UNIVERSITY OF THESSALY

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ENERGY ANALYSIS OF A TECHNICAL EDUCATION SCHOOL USING SOFTWARE

Diploma Thesis

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Περίληψη

Ο σύγχρονος τρόπος ζωής χαρακτηρίζεται από την αυξημένη κατανάλωση ενέργειας με αποτέλεσμα την έντονη επιβάρυνση του περιβάλλοντος. Σημαντική συνεισφορά στην κατανάλωση αυτή έχουν τα κτήρια, η κατανάλωση των οποίων στον Ευρωπαϊκό χώρο φτάνει το 40% της συνολικής καταναλισκόμενης ενέργειας στην Ευρώπη. Μετά την επιβολή Ευρωπαϊκών κανονισμών κρίνεται απαραίτητο πλέον τα νέα κτήρια να τηρούν ορισμένες προδιαγραφές και τα ήδη υπάρχοντα να προσαρμοστούν σε αυτές. Οι κανονισμοί αυτοί οδήγησαν στον σχηματισμό προδιαγραφών για τα Ελληνικά δεδομένα μέσω του Κανονισμού Ενεργειακής Απόδοσης Κτηρίων (ΚΕΝΑΚ), τον οποίο θα πρέπει να τηρούν όλα τα κτήρια της Ελληνικής επικράτειας. Για την εύρεση της ενεργειακής απόδοσης των κτηρίων πιο αξιόπιστος, εύκολος και γρήγορος τρόπος είναι η χρήση ειδικού λογισμικού.

Στο λογισμικό αυτό ο χρήστης μπορεί να εισάγει τα δομικά δεδομένα του κτηρίου βάσει των ελάχιστων προδιαγραφών και στη συνέχεια να βρει το κατάλληλο σύστημα θέρμανσης αερισμού και ψύξης, σύμφωνα με το είδος του κτηρίου και τη χρήση του. Συγκεκριμένα, υπολογίζονται τα θερμικά κέρδη και οι απώλειες από την ανταλλαγή θερμότητας μεταξύ του εσωτερικού του κτηρίου και του φυσικού περιβάλλοντος καθώς και τα εσωτερικά κέρδη που πηγάζουν από τον εσωτερικό εξοπλισμό, τον φωτισμό και την πληρότητα του κτηρίου. Τα θερμικά αυτά κέρδη και απώλειες, σε συμφωνία με το πρόγραμμα χρήσης του κτηρίου και τις επιθυμητές θερμοκρασίες, οδηγούν στη διαστασιολόγηση του συστήματος, με τον υπολογισμό του δυσμενέστερου θερμικού και ψυκτικού φορτίου. Οι υπολογισμοί της διαστασιολόγησης αφορούν την δυσμενέστερη ημέρα σε κάθε περίπτωση, μία για το θερμικό και μία για το ψυκτικό φορτίο. Ακόμα ορισμένα προγράμματα έχουν τη δυνατότητα προσομοίωσης των θερμικών κερδών, απωλειών αλλά και καταναλώσεων για ένα επιλεγόμενο από το χρήστη διάστημα, το οποίο μπορεί να φτάσει και τον έναν ολόκληρο χρόνο. Ακόμα για τους υπολογισμούς αυτούς είναι πολύ σημαντικά τα κλιματικά δεδομένα της περιοχής, ο προσανατολισμός του κτηρίου καθώς και η αρχιτεκτονική του.

Η συγκεκριμένη διπλωματική έχει αναλάβει την ενεργειακή ανάλυση ενός ήδη υπάρχοντος κτηρίου με εγκατεστημένο σύστημα θέρμανσης, αερισμού και ψύξης. Αρχικά γίνεται μια εισαγωγή σε θεωρία απαραίτητη για την παρακολούθηση του αντικείμενου, από τον αναγνώστη και τη θεμελίωση της διπλωματικής. Ακολουθεί λεπτομερής παρουσίαση των δεδομένων και έπειτα γίνεται εξαγωγή και ανάλυση των αποτελεσμάτων για τις δυσμενέστερες ημέρες θερμικού και ψυκτικού φορτίου. Στο τέλος, γίνεται προσομοίωση για μία ημέρα της χειμερινής και μία ημέρα της θερινής περιόδου. Η προσομοίωση μας βοηθάει να μελετήσουμε ποσοτικά και ποιοτικά τα θερμικά κέρδη, τις απώλειες και το φορτίο που πρέπει να καλυφθεί από το σύστημα αναλυτικά μέσα στην επιλεγμένη ημέρα της κάθε περιόδου.

Σκοπός αυτής της διπλωματικής είναι η εναρμόνιση με τις σύγχρονες απαιτήσεις για εξοικονόμηση ενέργειας και διαβίωσης σε ένα βιώσιμο περιβάλλον, ακολουθώντας τα ευρωπαϊκά και διεθνή πρότυπα.

Abstract

In modern times the way of life is characterised by increased energy consumption, which causes a dramatic impact on the environment. An important contribution in this consumption is caused by the buildings, the consumption of which, in the European continent, reaches the 40% of the total energy consumption in Europe. After the European enforcement of rules, it is necessary for the new buildings to meet the enforced requirements and the existing buildings to adapt to the requirements. These rules led to the formation of standards for the Greek community, with the Energy Performance Regulation for buildings (KENAK). This regulation should be followed by every building of the Greek community. The easiest, fastest and most reliable way to calculate the energy performance of a building is with the use of specific software.

In this software the user can insert the structural data of the building, which should follow the minimum requirements, and then to find the appropriate Heating Ventilation and Air Conditioning (HVAC) system, based on the kind and the usage of the building. Specifically, the heat gains and losses, coming from the heat exchange between the internal of the building and the outside environment, as well as the internal gains coming from the internal equipment, lighting and occupancy of the building are calculated. These heat gains and losses in accordance with the schedule of the building and the desirable temperatures lead to the dimensioning of the (HVAC) system after the calculation of the most unfavourable heating and cooling load. The dimensioning of the system refers to the most unpleasant day for the cooling load and the most unpleasant day for the heating load. Additionally, certain computer programs can simulate the heat gains, heat losses and the consumption of the system, for a chosen time period, even for an entire year. Furthermore, the climatic data, the building's orientation and the design of the building are significant for these calculations.

The current thesis has undertaken the energy analysis of an existing building with an installed heating, ventilation and cooling system. At the beginning, is introduced the essential theory, in order to found the thesis and to become easy understood by the reader. Then follows a detailed presentation of the data and after that is the analysis of the most unpleasant heating and cooling loads. Last is the simulation. The simulation help us study quantitatively and qualitatively the heating gains, losses and the load which the HVAC system should cover, in a selected day for the winter and for the summer period.

The target of the current thesis to harmonise the contemporary requirements for energy saving and for a sustainable environment, adhering to the European and international standards.

Dedication and acknowledgements

In the first place I would like to thank my supervisor, Tsoukalas Eleftherios for the accomplishment of the thesis and Bargiotas Dimitrios for his support.

I would like to specially thank Zimeris Dimitrios for his contribution to my academic experience, the introduction in a field I found important for my career and interests, his support and unreserved guidance during my work.

Last, I would like to thank my family for their support all these years.

Author’s declaration

I declare that the work in this diploma thesis was carried out in accordance with the requirements of the University’s Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate’s own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the thesis are those of the author.

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Chapter 1

Introduction

In contemporary times, daily life is inextricably linked to the energy consumption. The excessive energy consumption leads to rapid reduction of the nonrenewable energy sources and increases the footprint on our planet.

Specifically, the building's energy consumption in Europe represents the 40% of the European Union's total energy consumption and about one third of carbon dioxide emissions. This consumption depends on the geographical location of the building, the usage of it, the building's equipment, the lighting, heating and cooling system, ventilation, domestic hot water and shell of the building. Improvements in the building sector can reduce the total energy consumption.

Contemporary living conditions require an appropriate energy attitude of the buildings. This attitude includes an accurate management of energy and energy savings. In this way the building is not only safe and attractive, which used to be the basic criteria for a building, but it is also energy efficient with low energy consumption through excellent living conditions.

The European instruction 2002/91/EC based on Kyoto protocol mandated all European member states to bring into force national laws, regulations and administrative provisions for setting minimum requirements on the energy performance of new and under major renovation buildings and for energy performance certification. This instruction leads to the formation of the Hellenic Building's Energy Performance Regulation (KENAK), which was put into effect in 2010. Additionally, a new energy performance of buildings direction (2010/31/EC) strengthens the requirements of energy performance, clarifies and streamlines some of its provision for a common practice between the member states. One of the directions of (2010/31/EC) refers to all new buildings, which should be nearly zero energy buildings after 31 December 2020, while new buildings of public authorities should be nearly zero energy buildings after 31 December 2018 [1].

In the context of this directions and in accordance with the need for reduction of energy consumption, this thesis processes the energy analysis of an already existing non-residential building. The energy analysis is accomplished with the use of a new software, called FineGreen of 4M.

The structure of the thesis consists of 9 chapters. Chapter 1 is the introductory chapter. Chapter 2 continues giving a theoretical basis on heat transfer. Chapter 3 presents the Hellenic building's energy performance regulation (KENAK) and ASHRAE standards. Next is chapter 4, which presents the basis categories of air conditioning systems and their components. In the fifth chapter is displayed the software which was used in this research and additional software used for energy analysis. Chapter 6 presents the inserted building's data. The following is chapter 7 which presents and analyses the results of the heating and cooling design. Chapter 8, in turn, presents a winter single day and a summer single day simulation and then analyses the results. Finally, chapter 9 is the conclusion of the current thesis.

Chapter 2

Heat Transfer

The temperature difference inside of a body or between two different bodies in contact or in interaction is characterised by energy transfer. The procedure of energy transfer occurs due to the temperature difference and it is known as heat transfer. Heat can be transferred by three methods, conduction, convection and radiation. When temperature is function of one dimension of a space, the heat transfer phenomenon are one-dimensional. When temperature is function of two dimensions phenomenon are two-dimensional and when it is function of three phenomenon are three-dimensional.[2]

2.1 Heat conduction

Fourier's law, presented below, describes the heat flow per time unit, which passes from the fundamental surface of an isotropic body, to a solid flat body, (Figure 2.1) in which occurs one-dimentional heat conduction. The heat conduction is parallel to the x axis and the law for the time unit is :

$$q_x = -\lambda dT/dx \tag{2.1}$$

Where q_x $[W/m^2$ or $kJ/m^2h]$ is the density of the heat inflow. and λ is material's thermal conductivity $[W/mK]$

In the simple case, where thermal distribution in the flat body is linear, the Fourie's equation appears as:

$$q_x = \lambda(T_{S1} - T_{S2})/L = \lambda \Delta T/L \tag{2.2}$$

Temperatures T_{S1} and T_{S2} refer to positions 1 and 2 of the solid flat body and $L(m)$ is thickness of it. [2]

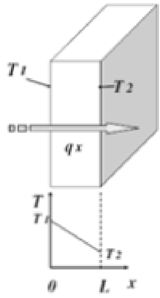


Figure 2.1: One-dimensional heat conduction in a solid flat body. [3]

2.2 Heat convection

Heat convection occurs among the surface of a solid body and a fluid one (liquid or gaseous), which are in contact and their temperatures differ.
Heat transfer by convection is the greatest close to the surface of contact of the bodies where the fluid's velocity is low, while at the points of zero fluid velocity heat transfer occurs by conduction. When the motion of the fluid is a result of external factors, convection is forced and when it is a result of temperature and density differences inside of the fluid, convection is natural. These describes the transfer of sensible heat by convection. Convection, also, occurs with the change of phase of the fluid. This phenomenon is characterized by the transfer of latent heat.
The density of heat inflow q $[W/m^2$ or $kJ/m^2]$ can be calculated with the use of Newton's correlation:

(2.3) $$q = h(T_S - T_\infty)$$

This correlation shows that the density of inflow heat is proportion to the temperature difference between the surface of the solid body T_S and the fluid body up to a point where the temperature of the solid body is not affected any more T_∞. The h $[W/m^2K]$ is a heat transfer convection factor which depends on the surface's geometry, the kind of the fluid it's properties and it's flow. [2]

2.3 Heat radiation

Heat transfer by radiation occurs via electromagnetic waves. It is based on the ability of bodies to absorb part of the radiation in which they are exposed to and to radiate it again. For this heat transfer the existence of a transmission material is not necessary, conversely, heat transfer is reinforced in space. The heat flow density q $[W/m^2$ or $kJ/m^2h]$ which is radiated by an body can be calculated by the correlation :

(2.4) $$q = \epsilon\sigma T_S^4$$

where ϵ is the body's radiation factor, this ranges from 0 to 1, $\sigma = 5{,}6697 * 10^{-8}$ $[W/m^2K^4]$ is the Stefan-Boltzmann's constant and T_S $[K]$ the temperature of the body. [2]

An usual case of heat transfer by radiation is the heat radiation of a small solid body to a bigger solid one while the space between them is covered by gas (Figure 2.2). The total heat flow Q $[W$ or $kJ/h]$ is the sum of the heat transfer by convection from the small solid body of T_{S1} temperature to the gas of T_∞ temperature, plus the heat transfer by radiation from the small solid body of T_{S1} temperature to the bigger body of T_{S2} temperature. [2]

(2.5) $$Q = Q_{conv} + Q_{rad} = hA(T_{S1} - T_\infty) + \epsilon A\sigma(T_{S1}^4 - T_{S2}^4)$$

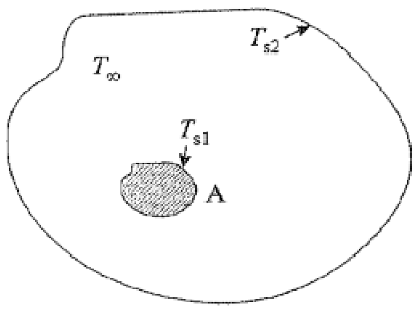


Figure 2.2: Heat transfer between two bodies where one of them surround the other body by convection and radiation. [4].

Chapter 3

KENAK Regulation

The objective of KENAK regulation is the achievement of energy savings during the construction of new buildings, the energy upgrade of buildings undergoing major renovation and the environmental protection. KENAK, according to [5], institutionalizes the complete energy design of a building through

- Energy efficient assessment of buildings,
- Establishment of minimum demands of buildings energy efficiency,
- Energy classification of buildings,
- Energy inspections of buildings, boilers, heating and cooling installations.

An energy efficient assessment is necessary for every building which is more than 50 square meters. KENAK illustrates the appropriate calculations for the estimation of the efficiency of the overall building. These calculations cover the demand of heating, cooling, ventilation, lighting and domestic hot water (DHW) of the building. After these calculations the results are compared with a reference building. A reference building is a building with the same geometrical features, position, orientation, usage and operating features with the studied building, but it fulfills marginal standards and the building's technical features of design, ceiling and building systems are defined. After the comparison the building is classified, based on the building's energy efficiency, into an energy category (A+ to G) [5].

3.1 Calculation parameters & Technical instructions for the classification of the efficiency

For the calculation of the energy efficiency and the classification into an energy category specific software, evaluated by the specific energy inspection agency (EYEPEN), is used. The calculation parameters are defined by the architectural and electromechanical study data. The standard internal circumstances are defined by the technical instructions of the technical chamber of Greece (TOTEE). [5]

3.1.1 Energy consumption of primary energy

Primary energy is the clear, pure energy form found in nature and not subjected to any human engineered conversion process.

For the calculation of the energy consumption of fuel into primary energy we can see the accepted factors, according to [5], on Table 3.1.

Table 3.1: Conversion factor of the eventual energy consumption of the building into primary energy.[5]

Energy Source	Conversion factor into primary energy	Released pollutants per energy unit (kgCO2/ kWh)
Natural Gas	1.05	0.196
Heating Oil	1.10	0.264
Electricity	2.9	0.989
Biomass	1.00	—

3.1.2 Climatic zones

According to the geographical location every building is categorized in a climatic zone. Greece is divided into four climatic zones based on the heating degree days. Table 3.2 presents these zones sorted from the warmer to the cooler one . [5]

Furthermore, the map shown in Figure 3.1, can give a clear view of the climatic zones of Greece.

Table 3.2: Prefectures of the Greek territory per climatic zone.[5]

Climatic zone	Prefectures
Zone A	Heraklion, Chania, Rethymno, Lasithi, Cyclades, Dodecanese, Samos, Messenia, Laconia, Argolis, Zakynthos, Cephalonia & Ithaki, Kythira & Saronikos Islands (Attica), Arcadia (lowland)
Zone B	Attica (except for Kythira & Saronikos Islands), Corinthia, Elis, Achaea, Aetolia-Acarnania, Phthiotis, Phocis, Boeotia, Euboea, Magnesia, Lesbos, Chios, Corfu, Lefkada, Thesprotia, Preveza, Arta
Zone C	Arcadia (highland), Evrytania, Ioannina, Larissa, Karditsa, Trikala, Pieria, Imathia, Pella, Thessaloniki, Kilkis, Chalkidiki, Serres (except for northeast department), Kavala, Xanthi, Rhodope, Evros
Zone D	Grevena, Kozani, Kastoria, Florina, Serres (northeast department), Drama

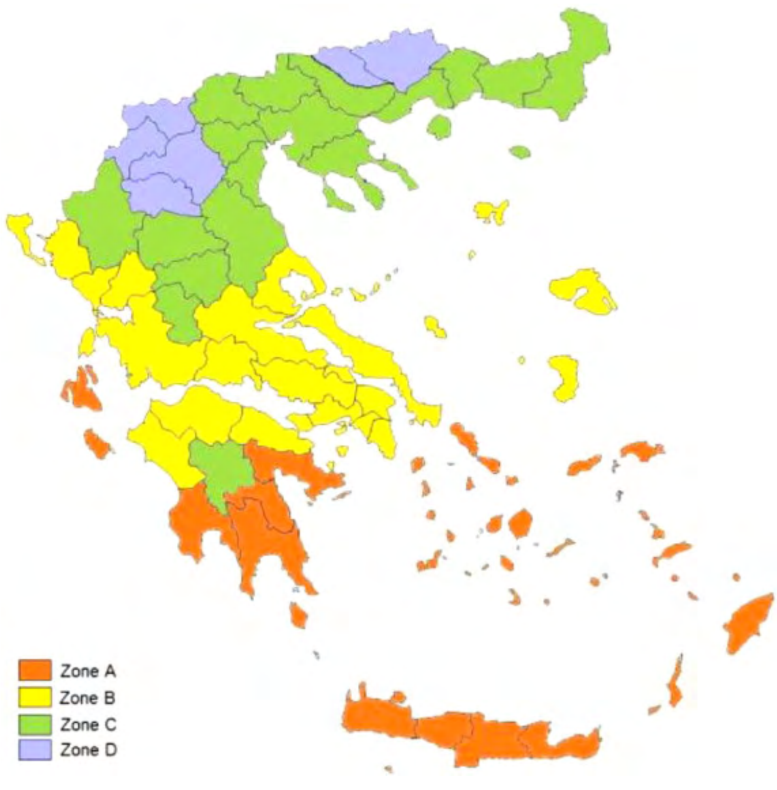


Figure 3.1: Schematic depiction of climatic zones of Greece.

