primarily due to the higher value of SEER. Furthermore, taking account of the fact that air conditioners are not the best solution in terms of thermal comfort, central cooling systems are much more preferable
- The weather data has a major impact in final results. As it mentioned in the comparison between Thesis and T.E.E. K.Eν.A.K. software, the weather data are not the same. There is difficulty to find reliable weather data. Moreover, the TRNSYS and T.E.E. K.Eν.A.K. software do not use the same weather data.

Future possible extensions of the developed software include:

- **Calculation of multiple thermal zones**. The calculation of a single thermal zone has been developed and the expansion to multiple zones is easily achievable. The extra thermal zone classes can be added in the building class. Furthermore, the EN ISO 13790 provides the detailed methodology regarding the coupling of multiple zones.
- **Creation of Graphical User's Interface (GUI).** One of the purpose of the current thesis was to developed a user friendly software. With the creation of a GUI, the user will add the data simply and rapidly in contrast with T.E.E. K.Eν.A.K. software which furthermore calculations must be done.
- **Fulfillment of thermal comfort**. The developed thesis uses set point temperature for cooling and heating. The relative humidity of the internal air was not examined and it is very important for the thermal comfort inside the thermal zone. Besides, various thermal comfort parameters can also be examined (e.g. Operative Temperature, Predictive Mean Vote, Predicted Percent Dissatisfied).
- **Addition of thermal bridges effects:** Thermal bridges are the "weak" points of the building envelope and act against their thermal protection. They affect its energy behavior and reduce the feeling of thermal comfort in the interior. They often end up being the cause of various damages and disasters, sometimes insignificant and insignificant, but mostly dangerous and serious. It is perceived that the thermal bridges has a major impact to the thermal balance of a building and further investigation would be done.
- **Several scenarios be checked and carry out an economic and technical assessment**. The developed software can be used to be checked the several thickness of insulation. With an extra economic assessment, the optimal thickness of insulation can be found. Moreover, it is possible to optimal the solar collector with the Thesis' simulation software and with an addition economic assessment. With the addition of more heating and cooling systems, dimensioning of them can be done because the developed software can find the peak demand energy for heating and cooling on an hourly step.

VIII. Annex A

The next figures shows the top view of the benchmark building:

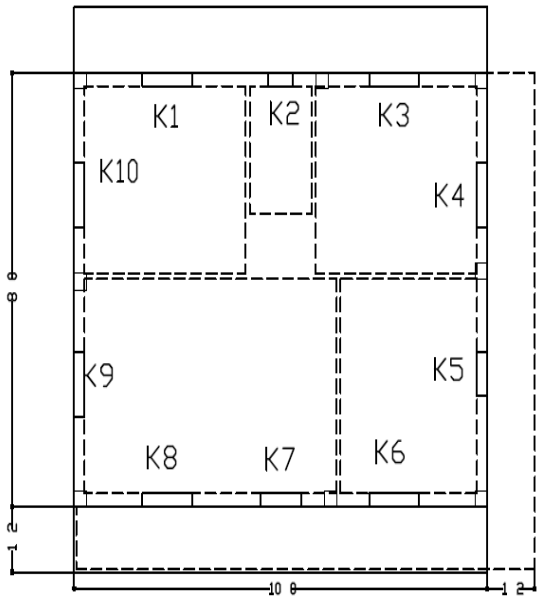

Figure 45: Top view of the studied house

Follows the geometry if the building:

- Facade length: 10.5m
- External left side length: 8.5m
- External right side length: 8.5m
- Length of center rear face: 10.5m
- Floor height: 3m
- Floor area: 80m^2

Moreover, the house has:

- Location: Athens
- Number of people in the house: 5
- Foreground Surface (R_g): 0.2 which is dry bare ground
- Categories of control and automation devices: B

There are two types of structural element for the wall:

- Coated brickwork in contact with external air with the follow elements from inside to outside:

Structure layers	Density (ρ)	Thickness (d)	Coefficient of thermal conductivity (λ)	Heat capacity (c)
	kg/m³	m	W/mK	J/kgK
Lime-cement mortal	1800	0.020	0.870	1000
Masonry	1700	0.090	0.580	1000
Insulation	20	0.040	0.035	1000
Masonry	1700	0.090	0.580	1000
Lime-cement mortal	1800	0.020	0.870	1000

Table 58: Coated brickwork in contact with external air

- Reinforced concrete in contact with external air with the follow elements from inside to outside:

Structure layers	Density (ρ)	Thickness (d)	Coefficient of thermal conductivity (λ)	Heat capacity (c)
	kg/m³	m	W/mK	J/kgK
Lime-cement mortal	1800	0.020	0.870	1000
Reinforced concrete	2400	0.250	2.500	1000
Insulation	20	0.040	0.035	1000
Lime-cement mortal	1800	0.020	0.870	1000

Table 59: Reinforced concrete in contact with external air

The next table shows the details of the walls:

Orientation	Element	Absorptivity ($\alpha_{S,c}$)	Emissivity (ε)	Surface resistance (Ra) [m²K/W]	Area (A) [m²]	Length (L) [m]	Depth (z) [m]	Angle α [°]	Angle β [°]	Angle γ_1 [°]	Angle γ_2 [°]
West	Reinforced concrete	0.4	0.8	0.04	7.29	0.33	0	24	12	0	0
West	Coated brickwork	0.4	0.8	0.04	12.99	0.26	0	24	12	0	0
North	Reinforced concrete	0.4	0.8	0.04	8.55	0.33	0	24	12	0	0
North	Coated brickwork	0.4	0.8	0.04	17.63	0.26	0	24	12	0	0
East	Reinforced concrete	0.4	0.8	0.04	7.29	0.33	0	24	12	0	0
East	Coated brickwork	0.4	0.8	0.04	14.09	0.26	0	24	12	0	0
South	Reinforced concrete	0.4	0.8	0.04	8.55	0.33	0	24	12	0	0
South	Coated brickwork	0.4	0.8	0.04	15.79	0.26	0	24	10	0	0

Table 60:Details of the walls

The roof is a clamber in contact with external air with the follow elements, from inside to outside:

Structure layers	**Density (ρ)**	**Thickness (d)**	**Coefficient of thermal conductivity (λ)**	**Heat capacity (c)**
	kg/m³	**m**	**W/mK**	**J/kgK**
Lime cement mortal (roof)	1800	0.015	0.870	1000
Plate of reinforced concrete	2400	0.150	2.500	1000
Smoothing layer of cement mortar	2000	0.010	1.400	1000
Asphalt coating as a water vapor barrier	1050	0.001	0.170	1000
Insulation	20	0.060	0.035	1000
Grabbling (slopes, medium thickness 8 cm)	1700	0.080	0.810	1000
Single coat of asphalt without tiles	1100	0.004	0.230	1000
Geotextile as a separating layer	80	0.001	0.040	1000
Cement mortar for paving slabs	2000	0.020	1.400	1000
Paving	2100	0.030	1.500	1000

Table 61: Clamber in contact with external air

The next table shows the details of the roof:

Absorptivity ($\alpha_{S,c}$)	**Emissivity (ε)**	**Surface resistance (Ra) [m²K/W]**	**Area (A) [m²]**	**Length (L) [m]**
0.9	0.8	0.04	80	0.371

Table 62: Details of the roof

The floor is divided into two types of structure elements:

- Floor reinforced concrete with wooden flooring with the follow elements, from inside to outside:

Structure layers	**Density (ρ)**	**Thickness (d)**	**Coefficient of thermal conductivity (λ)**	**Heat capacity (c)**
	kg/m³	**m**	**W/mK**	**J/kgK**
Casting (lithosphere)	2700	0.200	1.000	1000
Polyvinyl chloride sheet (nylon)	1390	0.001	0.200	1000
Cleaning concrete	2300	0.100	1.500	1000
Softening layer of cement mortar	2000	0.010	1.400	1000
Single layer of asphalt	1100	0.004	0.230	1000
Geotextile as a protective layer	80	0.001	0.040	1000
Reinforced concrete slabs	2400	0.150	2.500	1000
Softening layer of cement mortar	2000	0010	1.400	1000
gap between beams (for 5 cm gap)	-	0.060	-	1000
Substrate scraping (pond)	700	0.020	0.180	1000
Wooden parquet	800	0.020	0.210	1000

Table 63: Floor reinforced concrete with wooden flooring

- Flooring reinforced concrete with tile laying on the ground with the follow elements, from inside to outside:

Structure layers	Density (ρ)	Thickness (d)	Coefficient of thermal conductivity (λ)	Heat capacity (c)
	kg/m^3	**m**	**W/mK**	**J/kgK**
Casting (lithosphere)	2700	0.200	1.000	1000
Nylon sheet to prevent reinforced concrete from penetrating into the ground	1390	0.001	0.200	1000
Cleaning concrete	2300	0.100	1.500	1000
Softening layer of cement mortar	2000	0.010	1.400	1000
Single layer of asphalt	1100	0.004	0.230	1000
Polyvinyl chloride sheet (nylon)	1390	0.001	0.170	1000
Reinforced concrete slabs	2400	0.150	2.500	1000
Grubbing as a balancing layer	1900	0080	1.100	1000
Cement mortar	1800	0.020	1.400	1000
Ceramic tiles (mosaic or marble)	2000	0.010	1.840	1000

Table 64: Flooring reinforced concrete with tile laying on the ground

The next table shows the details of the floors:

Element	Exposed perimeter (Π) [m]	Area (A) [m^2]	Depth (z) [m]	Length (L) [m]
Floor reinforced concrete with wooden flooring	16	32	0.5	0.576
Flooring reinforced concrete with tile laying on the ground	20	48	0.5	0.596

Table 65: Details of the floors

The details of the windows of the studied house are show to the next table:

Name	**K1**	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**K9**	**K10**
Type	Exterior door	Bath window	Exterior door	Room window	Exterior door	Room window	Door	Exterior door	Exterior door	Exterior door
Orientation	North	North	North	East	East	South	South	South	West	West
$P_{v\text{-crevice}}$ [$m^3/(m^2h)$]	6.8	6.8	11.8	6.8	11.8	6.8	12.5	11.8	11.8	11.8
A_g [m^2]	1.00	0.16	2.00	1.00	1.40	1.00	0	2.00	1.00	2.00
A_f [m^2]	0.68	0.20	1.08	0.68	0.58	0.68	2.20	1.08	0.68	1.08
A_p [m^2]	0	0	0	0	0	0	0	0	0	0
l_g [m]	6.00	1.60	10.00	6.00	5.40	6.00	0	10.00	6.00	10.00
l_p [m]	5.20	2.40	7.20	5.20	6.20	5.20	6.40	7.20	5.20	7.20
U_g [W/m^2K]	2.80	2.80	2.80	2.80	2.80	2.80	5.70	2.80	2.80	2.80
U_f [W/m^2K]	7.00	7.00	7.00	7.00	7.00	7.00	7.00	2.00	7.00	7.00
U_p [W/m^2K]	0	0	0	0	0	0	0	0	0	0
Ψ_g [W/m^2K]	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.02	0.02	0.02
Ψ_p [W/m^2K]	0	0	0	0	0	0	0	0	0	0
g_{gl}	0.45	0.27	0.45	0.45	0.45	0.45	0	0.45	0.45	0.45
α [^{o}]	22	18	29	22	29	7	9	9	22	29
β [^{o}]	13	17	10	13	10	13	10	10	13	10
γ_1 [^{o}]	0	0	0	0	0	0	0	0	0	0
γ_2 [^{o}]	0	0	0	0	0	0	0	0	0	0
Quantity	2	1	2	2	1	2	1	2	2	2

Table 66: Details of the windows

The ventilation of the studied house has the follow details:

- Type: Natural
- $P_{v\text{-port}}$: 0 m^3/h
- Recirculation: no

The lights of the studied house have the follow details:

- Power density per 100 lx: 4.5
- F_d: 0.7
- F_o: 1.0
- Quantity: 2

The heating system (boiler) of the studied house has the follow details:

Type	Fuel	Pn [kW]	Pm [kW]	Before 1980	Energy label	Insulation	Insulation state
Typical boiler	Heating oil	10	10	no	yes	Equal to the radius of the pipes	good

Table 67: Heating system boiler details

Moreover, the heating system (boiler) has distribution networks with high temperature of working fluid (≥60°C).

The cooling system (air condition) of the studied house has the follow details:

- Quantity: 2
- Power: 1200 BTW
- After 2001

The heating terminal of the studied house has the follow details:

- F_{rad}: 0.95
- f_{im}: 0.97
- f_{hydr}: 1.03
- Damage: yes

The DHW (domestic hot water) of the studied house has the follow details:

- Connected to the boiler
- Recirculation: no
- Insolation state: okay
- Type of solar collector: flat plate
- Distribution system efficiency: 0.6
- Solar collector area: 3 m^2
- Tilt angle (Σ): 30°
- Orientation: South

IX. Tables

X. Figures

XI. Biobliography

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