3.1.3 Minimum demands of KENAK

KENAK according to [5] defines minimum demands about buildings energy efficiency, which refer to

- The design of the building
- The shell of the building
- The electromechanical installation

The shell consists of structural components and the heating features of these components should observe some restrictions. The restrictions refer to the heating insulation of the building and especially to the thermal transmittance factor. Table 3.3 presents the maximum permitted thermal transmittance factor of the structural components per climatic zone.

Table 3.3: Maximum permitted thermal conductivity factor of structural components per climatic zone. [6]

Structural Components	Thermal Conductivity Factor U [$W/(m^2 * K)$]			
	Zone A	Zone B	Zone C	Zone D
External horizontal or inclined surface interacting with the external air (roofs)	0.45	0.40	0.35	0.30
External walls interacting with the external air	0.55	0.45	0.40	0.35
Floors interacting with the external air (pilotis)	0.45	0.40	0.35	0.30
Floors interacting with the ground or with closed unheated space	1.10	0.80	0.65	0.60
External walls in contact with unheated space or with the ground	1.30	0.90	0.70	0.65
Glass frontage of buildings non-opening or partially opening in contact with the external air	2.10	1.90	1.75	1.70
Glass frontage of buildings non-opening or partially opening in contact with unheated space	3.80	3.40	3.00	2.80
opening frame (with or without sheet glass) in contact with the external air	2.80	2.60	2.40	2.20
opening frame (with or without sheet glass) in contact with unheated space	5.00	4.60	4.30	4.00

Furthermore, the spaces of the building should provide the appropriate lighting, depending on the use of each space, in order to ensure visual comfort to the users of the spaces[6]. The level of the general lighting per usage of the building, according to the directions of the Technical Chamber of Greece, is presented on Tables 3.4 and 3.5.

Table 3.4: Level of the general lighting per usage of the building, according to EN 12464-1 2011, (part 1). [6]

Building's or zone's usage	lighting level (lx)	measurement's reference level (m)	Upper Glare Rate (UGR)	Uniformity of lighting (min/mean value)
Detached or Apartment building	200	0.8	-	-
Hotel	300	0.8	22	0.6
Boarding house	300	0.8	22	0.6
Hotel room	250	0.8	-	-
hotel's shared space	100	0.5	28	0.4
Restaurant	200	0.8	-	-
Pastry shop, Cafe	250	0.8	-	-
Night dance hall, music scene	100	0.8	-	-
Theater, cinema	100	0.8	25	0.4
Concert space	100	0.8	25	0.4
Exhibition space, museum	200	0.8	22	0.4
Conference space, amphitheater, court room	500	0.8	19	0.6
Bank	500	0.8	19	0.6
Room of multiple use	300	0.8	19	0.6
Indoor fitness centre, swimming pool	300	0.5	22	0.6
Passageway, shared auxiliary space	100	0	28	0.4
(Shared) bathroom	200	0.8	25	0.4
Kindergarten	300	0.8	19	0.6
Primary and secondary education	300	0.8	19	0.6
Tertiary education, classroom	500	0.8	19	0.6
Tutorial, music school	500	0.8	19	0.6
Hospital	300	0.8	19	0.6
Patient room	100	0.8	19	0.4
Surgery	1000	0.8	19	0.6
Outpatient clinic	500	0.8	19	0.6
Waiting room	200	0.8	22	0.4

Table 3.5: Level of the general lighting per usage of the building, according to EN 12464-1 2011, (part 2). [6]

Building's or zone's usage	lighting level (lx)	measurement's reference level (m)	Upper Glare Rate (UGR)	Uniformity of lighting (min/mean value)
Health centre, medical practice	500	0.8	19	0.6
Psychiatric institution, nursery, special needs institute	300	0.8	19	0.6
Preschool	300	0.8	22	0.4
Prison	300	0.8	22	0.4
Police station	500	0.8	19	0.6
Shopping center	300	0.8	22	0.4
Shop, pharmacy	500	0.8	19	0.6
Fitness institute	400	0.8	22	0.6
Hair salon	400	0.8	19	0.6
Office	500	0.8	19	0.6
Library	500	0.8	19	0.6

Additionally, the renewal of the inside air is essential for the insurance of hygiene conditions. The requirements of fresh air are defined by the use of the conditioned spaces and the occupancy. There are provided different methods, by ELOT EN 15251:2007, for the calculation of the appropriate level of fresh air. The most practical method for the calculation of the air renewal is based on the minimum required levels for the insurance of the appropriate hygiene conditions and for the minimum renewal based on the volume and the occupancy of the building[6]. According to the directions of the Technical Chamber of Greece [6] the design of the ventilation system of a building should be the appropriate based on the building, but it should meet the regulations and the energy analysis of the building should be based on the values of the provided Tables 3.6 and 3.7.

3.2 Classes of building's energy efficiency according to KENAK regulation

According to KENAK regulation [5] buildings are classified into an energy class from A+ to H. The classification is defined on Table 3.8 where:

- R_R is the calculated consumption of primary energy of the reference building.
- T is the quotient of the calculated consumption of primary energy of the building in interest (EP) divided by the calculated consumption of primary energy of the reference building. and the entire classification is based on T.

Table 3.6: Required fresh air per usage of the building (for nonsmoking areas) for the calculation of the energy performance of the building, (part 1). [6]

Building's or zone's usage	People/100m^2 floor surface	fresh air $[m^3/h/person]$	fresh air $[m^3/h/m^2]$
Detached or Apartment building	5	15	0.75
Hotel	15	20	3.00
Boarding house	10	15	1.5
Hotel room	8	15	1.2
hotel's shared space	25	25	6.25
Restaurant	70	25	17.50
Pastry shop, Cafe	80	25	20
Night dance hall, music scene	100	45	45.00
Theatre, cinema	100	25	25.00
Concert space	100	30	30.00
Exhibition space, museum	50	20	10.00
Conference space, amphitheatre, court room	110	25	27.50
Bank	20	30	6.00
Room of multiple use	75	30	22.50
Indoor fitness centre, swimming pool	75	45	33.75
Passageway, shared auxiliary space	-	-	2.60
(Shared) bathroom	-	-	6.00
Kindergarten	50	22	11.00
Primary and secondary education	50	22	11.00
Tertiary education, classroom	50	22	11.00
Tutorial, music school	50	22	12.10
Hospital	30	35	10.50
Patient room	22	25	5.50
Surgery	20	150	30.00
Outpatient clinic	10	50	5.00
Waiting room	55	45	24.75

The total annual consumption of primary energy of the reference building classify it into class B.

A typical certificate of energy efficiency is presented at Figure 3.2 below.

Table 3.7: Required fresh air per usage of the building (for nonsmoking areas) for the calculation of the energy performance of the building, (part 2). [6]

Building's or zone's usage	People/100m^2 floor surface	fresh air $[m^3/h/person]$	fresh air $[m^3/h/m^2]$
Health centre, medical practice	15	50	7.50
Psychiatric institution, nursery, special needs institute	15	25	3.75
Preschool	25	45	11.25
Prison	20	22	4.40
Police station	10	30	3.00
Shopping centre	30	22	6.60
Shop, pharmacy	14	22	3.08
Fitness institute	15	45	6.75
Hair salon	15	30	4.50
Office	10	30	3.00
Library	22	30	6.60

Table 3.8: Classes of buildings' energy efficiency. [5]

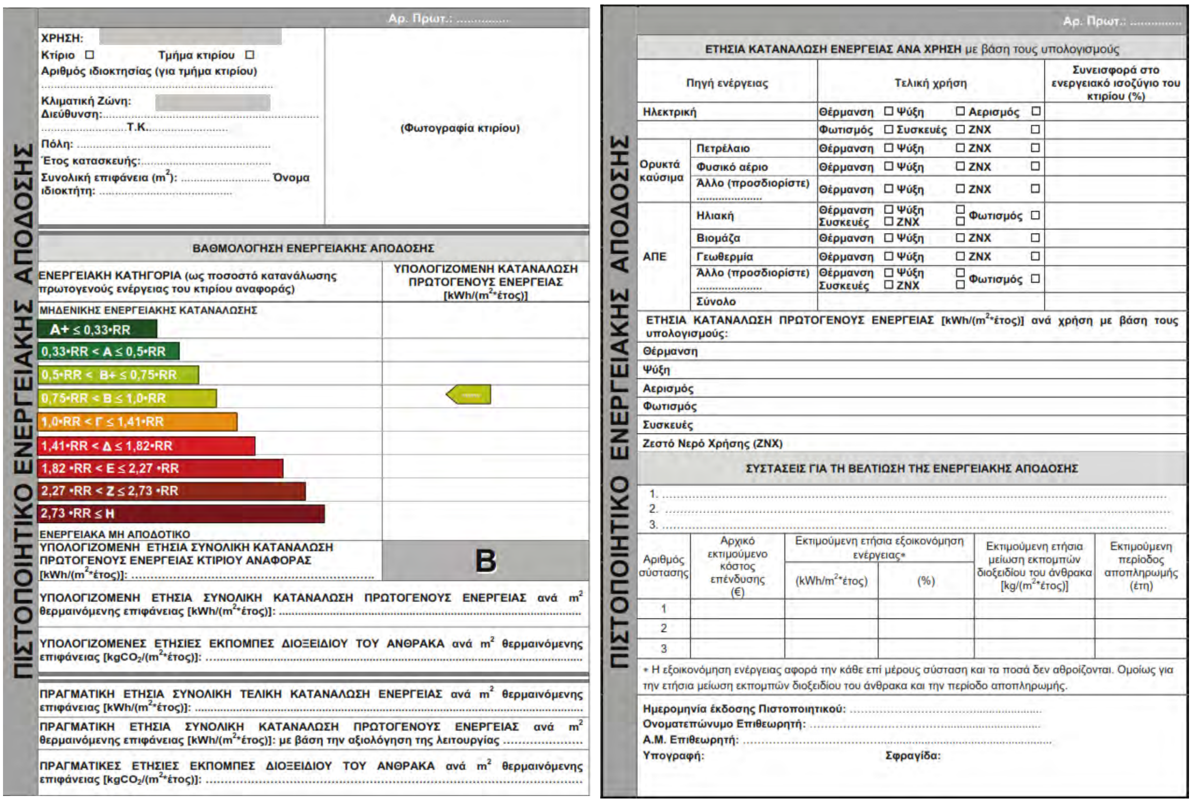
Class	Limits of the class	Limits of the class
A+	$EP \leq 0.33R_R$	$T \leq 0.33$
A	$0.33R_R < EP \leq 0.50R_R$	$0.33 < T \leq 0.50$
B+	$0.50R_R < EP \leq 0.75R_R$	$0.50 < T \leq 0.75$
B	$0.75R_R < EP \leq 1.00R_R$	$0.750 < T \leq 1.00$
C	$1.00R_R < EP \leq 1.41R_R$	$1.00 < T \leq 1.41$
D	$1.41R_R < EP \leq 1.82R_R$	$1.41 < T \leq 1.82$
E	$1.82R_R < EP \leq 2.27R_R$	$1.82 < T \leq 2.27$
F	$2.27R_R < EP \leq 2.73R_R$	$2.27 < T \leq 2.73$
G	$2.73R_R < EP$	$2.73 < T$

3.3 ASHRAE

[7] ASHRAE was formed as the American Society of Heating, Refrigerating and Air-Conditioning Engineers by the merger in 1959 of American Society of Heating and Air-Conditioning Engineers (ASHAE) founded in 1894 and The American Society of Refrigerating Engineers (ASRE) founded in 1904.

ASHRAE provides some standards and guidelines to guide the industry describing recommended practices in designing and installing equipment and providing auxiliary information. These standards and guides refer to the indoor air quality, thermal comfort, energy conservation in buildings, reduction of refrigerant emissions and the designation and safety classification of refrigerants. [8]

(a) (b)



(a)

ΠΙΣΤΟΠΟΙΗΤΙΚΟ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ

Αρ. Πρωτ.: ....

ΧΡΗΣΗ:
Κτίριο ☐ Τμήμα κτιρίου ☐
Αριθμός ιδιοκτησίας (για τμήμα κτιρίου)
....
Κλιματική Ζώνη:
Διεύθυνση:...
..........................Τ.Κ.........................
Πόλη: ....
Έτος κατασκευής:..
Συνολική επιφάνεια (m^2): .... Όνομα ιδιοκτήτη: ....

(Φωτογραφία κτιρίου)

ΒΑΘΜΟΛΟΓΗΣΗ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ

ΕΝΕΡΓΕΙΑΚΗ ΚΑΤΗΓΟΡΙΑ (ως ποσοστό κατανάλωσης πρωτογενούς ενέργειας του κτιρίου αναφοράς)	ΥΠΟΛΟΓΙΖΟΜΕΝΗ ΚΑΤΑΝΑΛΩΣΗ ΠΡΩΤΟΓΕΝΟΥΣ ΕΝΕΡΓΕΙΑΣ [kWh/(m^2*έτος)]
ΜΗΔΕΝΙΚΗΣ ΕΝΕΡΓΕΙΑΚΗΣ ΚΑΤΑΝΑΛΩΣΗΣ	
A+ ≤ 0,33•RR	
0,33•RR < A ≤ 0,5•RR	
0,5•RR < B+ ≤ 0,75•RR	
0,75•RR < B ≤ 1,0•RR	
1,0•RR < Γ ≤ 1,41•RR	
1,41•RR < Δ ≤ 1,82•RR	
1,82 •RR < E ≤ 2,27 •RR	
2,27 •RR < Z ≤ 2,73 •RR	
2,73 •RR ≤ H	
ΕΝΕΡΓΕΙΑΚΑ ΜΗ ΑΠΟΔΟΤΙΚΟ	
ΥΠΟΛΟΓΙΖΟΜΕΝΗ ΕΤΗΣΙΑ ΣΥΝΟΛΙΚΗ ΚΑΤΑΝΑΛΩΣΗ ΠΡΩΤΟΓΕΝΟΥΣ ΕΝΕΡΓΕΙΑΣ ΚΤΙΡΙΟΥ ΑΝΑΦΟΡΑΣ [kWh/(m^2*έτος)]:	B

ΥΠΟΛΟΓΙΖΟΜΕΝΗ ΕΤΗΣΙΑ ΣΥΝΟΛΙΚΗ ΚΑΤΑΝΑΛΩΣΗ ΠΡΩΤΟΓΕΝΟΥΣ ΕΝΕΡΓΕΙΑΣ ανά m^2 θερμαινόμενης επιφάνειας [kWh/(m^2*έτος)]: ....

ΥΠΟΛΟΓΙΖΟΜΕΝΕΣ ΕΤΗΣΙΕΣ ΕΚΠΟΜΠΕΣ ΔΙΟΞΕΙΔΙΟΥ ΤΟΥ ΑΝΘΡΑΚΑ ανά m^2 θερμαινόμενης επιφάνειας [$kgCO_2$/(m^2*έτος)]: ....

ΠΡΑΓΜΑΤΙΚΗ ΕΤΗΣΙΑ ΣΥΝΟΛΙΚΗ ΤΕΛΙΚΗ ΚΑΤΑΝΑΛΩΣΗ ΕΝΕΡΓΕΙΑΣ ανά m^2 θερμαινόμενης επιφάνειας [kWh/(m^2*έτος)]: ....

ΠΡΑΓΜΑΤΙΚΗ ΕΤΗΣΙΑ ΣΥΝΟΛΙΚΗ ΚΑΤΑΝΑΛΩΣΗ ΠΡΩΤΟΓΕΝΟΥΣ ΕΝΕΡΓΕΙΑΣ ανά m^2 θερμαινόμενης επιφάνειας [kWh/(m^2*έτος)]: με βάση την αξιολόγηση της λειτουργίας ....

ΠΡΑΓΜΑΤΙΚΕΣ ΕΤΗΣΙΕΣ ΕΚΠΟΜΠΕΣ ΔΙΟΞΕΙΔΙΟΥ ΤΟΥ ΑΝΘΡΑΚΑ ανά m^2 θερμαινόμενης επιφάνειας [$kgCO_2$/(m^2*έτος)]: ....

(b)

ΠΙΣΤΟΠΟΙΗΤΙΚΟ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ

Αρ. Πρωτ.: ....

ΕΤΗΣΙΑ ΚΑΤΑΝΑΛΩΣΗ ΕΝΕΡΓΕΙΑΣ ΑΝΑ ΧΡΗΣΗ με βάση τους υπολογισμούς

Πηγή ενέργειας		Τελική χρήση	Συνεισφορά στο ενεργειακό ισοζύγιο του κτιρίου (%)
Ηλεκτρική		Θέρμανση ☐ Ψύξη ☐ Αερισμός ☐	
		Φωτισμός ☐ Συσκευές ☐ ΖΝΧ ☐	
Ορυκτά καύσιμα	Πετρέλαιο	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	
	Φυσικό αέριο	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	
	Άλλο (προσδιορίστε)	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	
ΑΠΕ	Ηλιακή	Θέρμανση ☐ Ψύξη ☐ Φωτισμός ☐ Συσκευές ☐ ΖΝΧ ☐	
	Βιομάζα	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	
	Γεωθερμία	Θέρμανση ☐ Ψύξη ☐ ΖΝΧ ☐	
	Άλλο (προσδιορίστε)	Θέρμανση ☐ Ψύξη ☐ Φωτισμός ☐ Συσκευές ☐ ΖΝΧ ☐	
	Σύνολο		

ΕΤΗΣΙΑ ΚΑΤΑΝΑΛΩΣΗ ΠΡΩΤΟΓΕΝΟΥΣ ΕΝΕΡΓΕΙΑΣ [kWh/(m^2*έτος)] ανά χρήση με βάση τους υπολογισμούς:

Θέρμανση
Ψύξη
Αερισμός
Φωτισμός
Συσκευές
Ζεστό Νερό Χρήσης (ΖΝΧ)

ΣΥΣΤΑΣΕΙΣ ΓΙΑ ΤΗ ΒΕΛΤΙΩΣΗ ΤΗΣ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ

1. ....
2. ....
3. ....

Αριθμός σύστασης	Αρχικό εκτιμούμενο κόστος επένδυσης (€)	Εκτιμούμενη ετήσια εξοικονόμηση ενέργειας*		Εκτιμούμενη ετήσια μείωση εκπομπών διοξειδίου του άνθρακα [kg/(m^2*έτος)]	Εκτιμούμενη περίοδος αποπληρωμής (έτη)
		(kWh/m^2*έτος)	(%)		
1					
2					
3					

* Η εξοικονόμηση ενέργειας αφορά την κάθε επί μέρους σύσταση και τα ποσά δεν αθροίζονται. Ομοίως για την ετήσια μείωση εκπομπών διοξειδίου του άνθρακα και την περίοδο αποπληρωμής.

Ημερομηνία έκδοσης Πιστοποιητικού: ....
Ονοματεπώνυμο Επιθεωρητή: ....
Α.Μ. Επιθεωρητή: ....
Υπογραφή: Σφραγίδα:

Figure 3.2: Figures 3.2(a) and 3.2(b) present the typical certificate of energy efficiency. [5]

3.3.1 ASHRAE 62.1 and 90.1 standards

In the current thesis standards 62.1 and 90.1 of ASHRAE are followed in the appropriate fields. Standard 62.1 specialises at ventilation for acceptable indoor air quality and standard 90.1 is an energy standard for buildings except low-rise residential buildings [8].

According to [8], the purpose of standard 62.1 is to specify minimum ventilation rates and auxiliary measures to provide acceptable indoor air quality to occupants. It defines requirements for ventilation and air-cleaning system, the design of it, the installation, the commissioning, the operation and maintenance. The ventilation requirements are based on chemical, physical and biological contaminants which can pollute the quality of the air. Additionally, it addresses the new and existing buildings. [9]

The purpose of standard 90.1, according to [8]is to provide minimum requirements for the energy efficient design of buildings, except of the low-rise residential buildings. These requirements refer to the design, construction and plan for operation and maintenance as well as utilisation of on site, energy resources. Furthermore, the provisions of the standard do not apply to single-family houses, multi-family structures of three stories or fewer, mobile and modular houses. Additionally, the provisions do not apply to buildings that do not use either electricity or fossil fuel. It applies to new buildings or new portions of buildings and their systems and new systems and equipment in existing buildings. The scope of this standard is not to circumvent any safety, health or environmental requirements according to [8].

3.3.2 RTS Method

The heating and cooling loads of a commercial building can be calculated by different methods. One method of ASHRAE is the Radiant Time Series (RTS).

The following calculations are in accordance with [10], [11], [12], [13], [14]. For every element is calculated the heat gain of it for 24 hours a of the design day. The heat gains are divided into gains from radiation and transduction. Moreover, at the gain of radiation is implemented the appropriate time sequence. Additionally, the cooling load of every hour and every consisting cooling load calculation needs the sum of the conductive and the offset time radiation.

Starting with the gained heat by the walls and roofs, the calculation of their conduction needs the use of the conductive time sequence (CTS). The equation which gives the surface hourly heat gain is

$$q_\theta = c_0 q_{i,\theta} + c_1 q_{i,\theta-1} + c_2 q_{i,\theta-2} + c_3 q_{i,\theta-3} + \ldots.. + c_{23} q_{i,\theta-23} \tag{3.1}$$

Where q_θ is the hourly surface heat gain, $q_{i,\theta}$ is the heat by conduction for the calculated hour, $q_{i,\theta-n}$ is the heat by conduction of the surface n hours before the calculated hour and $c_0, c_1, ..$ the factors of conduction sequence. The calculation of every hourly heat gain uses the conduction time sequence for the previous 23 hours.

Next is the heat gain of the openings. This is divided into heat gain due to direct radiation, diffusion and conductivity and it is described by the equations 3.2 , 3.3 and 3.4.

$$q_{b,i} = AE_D SHGC(\theta) \tag{3.2}$$

Where

- $q_{b,i}$ is the heat gain due to direct radiation
- A is the surface area of the opening
- E_D is the direct radiation of the surface
- $SHGC(\theta)$ is the sun's heating gain factor

$$q_{d,i} = A(E_d - E_r) < SHGC >_D \tag{3.3}$$

- $_{d,i}$ is the heat gain due to diffusion
- A is the surface area of the opening
- E_d is the diffusion's radiation

- E_r is radiation of the ground's reflection
- $< SHGC >_D$ is the sun's heat gain factor of direct radiation

(3.4) $$q_{c,i} = AU(t_{out} - t_{in})$$

- $q_{c,i}$ is the heat gain due to conductivity
- A is the surface area of the opening
- U is the surface's thermal permeability factor
- t_{out} is the external temperature
- t_{in} is the desirable internal temperature

In case of internal shading these three parts are added and handled as a quantity in the next steps.

After these heat gains follow the internal gains. The internal gains are heat gains which come from the lighting, occupancy and internal equipment. The heat gains which come from the lighting are calculated by the 3.5 equation.

(3.5) $$q_{tot} = q_{c,\theta} + q_{r,\theta} = (q_{t,\theta} * C_p) + R_p * (r_0 * q_{r,\theta} + r_1 * q_{r,\theta-1} + ... + r_{23} * q_{r,\theta-23})$$

Where

- $q_{t,\theta}$ equals to $q_\theta * L_c * H_{c,\theta}$
- qr,θ equals to $q_{t,\theta} * R_p$
- q_θ is the lighting load per hour θ
- L_c is the lighting factor
- $H_{c,\theta}$ is the heterochronism per hour θ
- R_p, C_p is the percentage of the radiant and conductive heat gain
- $r_0, r_1, ..$ are the factors of the radiant sequence

The heat gains which come from the occupancy are divided into sensible and latent. The sensible heat gain is calculated by the 3.6 equation.

(3.6) $$q_{ai} = \sum_{j=1}^{k} F_{aj} * N_{ji}$$

Where

- q_{ai} is the sensible heat gain coming from the people at i hour.
- j is the type of energy grade of the people according to ASHRAE's table
- F_{aj} is the sensible load of a person with j energy grade, which is dependent on the dry bulb temperature of the space
- N_{ji} is the number of the people with j energy grade, which occupy the space at i hour

The heat gain coming from the equipment is, also, divided into sensible and latent. The equation for the calculation of the sensible heat gain is presented at 3.7.

(3.7)
$$q_a = (\sum_{j=1}^{k} F_{aj} * N_j) + q_1$$

Where

- q_a is the total sensible heat gain coming from the equipment
- j is the type of the equipment according to ASHRAE
- F_{aj} is the sensible load of a type j appliance
- N_j the number of type j appliances which operate in the space
- q_1 is the total sensible heat gain coming from the appliances, which are not included into the tables

The cracks, also, contribute to the total load of the building. The RTS method consider the heat gains coming from the cracks only when there are no air changes, in the space, coming from an air handling unit. The heat gains of the cracks are calculated by the 3.8 equation.

(3.8)
$$q_i = (\sum_{j=1}^{n} P_j * a_j * b) * \Delta t_i$$

Where

- q_i is the total heat gain by the cracks at i hour
- P_j is the perimeter of the j opening
- n is the number of the openings
- a_j is the air infiltration factor of the j opening, which is dependent on the type of the opening.
- b is a factor, which depends on the building's exposure to air, the ratio of the external openings' surface to the internal openings' surface and the openings' location

- Δt_i is the difference between the external and the internal dry bulb temperature at i hour

The ventilation refers to the introduction of outside air for the ventilation of the conditioned spaces. heat gain by the ventilation is divided into sensible and latent and is calculated by 3.9 equation.

$$q_{ai} = 0.29 * V * n * \Delta t_i \tag{3.9}$$

Where

- q_{ai} is the sensible heat gain by ventilation at i hour
- V is the volume of the space
- n is the number of the air changes per hour
- Δt_i is the difference between the external and the internal dry bulb temperature at i hour

The RTS method converts the heat gains by radiation into cooling load with the use of the radiation's sequence factors. In this way cooling load due to radiation is calculated by the 3.10 equation.

$$Q_{r,\theta} = r_0 q_{r,\theta} + r_1 q_{r,\theta-1} + r_2 q_{r,\theta-2} + .. + r_{23} q_{r,\theta-23} \tag{3.10}$$

Where

- $Q_{r,\theta}$ is the radiation's cooling load (Q_r) for the current hour θ
- $q_{r,\theta}$ is the radiation's heat gain for the current hour θ
- $q_{r,\theta-n}$ is the radiation's heat gain for n hours earlier
- r_0, r_1 is the radiation's sequence factor

Finally, the total cooling load is the sum of the radiation's cooling load plus the transduction's heat gain.

Chapter 4

Air Conditioning

In this chapter we are going to present the appropriate theory about the air conditioning system. First we start with general information about this system and then we present specific information about the air conditioning system on this project.

Air conditioning refers to a cooling, heating and ventilation system. An important factor for the selection process of the air conditioning system is COP or coefficient of performance. COP represents the efficiency of a system. It can, also, indicate the air conditioning system of a building and describe the general function of it. COP is the ratio of the useful heating, cooling provided power to the required electric power.[15]

4.1 Categories of Air Conditioning Systems

Air conditioning systems, according to [16], are divided into

- Central Air conditioning and
- Room air conditioning systems

The methods and the means a system use in order to create the desirable conditions divide the air conditioning systems into

- All Air Systems
- All Water Systems
- Air-Water Systems

4.1.1 All Air Systems

The characteristic of all air systems, according to [16] , is the transfer of processed air into the conditioned space, through a pipe network. Figure 4.1 shows an all air system.

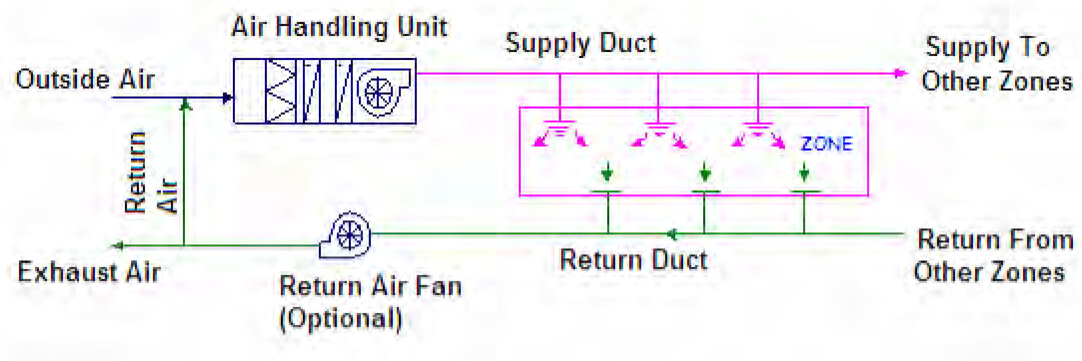


Figure 4.1: All Air System [17]

Air transports energy from the conditioned space to the Air Conditioning plant. In all air systems, air is processed in the air conditioning plant and then conveyed to the conditioned space through insulated ducts using blowers and fans. This air extracts -in summer- or supplies -in case of winter- the required amount of sensible and latent heat from/-to the conditioned space. the returned air from the conditioned space is conveyed back to the plant and then undergoes again the required processing in order to complete the cycle. [17]
The use of air-handing units (AHU) or roof top packages (RTP) to condition air categorises the system. The conditioned air is sent through a duct network to the occupied space, heat or cool the space as space's needs require and then returned back to the AHU or RTP through a return duct network. Air Handing Units contain a cooling coil, which is connected to a chiller or condensing unit, a heating coil, which is connected to boilers or electric heaters, filters and one or more circulating fans. Roof Top Packages contain refrigerant cooling cycle, heating coils, which are connected to boilers or electric heaters, filters and one or more circulating fans. [17]

All air systems require the majority of air supplied to a space be returned to the air-handing unit for reconditioning, or exhausted from the building. The air may be transmitted in a return duct system or through plenums formed by various elements of a building, such as suspended ceiling or the building structure. [17]

4.1.2 All Water Systems

In these systems, water is cooled or heated in a central installation and then delivered to terminal devices. Then, the terminal devices, which are installed locally in the conditioned spaces, undertake the cooling, heating, dehumidification, filtration and the renewal of the air in the conditioned space. [16]

Figure 4.2 is a schematic of a basic all water system. Cold or hot water is circulated through the distribution system when cooling or heating is required. A chiller is responsible for cooling water, which is circulated via pumps to the occupied space and passed through terminal units. The terminal units circulate room air and absorb unwanted heat. In this system a boiler is used in order to heat water. Hot water is circulated via pumps to the occupied space and passed through the same terminal units. The terminal units circulate room air and add heat to the space.[17]

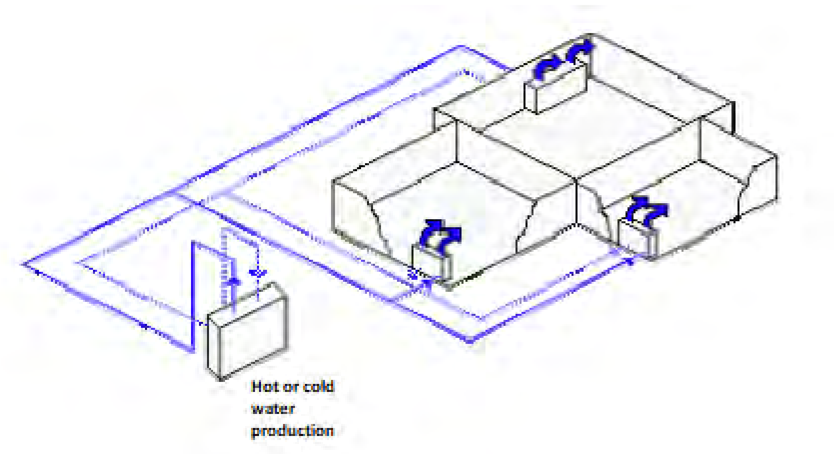


Figure 4.2: All Water System [17]

4.1.3 Air-Water Systems

Air-Water systems use air and water simultaneously, providing cooled or heated water and processed air, in order to provide the desirable conditions in a space. The air and water are cooled or heated in a central plant. The provided air covers ventilation needs, but it also assumes part of the heating-cooling load. A terminal unit receive the provided water and creates the desirable conditions in the air conditioned space. The complete system consists of a central plant for cooling or heating of water and air, ducting system with fans for conveying air, water pipelines and pumps for conveying water and a room terminal. The room terminal can be a fan coil unit, an induction unit or a radiation panel. Figure 4.3 can give a clearer view on these systems, showing the schematic of a basic air-water systems. Only one conditioned space is shown in the schematics, but in existing systems the air-water systems can serve multi-zones simultaneously. The latent energy primarily from outside air is removed in a dedicated air handling unit. The air handing unit distributes conditioned air for ventilation and pressurization to indoor space. The sensible energy from the indoor space is carried in the water, which reduces space requirements. [16] & [17]

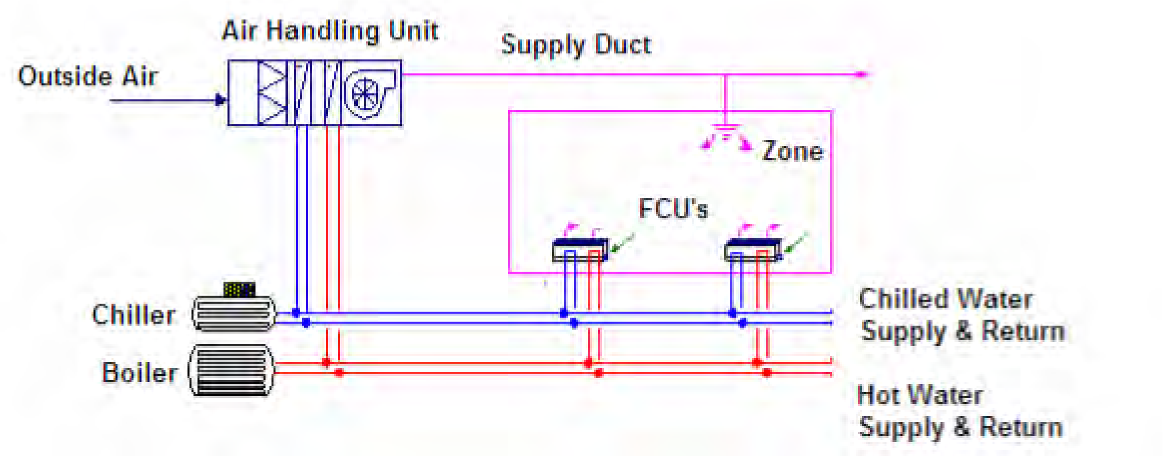


Figure 4.3: Air-Water Central System [17]

4.2 Dimensioning of the air conditioning load

The calculations for the cooling or heating loads of every space inside a building are based on the architectural plot of the building. Because of the complexity of the calculations the use of a specific software is usual in order to calculate these loads. After this we sum the cooling/heating loads of every space inside of the building in order to find the total cooling/heating load. The interesting load for the selection of the appropriate air conditioning system is the major load. Ultimately, the cooling load is the major one.

4.3 Boilers

Boilers transfer heat to a fluid. They are pressure vessels designed for this transport. The fluid is usually water in the form of liquid or steam. A boiler burns fossil fuels (or uses electric current) and transfers the released heat to water (in water boilers) or to water and steam (in steam boilers). Boilers can burn coal, wood, various grades of fuel oil, waste oil, various types of fuel gas or operate as electric boilers. [15]

4.4 Air cooled chiller

The basic components of a vapour-compression, liquid-chilling system, according to [15], include a compressor, liquid cooler (evaporator), condenser, compressor drive, liquid-refrigerant expansion or flowcontrol device, and control centre; it may also include a receiver, economiser, expansion turbine, and/or subcooler.

Describing the operation of an air cooled chiller, liquid (usually water) enters the cooler, where it is chilled by liquid refrigerant evaporating at a lower temperature. The refrigerant vaporises and is drawn into the compressor, which increases the pressure and temperature of the gas so that it may be condensed at the higher temperature in the condenser. The condenser cooling medium is warmed in the process. The condensed liquid refrigerant then flows back to the evaporator through an expansion device. Some of the liquid refrigerant changes to vapour (flashes) as pressure drops between the condenser and the evaporator. Flashing cools the liquid to the saturated temperature at evaporator pressure. It produces no refrigeration in the cooler. [15]

4.5 Fan Coil Unit

Fan Coil Units (FCU) are internal fan-element units. They are part of an HVAC system and they are found in residential, commercial and industrial buildings. We use them in water air conditioning systems. In these systems the air's condition control happens through the space's air circulation inside of the FCUs. FCU (Figure 4.4) is a terminal device and hot or cold water circulates in it. A fan inside of the FCU forces the air to circulate. It is installed in building's spaces. [15]

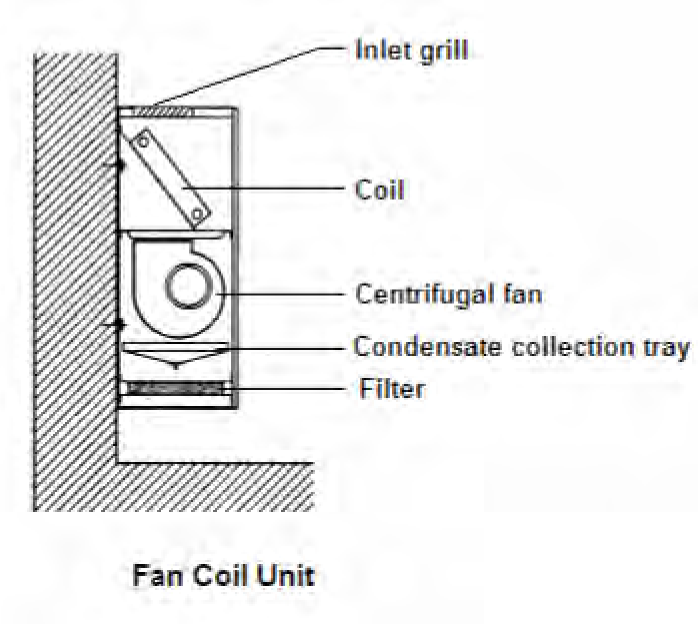


Figure 4.4: Fan Coil Unit [17]

A fan coil unit contains finned tube cooling coil, fan, air filter, insulated drain tray with provision for draining condensate water and connections for cold water lines. The cold water circulates through the finned tube coil while the fan draws warm air from the conditioned space and blows it over the cooling coil. The air is cooled and dehumidified as it flows through the cooling coil. Then, the cold and dehumidified air is supplied to the conditioned space for satisfaction of the conditioned space's demands. In some designs the fan coil unit also consists of a heating coil, which could be in the form of an electric heater or steam or hot water. [17]

4.6 Radiator heating

Radiators are heat-distributing devices. They are used in low-temperature and steam water-heating systems. They emit heat by a combination of radiation to surfaces and occupants in the space and convection to the air in the space. Radiators are used with steam or hot water. Lastly, they are installed in areas of greatest heat loss such as under windows, along cold walls and at doorways. [15] Figure 4.5 shows a radiator system.

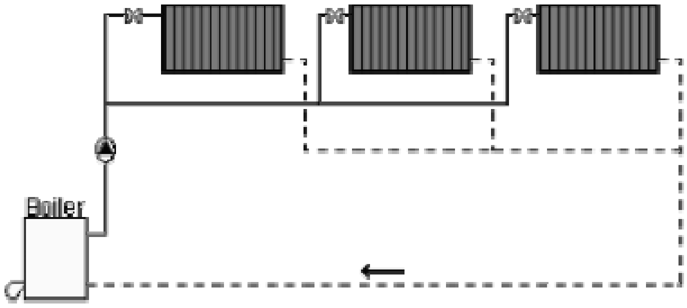


Figure 4.5: Radiator System [17]

Radiators need a fluid to operate, usually water, which is heated by a boiler. The hot water, starting from the boiler, is circulated to multiple radiator units and then returned after exchanging heat with the room air.

4.7 Ventilation and Infiltration

Air exchange of outdoor air with the internal air of a building is classified into:

- Ventilation,
- Infiltration

Ventilation and infiltration are part of the acceptable indoor air quality and thermal comfort. Ventilation is used to provide acceptable indoor air quality.[18]

It can be forced or natural. Natural ventilation is the flow of air through openings like windows and doors or penetrations in the envelope of a building. Forced is the intentional movement of air into and out of a building using fans and vents, which is, also, called mechanical ventilation. Natural ventilation is not appropriate in commercial and institutional buildings, but the use of operable windows can be preferable for taking advantage of cool outdoor conditions when interior cooling is required.[18]

Infiltration is the flow of outdoor air into a building through cracks and other unintentional openings and through the normal use of exterior doors. Figure 4.6 is a schematic of air exchange in a building of two spaces. Exfiltration is the reserved process of infiltration. It is the flow of indoor air out of the building, which flows through the same type of openings. Transfer air is the air which transports from one interior space to the other one. [18]

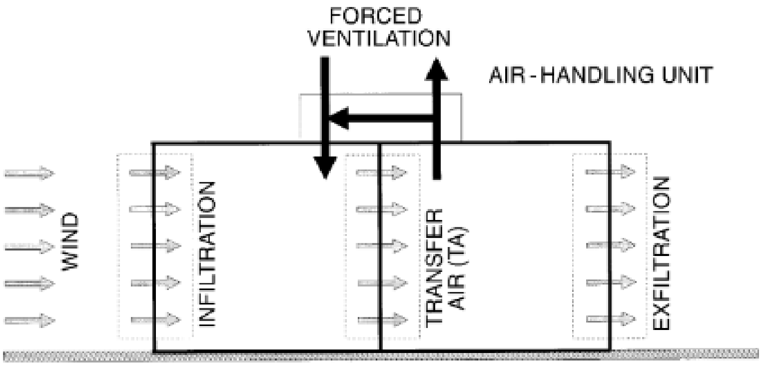


Figure 4.6: Forced Ventilation, Infiltration and Exfiltration in a Building of two spaces. [18]

Infiltration and natural ventilation can meet the needs of a residential building, but this depends on weather conditions, building construction and maintenance. Natural ventilation through operable windows can help control airborne contaminants and interior air temperature, but it can have a great impact at energy cost if used while a residence's heating or cooling equipment is operating. [18]

4.7.1 Forced-Air Distribution Systems

Commercial and institutional buildings are required to use forced ventilation and to reduce infiltration. In a suitable designed and operated system forced ventilation can control the air exchange. It should provide qualitative air and thermal comfort in the internal of the building [18]. Figure 4.7 shows a simple all air Air-Handling Unit.

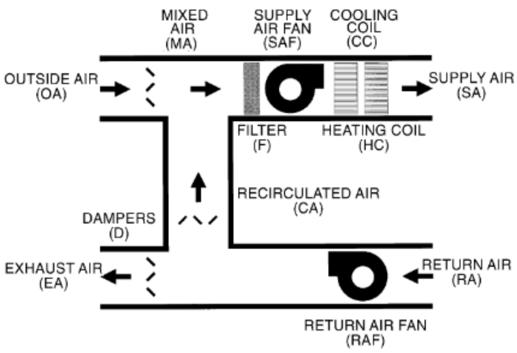


Figure 4.7: Simple All Air Air-Handling Unit with associated Airflows. [18]

An Air-Handling Unit (AHU) conditions the air of a building. According to [18], a simple Air-Handling Unit, as shown at figure 4.7 absorbs air from the environment (outside air), processes it and promotes it into the conditioned spaces (supply air). Then, air from the conditioned spaces (returned air) is returned through ducts. A part of that air is promoted outside of the building (exhaust air) and the rest of it is recirculated (recirculated air). The recirculated air is combined with new outside air, forming mixed air, conditioned and promoted to the thermal zones. Air handling systems varies and a particular system can have fewer airflows or it can be more complicated than the system of figure 4.7.

The outside airflow, which an air-handling unit inserts into a building or zone, can be described by the outside air fraction (X_{oa}). According to [18], the outside air fraction is the volumetric flow rate of outside air brought in by the air handler to the total supply airflow rate:

$$X_{oa} = Q_{oa}/Q_{sa} = Q_{oa}/Q_{ma} = Q_{oa}/(Q_{oa} + Q_{ca}) \tag{4.1}$$

where

- Q_{oa} is the volumetric flow rate of outside air
- Q_{sa} is the supply airflow rate
- Q_{ma} is the mixed airflow rate
- and Q_{ca} the recirculated airflow rate.

The outside air fraction in the form of a percentage is called percent outside air. The supply air is required to meet the thermal load and the quality requirements [18]. ASHRAE standard 62.1 provides requirements for a ventilation system. The outside air fraction describes the degree of recirculation, where a low value shows a high rate of recirculation and similarly a high value shows a low rate of recirculation. Conventional all air air-handling systems for commercial and institutional buildings, according to [18], have approximately 10 to 40% outside air.

4.7.2 Indoor Air Quality

The concentration of pollutant inside of a building depends on the impact of pollutant sources and the total rate of pollutant removal. Pollutant sources include the outdoor air and indoor sources like occupants, furnishings, appliances and the soil adjacent to the building. The processes of pollutant removal include dilution of the air with outside air, local exhaust ventilation, deposition on surfaces, chemical reactions and air cleaning processes. When contaminant source strength is high, a ventilation rate increase is impractical to control contaminant levels. Effective control methods can be removal or reduction of contaminant sources and local exhaust to control a localised source. [18]

4.7.3 Thermal Loads

The introduced outdoor air into a building constitutes an important part of the total space conditioning load, which includes heating, cooling, humidification, dehumidification. For this reason a reduction of the air exchange rate to the minimum is required. According to [18] air exchange typically represents 20 to 50% of the building's thermal load. Air exchange increases a building's thermal load in three ways based on [18]. First of all is the heating or cooling of the incoming air from the external temperature to the internal or supply air temperature. The rate of energy consumption due to this is:

$$q_s = 60Q\rho c_p \Delta t = 1.1Q\Delta t \tag{4.2}$$

where

- q_s is the sensible heat load, Btu/h
- Q is the airflow rate, cfm
- ρ is the air density, lb/ft^3 (it is about 0.075)
- c_p is the specific heat of air, Btu/lbF^o (it is about 0.24)
- Δt is the temperature difference between indoors and outdoors, F^o

Second is the modification of the internal moisture content of the air. These are latent loads and the rate of their energy consumption is described by equation 4.3 , according to [18].

$$q_l = 60Q\rho\Delta W(1061 + 0.444t) \tag{4.3}$$

where

- q_1 is the latent heat load, Btu/h
- ΔW is the humidity ratio difference between indoors and outdoors, $lb_m water/lb_m dry\ air$
- t is the average of indoor and outdoor temperatures, F^o

Last is the modification of the performance of the envelope insulation system. Airflow through the insulation causes heat exchange between infiltrating or exfiltrating air and the thermal load and thermal load is decreased. Conversely, air exchange in and out of the insulation from outside can increase the thermal load. [18]

Chapter 5

Software of the analysis and alternatives

As it is stated at chapter 3 , for the energy analysis of a building we need the use of specific software. In this chapter we are going to present the software which was used for this research, the reason why we have used especially this software and additional programs which can be used for an energy analysis.

5.1 TEE-KENAK

A recognized program in the Greek community is TEE-KENAK software. It adheres to European standards (ΕΛΟΤ EN ISO 13790) and to national standards. TEE-KENAK was developed by a team of energy saving of the environment research and sustainable evolution institute of the National Observatory of Athens in association with the Technical Chamber of Greece (TEE).

5.2 DOE2

The DOE-2 software was developed by James J. Hirsch & Associates (JJH) in collaboration with Lawrence Berkeley National Laboratory (LBNL). It is a building energy analysis software which can predict the energy use and cost for all types of buildings. It uses a description of the building layout, constructions, operating schedules, conditioning systems, utility rates and weather data in order to execute an hourly simulation of the building and to estimate utility bills. [19]

5.3 EnergyPlus®

Another utilized energy software is EnergyPlus®. EnergyPlus® is an energy simulation program for an entire building. It is used by engineers, architects and researchers in order to model both energy consumption and water use in buildings. The program gives solutions of thermal zones and HVAC system response simultaneously, heat balanced-based solution. It presents hourly results for interaction between thermal zones and the environment with automatically varied time steps for interactions between thermal zones and HVAC systems, data of combined heat and mass transfer between zones, models about window placement, illuminance and glare calculations, HVAC components, build-in HVAC and lighting control strategies, standard summary and detailed output reports with results from annual to sub-hourly. [20]

5.4 FineGreen

In this thesis a program, new for the Greek community was used. This program is FineGreen of 4M company. It's freshness in our country in accordance with the operation method it uses and the results it presents made it appropriate for this thesis.

FineGreen is a BIM simulation program. It embeds the latest version of EnergyPlus® and allows the easy determination of the best energy-efficient building design solution based on the architectural concept through the HVAC (Heating, Ventilation and Air Conditioning) design and the entire project completion. [21]

The program processes the input data from the building envelope to the necessary complementary data. It needs geometry parameters of the building elements, the building location and orientation, the location of a neighbouring building, climate data, system's parameters regarding HVAC and lighting, zone parameters such as operating schedules, density of occupants.

It allows the user to insert the structural data in a 2D view and then to check or edit them in a 3D view. He can, also, define non-conditioned spaces and shading from adjacent buildings. When all these data are inserted into the program, then it is ready to make heating and cooling calculations. It presents separately the heating and the cooling results in a new tab. There the consumption results are available for the entire building or for every defined zone separately. After these the software is ready to make a simulation for a specific time period. This time period can reach an entire year, extracting real time results for the annual energy consumption of the building. [21]

Chapter 6

Data insertion

In this chapter is presented the insertion of the data in the software, giving specific information about the building's data. Here is a 3D view of the studied building (Figure 6.1).

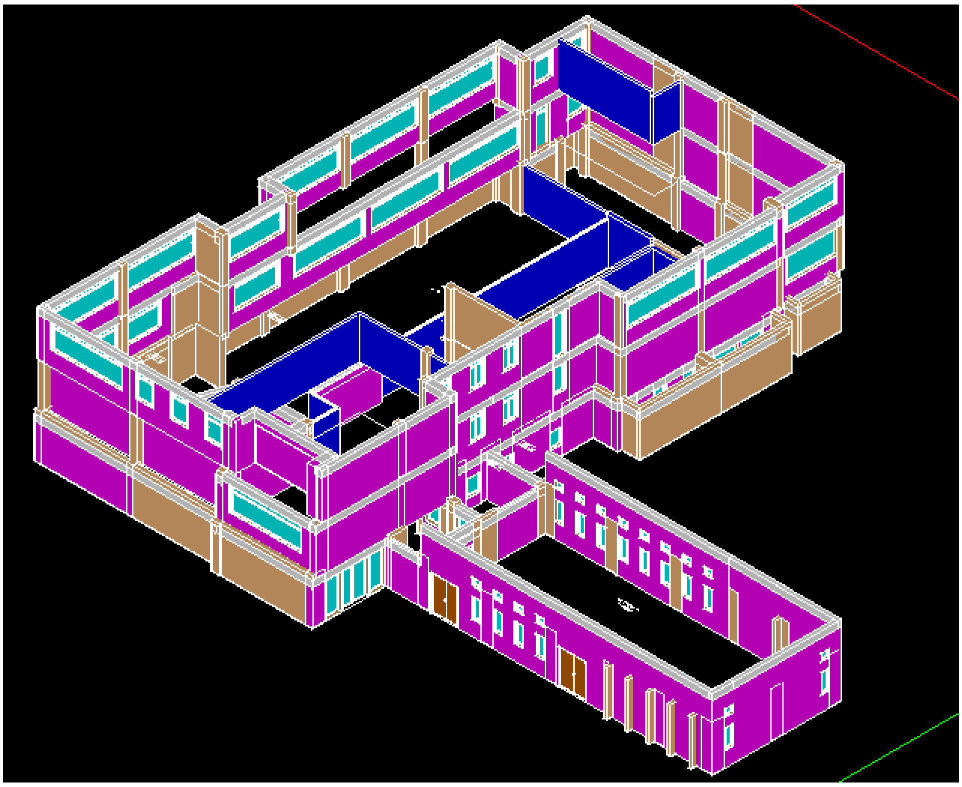


Figure 6.1: A 3D view of the studied building. Personal file.

The energy analysis of the building is calculated with the use of the location and structural data of the building, the activity, lighting, HVAC and external infiltration data of every conditioned zone of the building. These data are presented and analysed in the current chapter.

6.1 Architectural design of the building

The building of the current thesis is an existing building. It is located at Velestino settlement. The data of use was these of Technical education school building of Velestino construction project, February 2015, where employer was the municipality of Riga Feraiou and electrical engineer of the electrical study was Dimitrios Zimeris, by whom the data was provided.

The initial file with architectural design of the studied building is presented at Figure 6.2. After that is presented the plot of every floor, taken as block from the initial file, at Figures 6.3, 6.4, 6.5. The use of these plots is specified in the next section which is levels management 6.2.

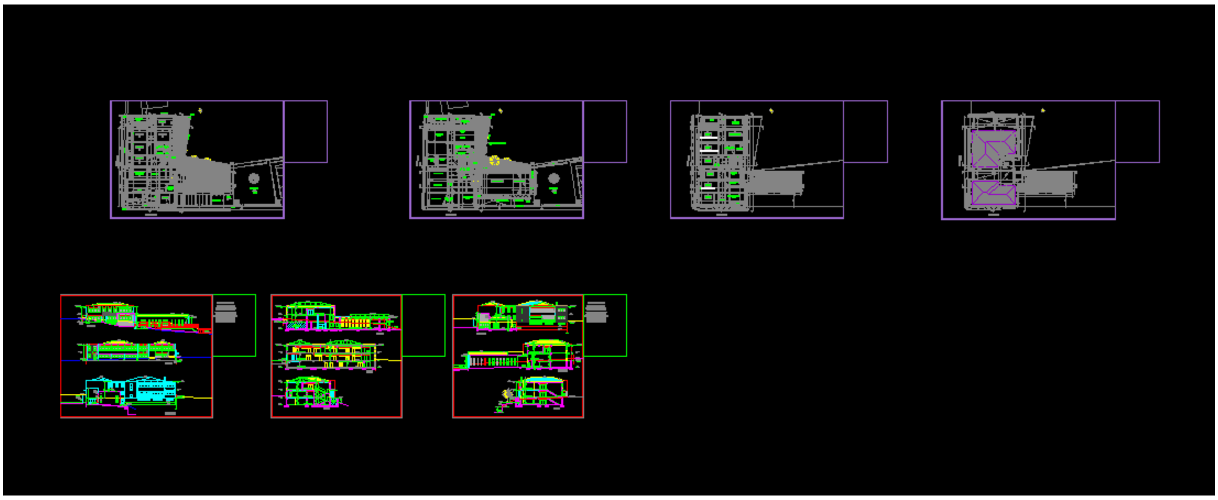


Figure 6.2: The architectural design of the studied building. Personal file.

Figure 6.3: The plot of the basement, taken as a block and inserted into the file of the analysis. Personal file.

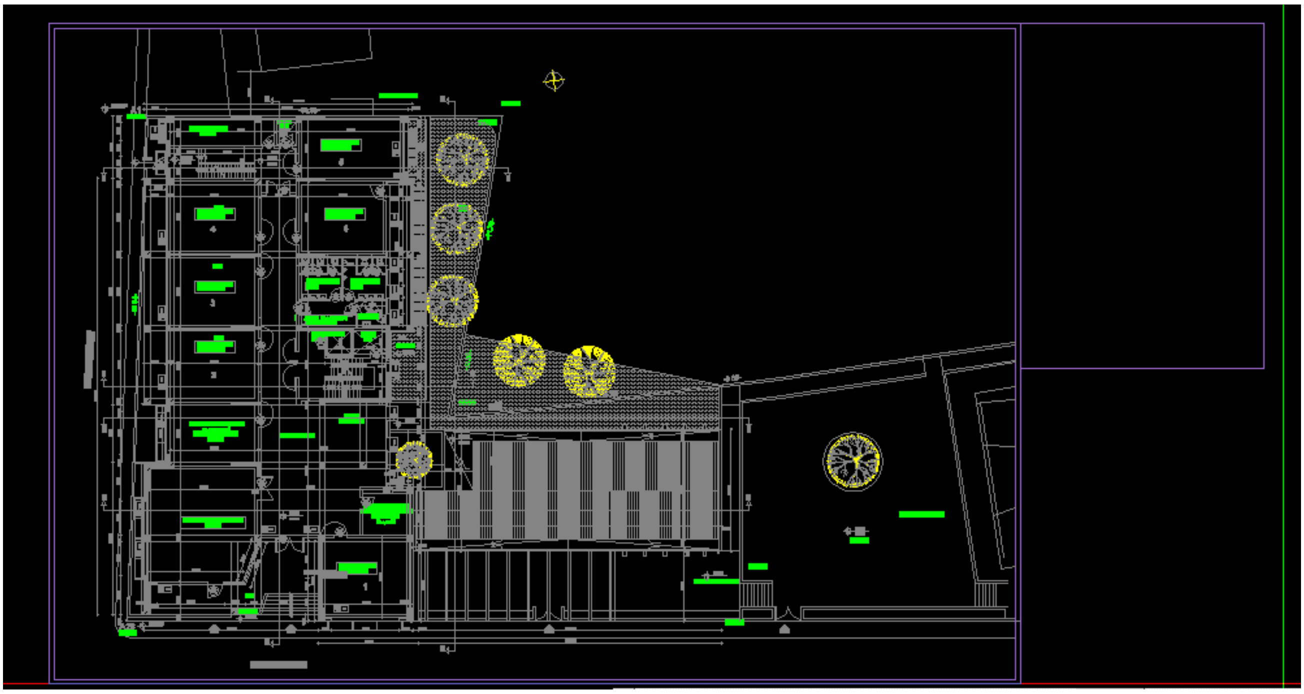


Figure 6.4: The plot of the ground floor, taken as a block and inserted into the file of the analysis. Personal file.

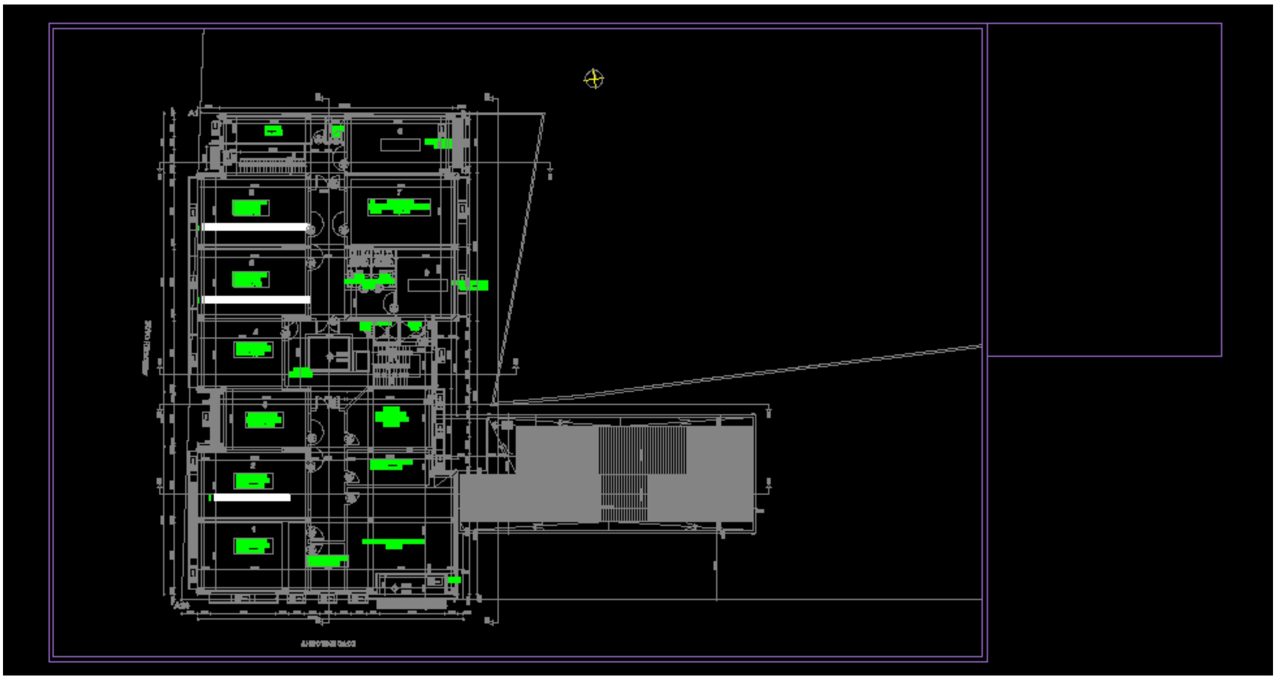


Figure 6.5: The plot of the first floor, taken as a block and inserted into the file of the analysis. Personal file.

6.2 Levels management

In the first stage of the creation of the file for the energy analysis, the initial architectural design should be considered, where the management of the levels is based on this initial plot. The levels management helps us manage the levels of the building in the 3D plot.

First the user insert the architectural design of the building from a .dwg file. Specifically, the plot of every floor is inserted as a block from the initial file into a new .dwg file for the project. Every floor's characteristics (height, name of the floor) should be specified.

For this thesis the building consists of 3 floors, the basement, ground floor and first floor with height -3.30, 0.00 and 3.60 respectively. Moreover, on the basement there is a different space, connected with the rest of the floor, which is a room of multiple use. This room starts from the height of -3.30m and reaches the height of 5.60m. (Figure 6.6)

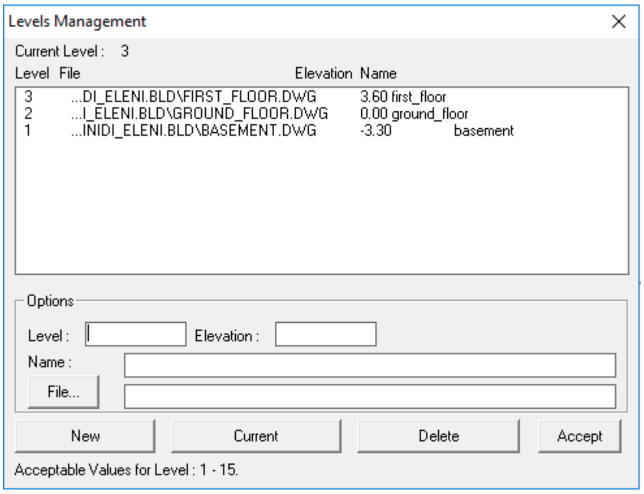


Figure 6.6: Level Management: definition of floors in the software. Personal file.

6.3 Location data

Now, some attributes related the location of the building and settings for the calculations should be stated. Location and weather options are selected from the provided library, which contains EnergyPlus® options. The appropriate option, from the provided, is Thessaloniki.

6.4 Structural data

The insertion of the structural data will give form to the building. These data are presented and analysed in this chapter. Figures 6.7,6.8, 6.9 present the 3D plot for the basement, ground floor and first floor respectively of the formed building.

6.4.1 Walls

Next in turn is the definition of the walls. There is the opportunity to specify a wall and create a special one, if it is not defined by the software (Figure 6.10). So, here, four different walls was defined and used. These are

- an **external wall** made of 5 layers: Gypsum board (2cm), Brick - fired clay - 1120 kg/m3 (9cm), Insulation: Expanded polystyrene - molded beads - 24kg/m3 density (8cm), Brick - fired clay - 1120 kg/m3 (9cm), Gypsum board (2cm), with Inside air film resistance 0.13 and outside air film resistance 0.040. The calculated U factor is U = 0.275.

- an **external underground wall** made of 4 layers, from the outer layer to the inner layer : Gypsum board (2cm), Insulation: Expanded polystyrene - molded beads - 24kg/m3 density (7cm), 4 in.

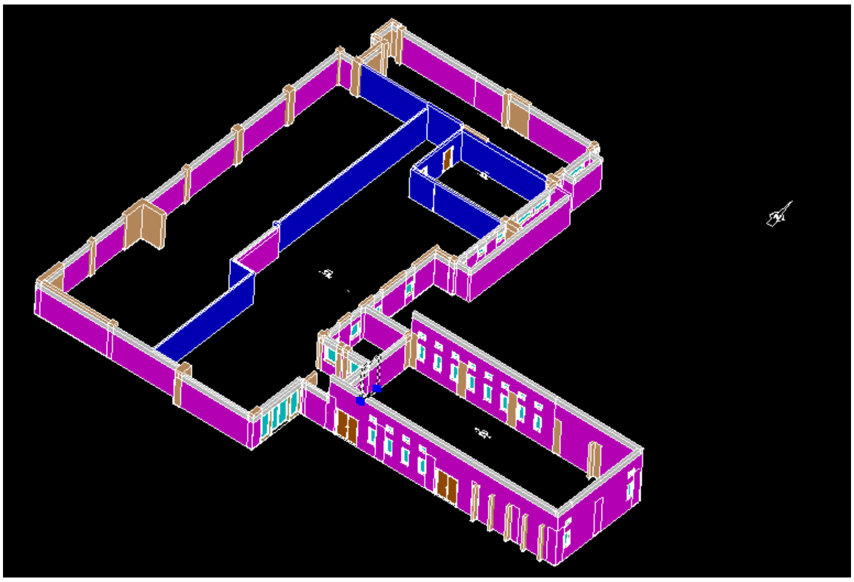


Figure 6.7: The 3D plot of the basement. Personal file.

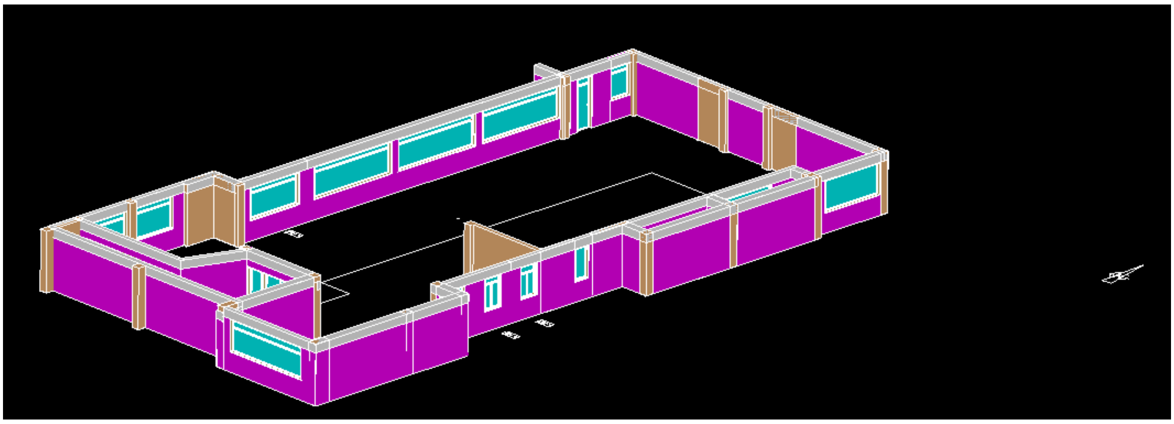


Figure 6.8: The 3D plot of the ground floor. Personal file.

Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete) (25cm), Gypsum board (2cm) with Inside air film resistance 0.13 and outside air film resistance 0.040. The calculated U factor is U = 0.395.

- a **wall for the beam-column** made of 4 layers, from the outer layer to the inner layer : Gypsum board (2cm), Insulation: Expanded polystyrene - molded beads - 24kg/m3 density (7cm), 4 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete) (25cm), Gypsum board (2cm) with Inside air film resistance 0.13 and outside air film resistance 0.040. The calculated U factor is U = 0.395. This wall is defined in order to define the beams and the columns of the building. The height of every beam is 0.50m and the width of it is equal to the width of the wall it belongs to.
- an **internal wall to unconditioned space** made of 4 layers, from the outer layer to the inner layer : Gypsum board (2cm), Insulation: Expanded polystyrene - molded beads - 24kg/m3 density (5cm)

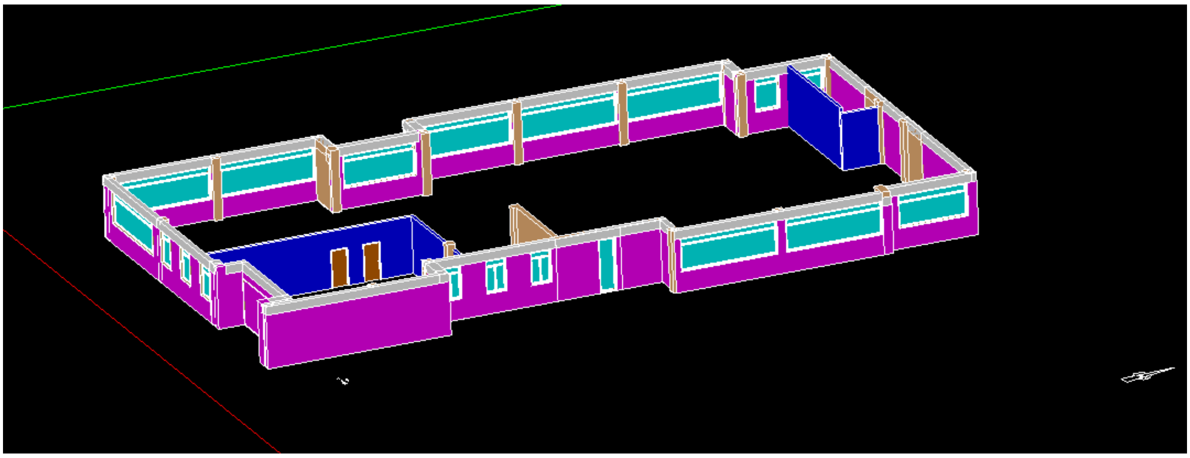


Figure 6.9: The 3D plot of the first floor. Personal file.

Brick - fired clay - 1120 kg/m3 (9cm) Gypsum board (2cm) with inside air film resistance 0.040 and outside air film resistance 0.130. The calculated U factor is U = 0.483.

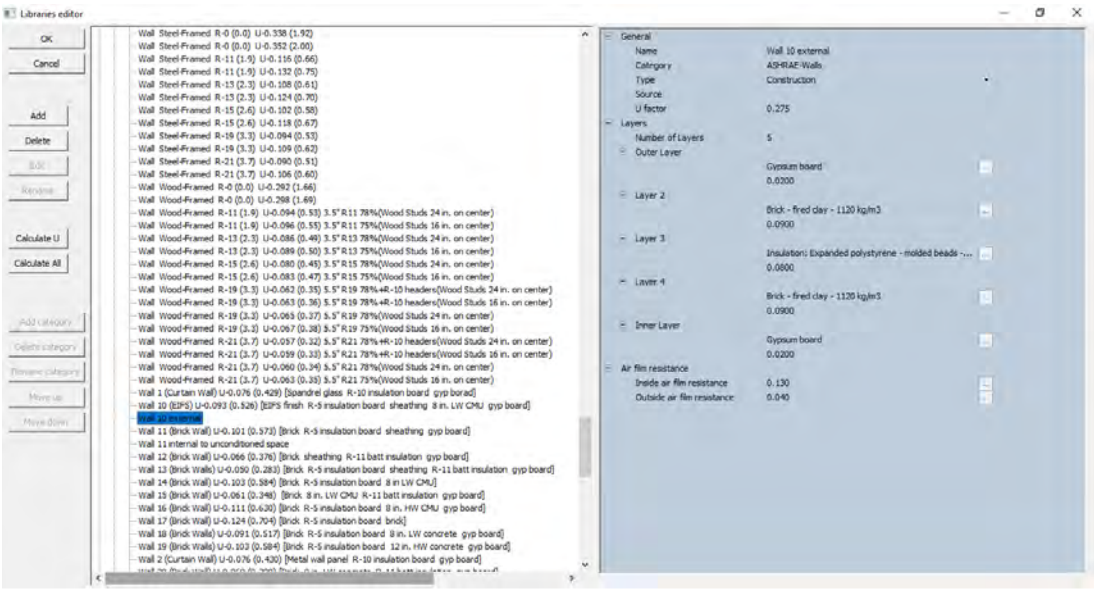


Figure 6.10: Defining the components of the external wall in the library. Personal file.

6.4.2 Openings

The selected windows of the building are defined by the software. These consist of 3 layers, which are from the outer to the inner layer : Clear 3mm. Argon 13mm, Clear 3mm and have U factor U = 2.556.

6.4.3 Floor

Additionally, two types of floor were used, one for a floor above a heated space and one for a floor above the natural environment.

- **Floor above a Heated space** consists of 5 layers and these are - from the outer layer to the inner layer - Acoustic tile (2cm), Stucco (3cm), 4 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete) (15cm), Insulation: Expanded polystyrene - molded beads - 24kg/m3 density (5cm), Gypsum board (2cm) with inside air film resistance 0.10 and outside air film resistance 0.17. The calculated U factor is U = 0.443

- **Floor to natural environment** consists of 4 layers and these are - from the outer layer to the inner layer - Insulation: Expanded polystyrene - molded beads - 24kg/m3 density (5cm), Concrete block (filled) (20cm), Stucco (4cm), Slate or tile (2cm), with inside air film resistance 0.10 and outside air film resistance 0.17. The calculated U factor is U = 0.349

6.4.4 Roof

The first floor and the room of multiple use of the building are the only places which need ceiling. For this reason two different roofs are defined.

- **Roof of the building** (for the first floor), which consists of 5 layers – from the outer layer to the inner layer - Acoustic tile (2cm), Stucco (4cm), Insulation: Expanded polystyrene - molded beads - 28 k6/m3 density (8cm), 4 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete) (15cm), Gypsum board (2cm), with inside air film resistance 0.13 and outside air film resistance (4cm) The calculated U factor is U = 0.33.

- **Roof for the room of multiple use** consists of 3 layers. These layers are - from the outer layer to the inner one - Gypsum board (2cm), 4 in. Concrete at R-0.0625/in (NW 145 lb/ft3 solid concrete) (15cm), Insulation: Expanded polystyrene - molded beads - 24kg/m3 density (8cm) with inside air film resistance 0.13 and outside air film resistance (4cm) The calculated U factor is U = 0.378

6.5 Zones

After the definition and the placement of every structural component in the plot, it is time to define the zones of the building (Figure 6.11). The building of the study is a technical education school. The rooms of the school are separated to conditioned and unconditioned. The conditioned spaces are important for an energy analysis. These spaces are divided into different zones based on the needs of every space.
Three zones define the spaces of the building (Figures 6.12, 6.13, 6.14 presents the zones of every floor). The zones are determined as :

- **room of multiple use**
- **classroom**
- **office**

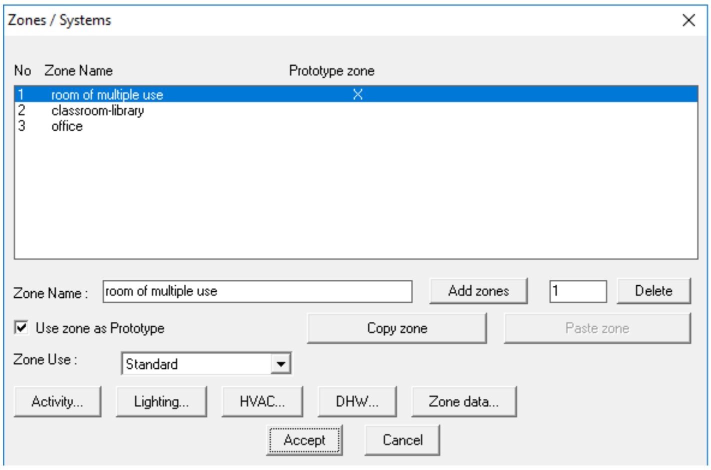


Figure 6.11: Definition of zones in the software. Personal file.

The conditioned spaces of the building occupies $2365m^2$ in total. On the basement somebody can find three zones, one of each category. The room of multiple use zone occupies A = $243.06m^2$, the classroom A = $388.25m^2$ and the office A = $60.55m^2$. On the ground floor there is only one zone, the zone of classroom A = $794.81m^2$. On the first floor there are two zones. One classroom which occupies A = $766.44m^2$ and one office A = $111.96m^2$. Different data, in respect of the activity, the lighting, the HVAC, define every zone. - The building, as an educational facility, has no needs of Domestic Hot Water (DHW).-

The special characteristics of every zone refer to the Activity, lighting and HVAC data.

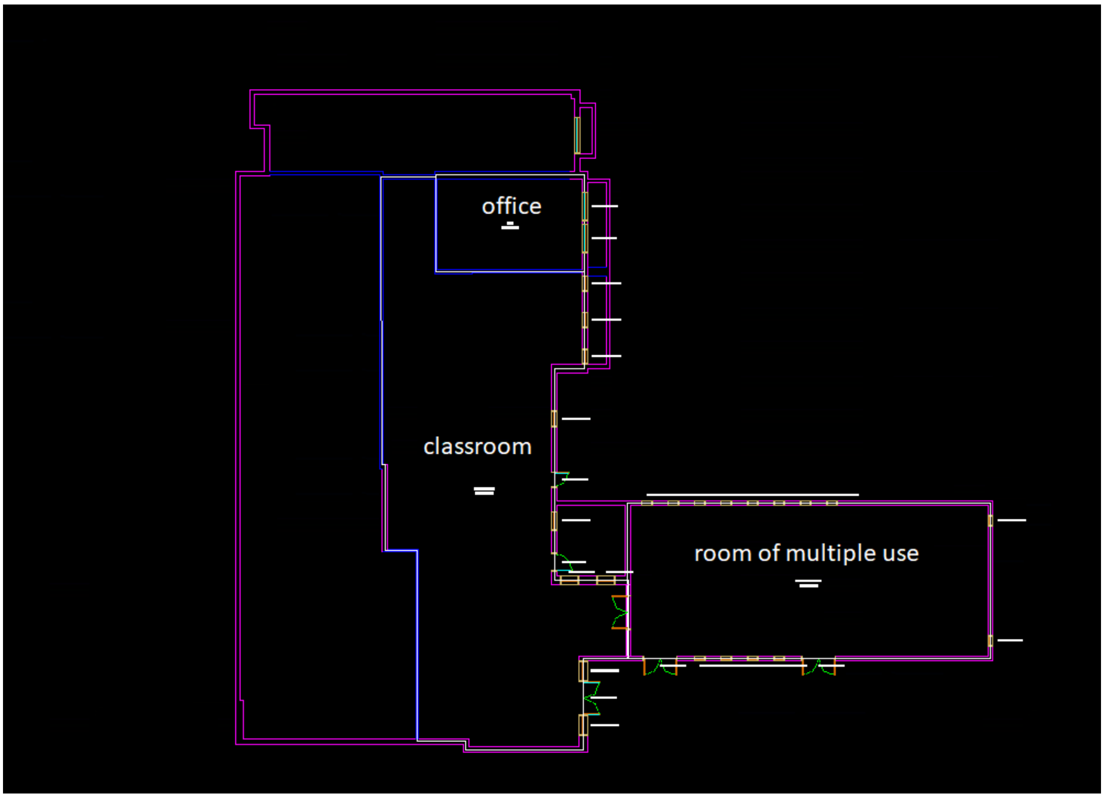


Figure 6.12: Plot of the basement showing the zones. Personal file.

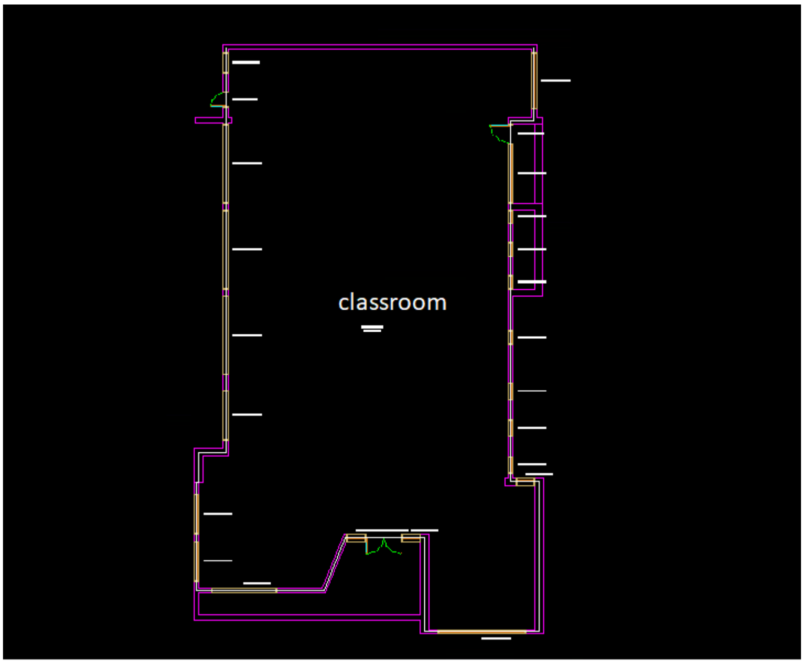


Figure 6.13: Plot of the ground floor showing the zones. Personal file.

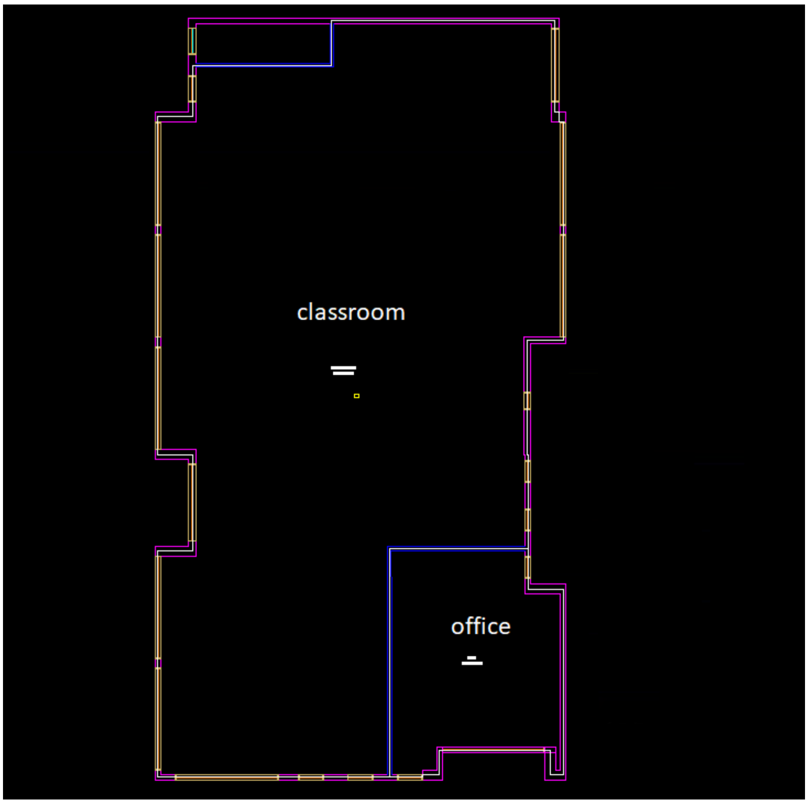


Figure 6.14: Plot of the first floor showing the zones. Personal file.

6.5.1 Room of multiple use

6.5.1.1 Activity data

The selected characteristics, of the room of multiple use, are based on the needs of the building. Starting with the activity data (Figure 6.15), the "Educational Facilities - Multi-use assembly" template is chosen from the library of the software. The floor area is calculated to be $243.06m^2$. The occupancy of the room is based on KENAK 2017 standards for rooms of multiple use and it has density $0.75people/m^2$. The Occupancy - Assembly schedule is based on ASHRAE 90.1 standards. The metabolic rate per person is founded on the activity of the people. The activity "seated, quiet" 108W/person of the provided data is used, which data can be derived from the ASHRAE Handbook of Fundamentals, Chapter 9, Thermal Comfort. The metabolic rate factor depends on the percentage of the men and the women inside the room.

Setpoint temperatures are especially important for the energy consumption of a building. The ideal heating temperature is set at 20^oC and the ideal cooling temperature at 26^oC. When the zone is unoccupied then a set back temperature is selected for energy saving. The selected heating set back is 13^oC and the cooling set back is 32^oC. This means that in an unoccupied period the heating supply is configured to maintain a lower temperature in winter and the cooling supply is configured to maintain a higher temperature in summer. In this building the heating set back is 13^oC and the cooling set back is 32^oC. Furthermore, the ventilation of the building is only mechanical. Staying with the activity data of the room of multiple use, the minimum fresh air, which is based on KENAK 2017 standards, is $8.3lt/s$ per person and $6.25lt/s$ per m^2. Lighting target and default display lighting density are, also, based on KENAK 2017 standards for a room of multiple use with the values of $300lux$ and $9.6W/m^2$ respectively. Additionally, a computer load of $5W/m^2$ is selected. The schedules of the zone are selected from the provided library. They are selected based on the schedule and the occupancy of a school and meet the targets of a room of multiple use.

(a) (b)

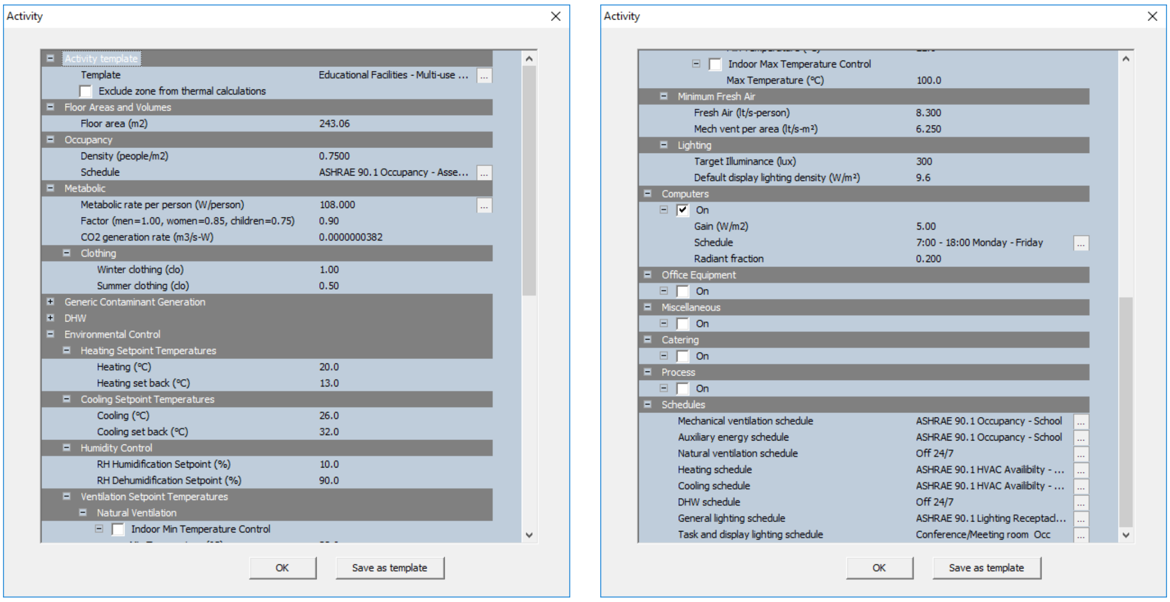


Figure 6.15: Figures 6.15(a) and 6.15(b) present the activity data of the room of multiple use. Personal file.

It is important to describe the used schedules, at this point. The selection of a schedule allows the user to influence scheduling of many items like occupancy density and activity, lighting and thermostatic controls [22]. Tables 6.1, 6.2 and 6.3 describe the Occupancy, HVAC and lighting schedule, respectively, which was used for the building schedules.

6.5.1.2 Lighting

The next group of parameters which should be completed is about lighting data, Figure 6.16. The first field refers to the lighting template, which depends on the nature of the space. Based on this template the next parameters are completed automatically, letting the user make the requiring changes.
Lighting control is enabled, using "Linear/off" type of lighting control. In "Linear/off" control type the lighting power and the electric output are calculated proportionally with the daylight illuminance, in order to satisfy the demands of the space. When the minimum dimming point is reached, then the lights

Table 6.1: Schedule: ASHRAE 90.1 Occupancy school. User's Manual.

Until Hour	Fraction
Through 31 December	
For Weekdays	
07:00	0
08:00	0.05
09:00	0.75
11:00	0.90
15:00	0.80
16:00	0.45
17:00	0.15
18:00	0.05
19:00	0.15
21:00	0.20
22:00	0.10
24:00	0.00
For Saturday	
08:00	0.00
13:00	0.10
24:00	0.00
For Sunday	
24:00	0.00
For Summer Design Day	
08:00	0
23:00	1
24:00	0
For All Other Days	
24:00	0.00

are switched off completely. Task and display lighting is not used here, it refers to lighting used for specific tasks, such as desk lamps, or for displaying items and it is not offset by lighting control.

6.5.1.3 HVAC

As a template for the heating, cooling and mechanical ventilation the room of multiple use employs boiler of natural gas, air cooled chiller and fan coil units. The next fields refer to the mechanical ventilation sizing where the outside air definition method is by zone, with $4ac/h$ outside air and heat recovery. The type of heat recovery is sensible, to be specified the latent and the sensible heat recovery when the temperature of the exhausted air is more advantageous than the temperature of the outdoor air.

The auxiliary energy of $7W/m^2$ refers to fans, pumps, control gear and other potential auxiliary systems, which have not been specified before, with their schedule. The heating is accomplished by a boiler with natural gas as fuel and cop = 0.9. The air condition supply temperature and the humidity is defined followed by the operation schedule. In addition, the heating limit type is "LimitCapacity".

Table 6.2: Schedule: ASHRAE 90.1 HVAC Availability School. User's Manual.

Until Hour	Fraction
Through 31 December	
For Weekdays	
06:00	0
22:00	1
24:00	0
For Saturday	
06:00	0
18:00	1
24:00	0
For Sunday	
24:00	0
For Summer Design Day	
08:00	0
23:00	1
24:00	0
For All Other Days	
24:00	0.00

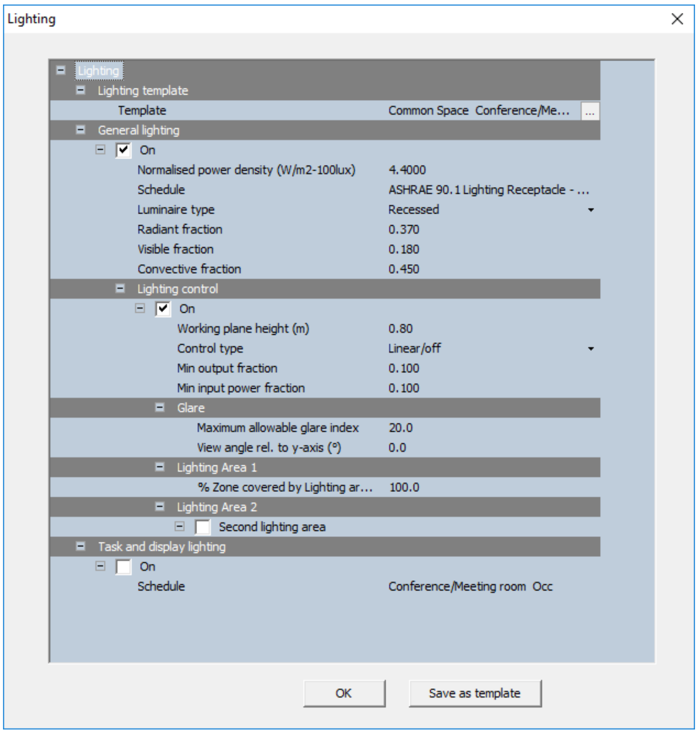


Figure 6.16: Lighting data of the room of multiple use. Personal file.

According to [23] "LimitCapacity" means that the sensible heating capacity will be limited to a capacity value, which is calculated based on the autosizing model option settings by E+ documentation. The

Table 6.3: Schedule: ASHRAE 90.1 Lighting Receptacle Assembly. User's Manual.

Until Hour	Fraction
Through 31 December	
For Weekdays	
06:00	0.05
09:00	0.40
22:00	0.75
23:00	0.25
24:00	0.05
For Saturday	
07:00	0.05
09:00	0.30
23:00	0.50
24:00	0.05
For Sunday	
07:00	0.05
12:00	0.30
22:00	0.65
24:00	0.05
For Summer Design Day	
08:00	0
23:00	1
24:00	0
For All Other Days	
24:00	0.00

cooling is accomplished by an air cooled chiller, using electricity as a fuel, with cop = 3.2 and cooling limit type ”LimitCapacity”.
The last to be defined in HVAC data (Figure 6.17) is the humidity control. Here humidification and dehumidification are used, with ”humidistat” as control type. Humidistat means that the humidity is controlled using the humidification and dehumidification set points defined in Activity data.

6.5.1.4 Zone data

The last tab is zone data (Figure 6.18) and it actually refers to infiltration. This software calculates infiltration based on EnergyPlus® documentation, with the 6.1 equation. The EnergyPlus® Input Output reference recommends that the coefficients of the equation should be defined by specific values. The default values of EnergyPlus® and FineGreen, give a constant volume flow of infiltration under all conditions.[23]

(6.1)

$$Infiltration = I_{design} * O_{schedule} * [A + B * (T_{in} - T_{out}) + C * (WindSpeed) + D * (WindSpeed)^2]$$

(a) (b)

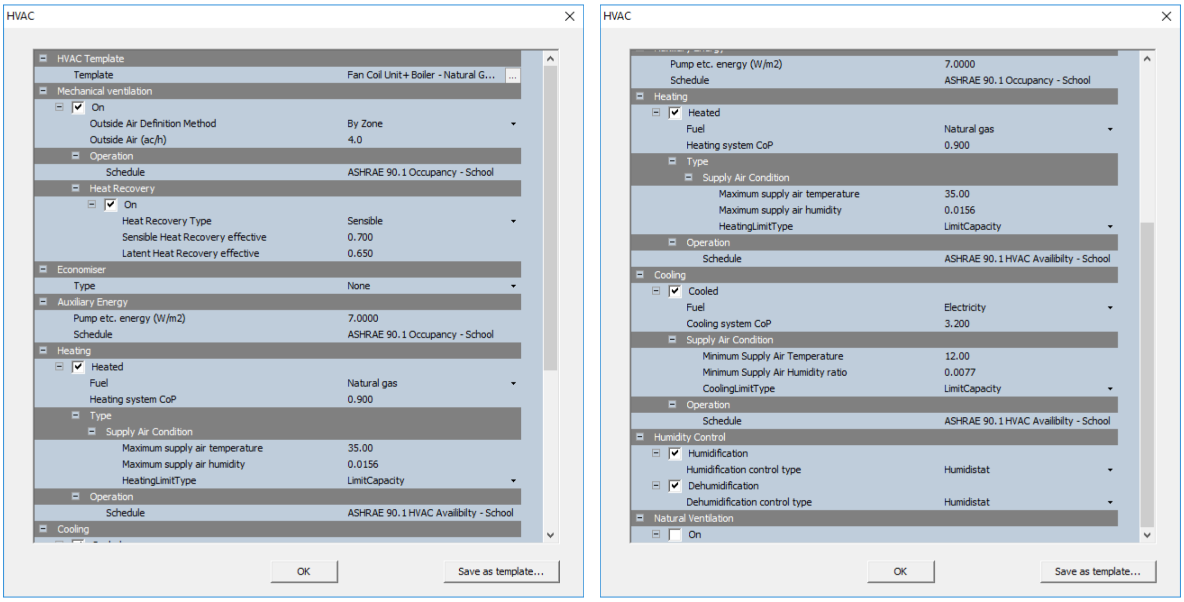


Figure 6.17: Figures 6.17(a) and 6.17(b) present the HVAC data of the room of multiple use. Personal file.

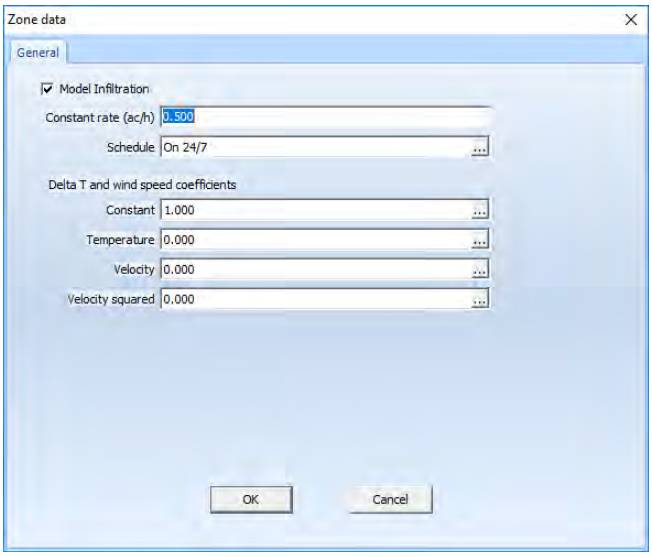


Figure 6.18: Zone data -Model Infiltration- of the room of multiple use. Personal file.

6.5.2 Classroom

6.5.2.1 Activity data

This zone has a provided template, appropriate for a classroom, which is ”Educational Facilities - Lecture classroom” and covers 1949.50 m^2 floor area (Figure 6.19). The occupancy has a density of

(a) (b)

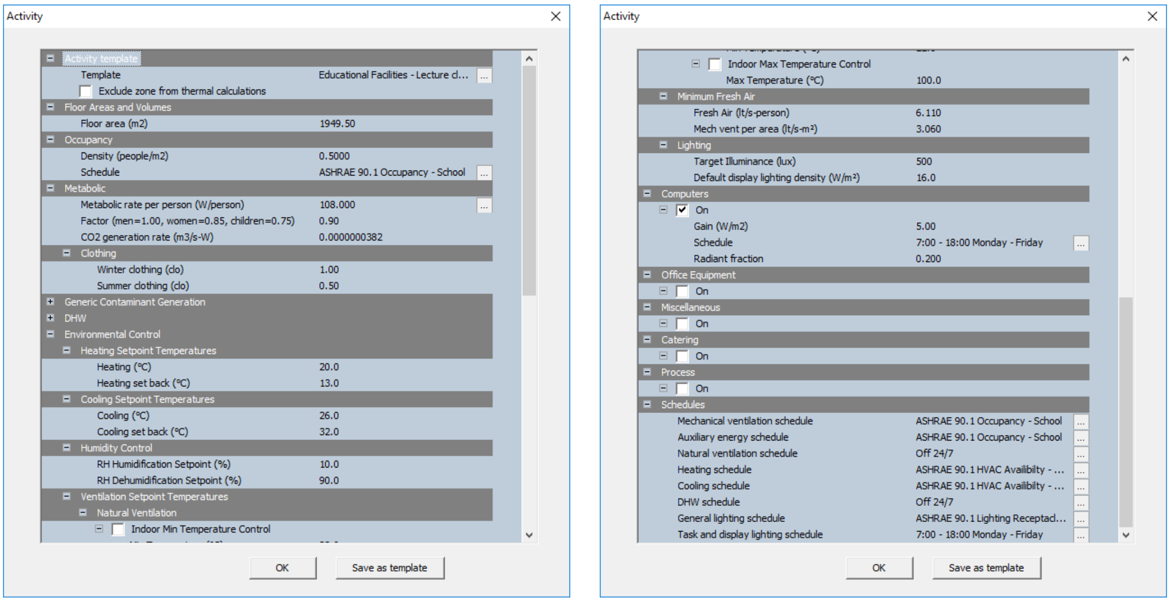


Figure 6.19: Figures 6.19(a) and 6.19(b) present the activity data of the classroom. Personal file.

$0.5 people/m^2$ based on KENAK 2017 standards with a schedule for school occupancy, of ASHRAE 90.1 . People there have a metabolic rate for seated quiet. The set point temperatures and humidity control values are the same with the values of the room of multiple use.
The ventilation is mechanical and minimum fresh air is 6.11 lt/s per person and $3.06 lt/s$ per m^2. The lighting target illuminance is 500lux with a density of 16 W/m^2, appropriate for the use of the classroom. Furthermore, a computer gain of 5 W/m^2 is selected with a schedule Monday to Friday 7:00 - 18:00. Last is the selection of the appropriate schedules of the zone, which are based on the nature and the use of the zone.

Lighting data are next in turn to be defined (Figure 6.20). A provided template is chosen as lighting template, which is appropriate for a classroom "Building Area Method School/University 10.7 W/m2 at 300 lux" General lighting is selected with the use of recessed luminaires. There is "linear/off" lighting control and last there is task and display lighting with the appropriate schedule.

6.5.2.2 Lighting

6.5.2.3 HVAC

It is time to estimate the HVAC data for this zone (Figure 6.21). As a template a system of boiler - natural gas-, air cooled chiller and fan coil units is used. Mechanical ventilation outside air definition method is by zone, with 4 air changes per hour, in accordance with KENAK 2017 standards. Mechanical ventilation operates in "ASHRAE 90.1 occupancy - school", which is provided and recovers heat with "Sensible" heat recovery. The auxiliary energy is estimated to be $7W/m^2$. Continuing with the heating

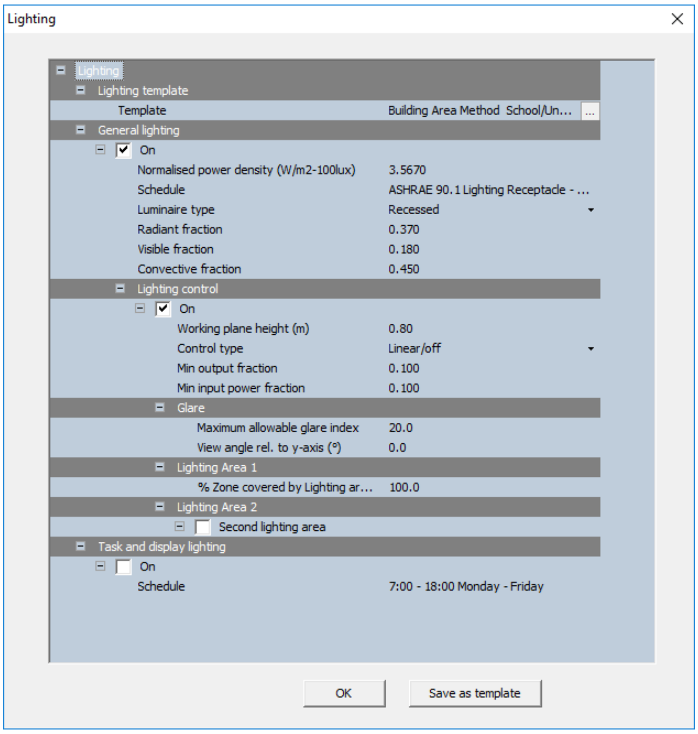


Figure 6.20: Lighting data of the classroom. Personal file.

system, the boiler uses natural gas and operates with cop = 0.9. Heating limit type is ”LimitCapacity” and it operates in an appropriate for School classroom schedule. The cooling system contains an air cooled chiller, which uses electricity as fuel and operates with cop = 3.2 . Last, there humidification and dehumidification control and the control type is ”Humidistat”.

6.5.2.4 Zone data

The zone data are the data for infiltration. They are chosen to be the same for all the zones and they are presented at zone data of the room of multiple use 6.5.1.4.

6.5.3 Office

6.5.3.1 Activity data

It is time to estimate the activity data of the office zone (Figure 6.22). An appropriate template for this zone is chosen, based on the use of the space. The template , selected from the library, is called ”Office Buildings - Office space”. The zone covers $172.51m^2$ in total. The density of the occupancy is $0.1people/m^2$, in accordance with KENAK standards 2017. The metabolic rate per person is, as for the previous zones, $108W/person$ for ”seated, quiet” activity. Heating, cooling and humidity control set points are the same with the previous zones, too. The ventilation of the spaces of office zone is mechanical, with fresh air 8.33lt/s per person and 0.83 lt/s per m^2, based on KENAK 2017 stan-

(a) (b)

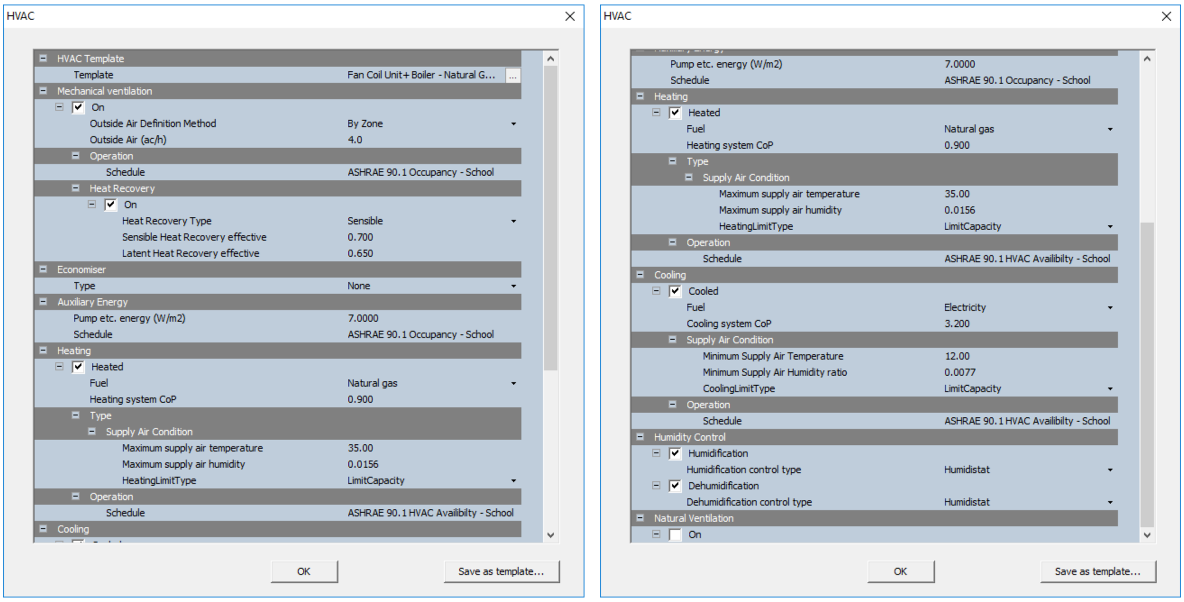


Figure 6.21: Figures 6.21(a) and 6.21(b) present the HVAC data of the classroom. Personal file.

(a) (b)

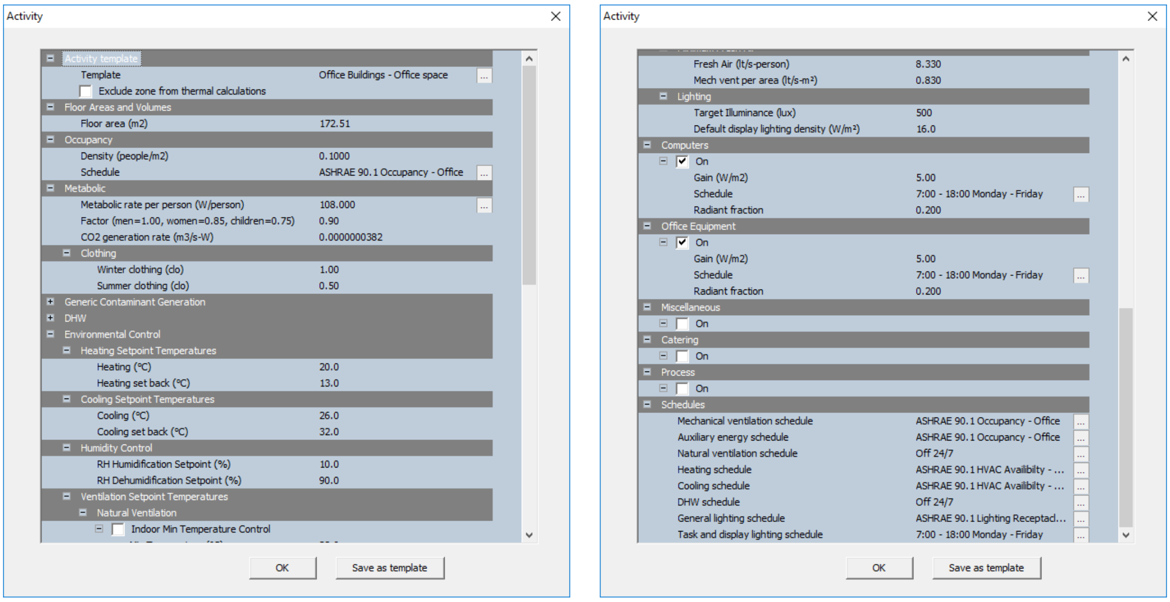


Figure 6.22: Figures 6.22(a) and 6.22(b) present the activity data of the office zone. Personal file.

dards. Furthermore, the target illuminance is 500 lux and the lighting density $16W/m^2$, as KENAK standards specifies for office spaces. Moreover, a computer gain of $5W/m^2$ and an office equipment gain of $5W/m^2$ are defined. Last, the appropriate schedules have been chosen, based on the nature and the demands of this zone.

6.5.3.2 Lighting

Lighting data for the office zone (Figure 6.23) are determined with an appropriate template for office, chosen from the library. Furthermore, general lighting is selected with the use of recessed luminaires. Last, there is ”linear/off” lighting control on the spaces of the zone.

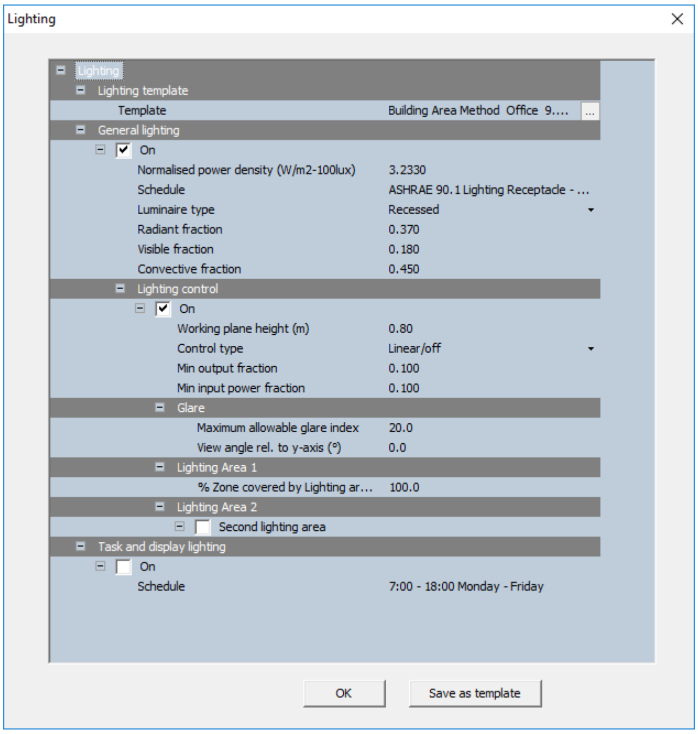


Figure 6.23: Lighting data of the office zone. Personal file.

6.5.3.3 HVAC

Estimating the HVAC data for the office zone (Figure 6.24) a template with boiler -natural gas-, air cooled chiller and fan coil units was suitable. Mechanical ventilation outside air definition method is by zone, with 4 air changes per hour. Mechanical ventilation operates in ”ASHRAE 90.1 occupancy - office”, which is provided and recovers heat with Sensible heat recovery type. The auxiliary energy is estimated to be $12W/m^2$. Regarding the heating system a boiler of natural gas with cop = 0.9 is used. The heating limit type is ”LimitCapacity” and the system operates with an appropriate schedule for office. The air cooled chiller of the cooling system uses electricity and operates with cop = 3.2. In addition, there is ”humidistat” humidification and dehumidification control.

(a) (b)

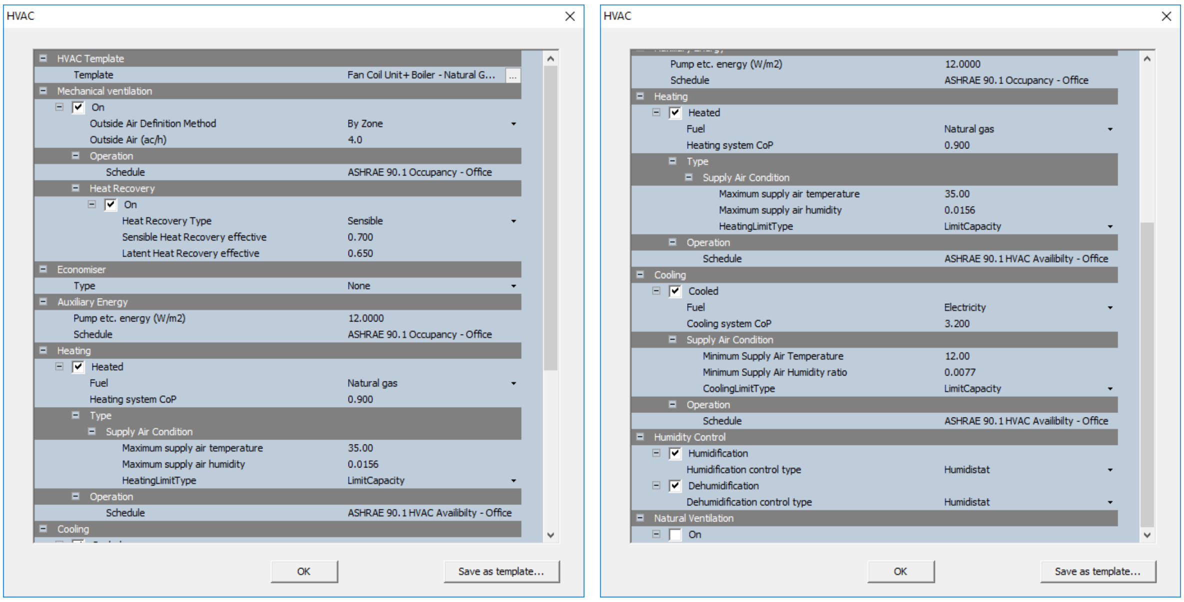


Figure 6.24: Figures 6.24(a) and 6.24(b) present the HVAC data of the office zone. Personal file.

6.5.3.4 Zone data

The zone data is already stated that define the data for infiltration. They are chosen to be the same for all the zones and they are presented at zone data of the room of multiple use 6.5.1.4.

6.6 Export options

Finally, there are some export options where the heating and cooling capacity data are calculated automatically using the EnergyPlus calculations. Additionally, in these options is estimated the mechanical ventilation sizing. Mechanical ventilation method is Ideal loads, which means that the simulation is affected by the heat recovery, economizer and humidity control [23]. In these options is, also, defined the heating and cooling design margin, which is 1.25, the summer design day and the simulation period.

Chapter 7

Design

After the data insertion follow the heating and cooling calculations. These calculations refer to a winter and a summer day load, respectively. In that way is determined the required heating and cooling equipment which can cover the load at the coldest and hottest, respectively, design weather conditions.

7.1 Heating Design

The calculations for the heating design take into account the external temperature, the speed of the wind and the direction of the wind, which are provided by the location and weather data, as it is described at [23]. Solar gain, shading effects and internal thermal gains, which come from internal equipment, lighting and occupancy, are not considered for the calculations. Furthermore heat conduction and convection between zones of different temperatures is important for the calculation process. Operation schedules are not used for these steady state analysis calculations. Last, the zones are heated constantly to meet the heating temperature set point. The process continues until heat flows in each zone have converged. The grid and chart of the heating design give the internal temperatures and the heat losses in detail. [23]

The heating design calculations export some results. The study of this building exported the results, which are presented in Figures 7.1 and 7.2.

First of all it is helpful to explain some terms, presented in heating design results. Air temperature is the temperature of the air inside a zone. Radiant temperature of a space is the combined effects of temperatures of surfaces within that space. Operative temperature is the average of the air temperature and radiant temperature of a zone. Zone sensible heating is the sensible load which should be covered in a zone by the terminal units. [22]

The results presented in Figures 7.1 and 7.4 show that every zone should achieve the ideal temperature of $20^o C$, as it was defined in activity data. The radiant temperature is slightly lower than the air temperature and the operative temperature is the average of the air temperature and radiant temperature. The outside dry bulb temperature is the most unfavourable temperature, which the heating system should be able to face and it is -3.2^oC. Relative humidity is inside the defined limits. The sum of mechanical ventilation and infiltration is presented in air changes per hour, natural ventilation is not used for this building.

Moreover, heat losses, which come from the glazing, walls, floors, ceilings, external infiltration and ventilation, are displayed. It is important to point out that ventilation is responsible for the greater part of heat losses. Furthermore, it is observable that heat losses, which come from the zone classroom are greater than the heat losses from the other zones. This happens because classroom zone occupies the bigger part of the building - classroom floor area is $1949.5m^2$ and the building floor area, which is conditioned and takes part in calculations, is 2365 m^2.

Figure 7.4 shows that zone sensible heating is 350.54kW for the entire building. At the end of the heating design results there is a summary, which displays that the Comfort temperature is 18.2^oC, the steady state heat loss is 350.54kW and the design capacity is 438.17kW or $185.25W/m^2$. Design capacity is the maximum output of the system in ideal conditions.

Steady State						
Comfort						
Zone	**Air temperature (°C)**	**Radiant temperature (°C)**	**Operative temperature (°C)**	**Outside dry bulb temperature (°C)**	**Relative humidity (%)**	**Mech vent + nat vent + Infiltration (ac/h)**
room of multiple use	20.000	16.09227	18.04614	-3.20000	20.0145726	4.81146
classroom	20.000	15.86935	17.93468	-3.20000	20.0145726	4.81149
office	20.000	17.10934	18.55467	-3.20000	20.0145726	4.81150
Heat loss						
Zone	**Glazing (kW)**	**Walls (kW)**	**Floors (kW)**	**Ceilings (kW)**	**External Infiltration (kW)**	**Ventilation (kW)**
room of multiple use	-0.9964191	-2.3863167	0.1501713	-2.7534643	-5.4180342	-40.1169770
classroom	-11.4754046	-14.1264749	-3.3710468	-6.6702426	-28.4721200	-210.6486912
office	-0.3880194	-2.2749811	-0.0260295	-0.9443506	-2.3678480	-17.5167722
Building total	-12.8598430	-18.7877727	-3.2469050	-10.3680575	-36.2580023	-268.2824404
Summary	**Comfort temperature (°C)**	**Steady state heat loss (kW)**	**Design capacity (kW)**	**Design capacity (W/m²)**		
	18.178493	350.5368571	438.1710714	185.2676967		

Figure 7.1: Heating design results in a grid form, page 1 out of 2.

The heating design results are, also, presented in a graphic form at figures 7.3 and 7.4.

In the chart of Figure 7.3 are visible the values of the radiant temperature, air temperature, operative temperature, which is the average of the two previous temperatures and the outside dry bulb temperature in a steady state. The chart of Figure 7.4, which follows, shows the heat losses, in a steady state, the effect of the ventilation to the total losses and the zone sensible heating, which should be covered in the zones by the terminal units.

Steady State	
Comfort	
Zone	
room of multiple use	
classroom	
office	
Heat loss	
Zone	**Zone sensible heating (kW)**
room of multiple use	51.7720072
classroom	274.8758088
office	23.8890411
Building total	350.5368571
Summary	

Figure 7.2: Heating design results in a grid form, page 2 out of 2.

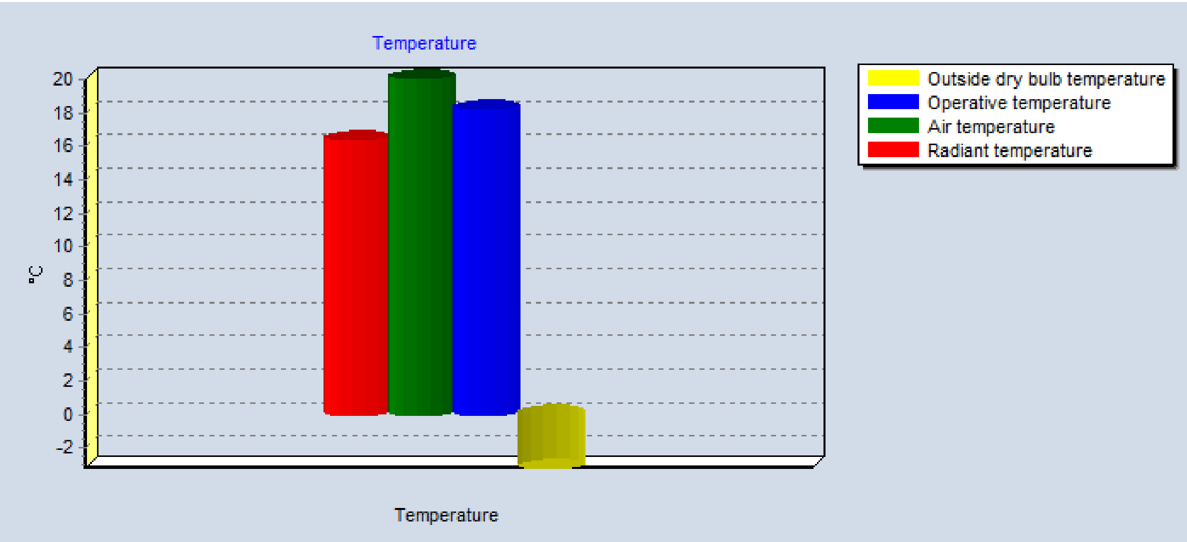


Figure 7.3: Heating design results in a chart form, temperatures in a steady state

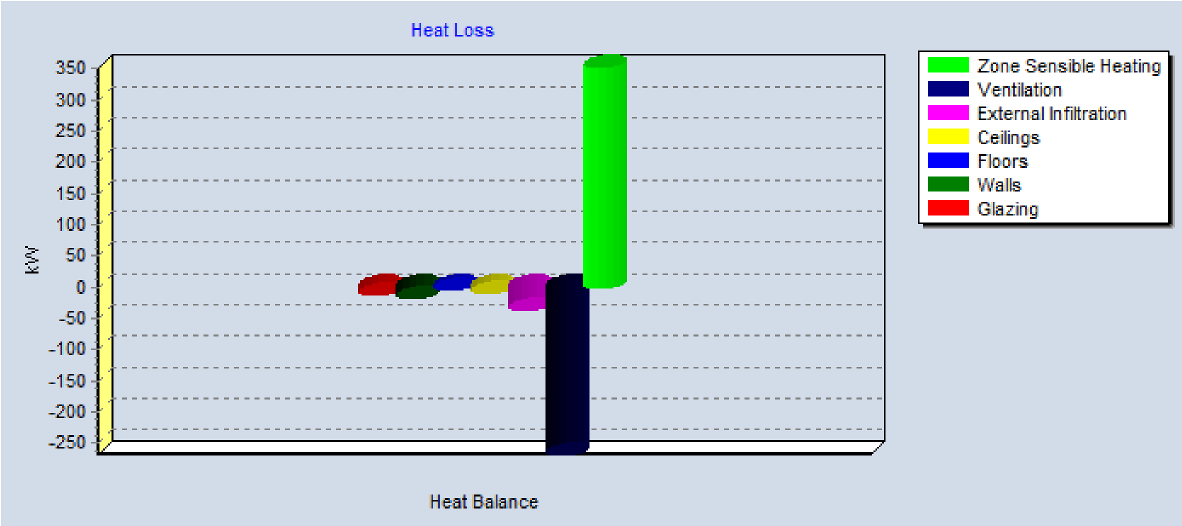


Figure 7.4: Heating design results in a chart form, heat losses in a steady state

7.2 Cooling Design

The calculations for the cooling design take into account the external minimum and maximum dry-bulb temperatures, which are provided by the location and weather data, according to [23]. The wind conditions are not considered for the calculations. Solar gains through windows, as well as, internal gains from lighting, occupants and internal equipment are important for the calculations. Additionally, heat conduction and convection between zones of different temperatures is considered for the calculation process. The process continues until cooling flows in each zone have converged.

Before the cooling design results presentation it would be helpful to explain some terms of the results. Air temperature is the temperature of the air inside a zone. Radiant temperature of a space is the combined effects of temperatures of surfaces within that space. Operative temperature is the average of the air temperature and radiant temperature of a zone. Zone sensible cooling is the sensible cooling energy supplied by the HVAC system to a zone. [22]

The cooling design results are based on the time of the day and the schedules of the building. The results are presented on Figures 7.5, 7.6 and 7.7. These results are calculated for the entire design day and presented per 2 hours. First of all is presented the air temperature, which starts from 29.5^oC at 2:00, falls at 26^oC at 6:00, then stays stable until 16:00 and finally reaches 30^oC until 24:00. Next is the radiant temperature, which ranges from 30^oC to 31.5^oC inside the day. Then follows the operative temperature, which is the average of the two previous temperatures. The outside dry bulb temperature starts from 23^oC rises up to 34^oC at 14:00 and then starts falling again. Relative humidity ranges in the permitted margin -relative humidity refers to the inside of the building and in the summer period is higher than relative humidity in the winter period- . The sum of mechanical ventilation and infiltration ranges from 1.4 air changes per hour to 1.5 air changes per hour. At this point it should be mentioned that the cooling design refers to the hottest day of the summer and that the building is a school building with zones of the appropriate schedules.

Next in turn to be displayed are the heat losses and heat gains. In cooling design calculations are taken part the heat gains, which are actually losses for the system because cooling is a negative heat gain. These come from the internal equipment, lighting equipment and occupancy. As it is presented in the figures of the results, the glazing, walls, floors, ceilings, external infiltration are load values, which switch from heat losses to heat gains and from heat gains to heat losses. This contribution to the total load depends on the time of the day, the location and weather data for each of the above parameters. The Occupancy and ventilation makes the greatest contribution in heat gains, but this depends on the time of the day and the schedules.

Sensible Cooling is the sensible only cooling heat transfer from the cooling coil to the supply air. Zone sensible cooling is the sensible cooling effect on the zone of any air introduced into the zone through the HVAC system. According to [24], total cooling for a compact HVAC sizing method is the sensible and latent cooling transfer to the supply air from the air handling unit and any single zone unitary and fan coil units in the building. Additionally, sensible cooling for a compact HVAC sizing method is only the sensible cooling heat transfer from the cooling coil to the supply air. Latent coil heat is the difference between total cooling and sensible cooling. Latent load refers to the dehumidification of the building and in this building it is affected by the occupancy, the ventilation and the external infiltration. Generally it is, also, affected by the natural ventilation and internal equipment. This latent load is visible in the results because the total cooling differs from the sensible cooling and the summary results shows that for the entire building the total cooling load is 319.7kW, where the sensible is 166.3kW and the latent is 153.4kW. Additionally, the time of max cooling is 14:30, the air temperature is maintained at the specified temperature and the design capacity of the cooling system for the entire building is 367.6kW.

Comfort					
	2:00	**4:00**	**6:00**	**8:00**	**10:00**
Air temperature (°C)	29.55792	29.27478	26.00000	26.00000	26.00000
Radiant temperature	30.45177	30.27475	30.03113	30.41520	30.60775
Operative temperature	30.00484	29.77477	28.01556	28.20760	28.30387
Outside dry bulb	23.79600	23.12400	23.12400	25.81200	29.84400
Relative humidity (%)	43.7968190	43.8479556	46.4487231	53.8561210	52.8127650
Mech vent + nat vent +	1.52902	1.53112	1.51504	1.50086	1.48097
Fabric and ventilation, Gains					
Glazing (kW)	-5.0393510	4.3513896	28.1301901	36.1111751	32.7557911
Walls (kW)	3.0009618	1.3670066	10.8890953	1.1385704	4.8307041
Floors (kW)	3.3550347	-1.4173219	15.4990366	-12.3592084	-6.5128934
Ceilings (kW)	5.6575011	5.0035954	7.4451293	-0.0682959	-0.2219924
External Infiltration (kW)	8.5095624	9.0323686	4.1094402	0.2727056	-5.3547537
Ventilation (kW)	0.0000000	0.0000000	0.0000000	0.0000000	45.1005609
Zone sensible cooling (kW)	0.0000000	0.0000000	32.3613275	143.9098344	156.0799906
Sensible cooling (kW)	0.0000000	0.0000000	32.3613275	141.8494281	201.2881952
Total cooling (kW)	0.0000000	0.0000000	39.6009117	181.9447982	256.3480480
Computers+Equipment (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Catering (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Process (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Miscellaneous (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
General Lighting (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Task Lighting (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Occupancy (kW)	0.0000000	0.0000000	0.0000000	68.2838034	68.2838034
Summary	**Design capacity (kW)**		**Total cooling load (kW)**	**Sensible (kW)**	**Latent (kW)**
room of multiple use	37.6825554		32.7674395	18.4372225	14.3302170
classroom	308.9133086		268.6202684	138.3454160	130.2748524
office	21.0395311		18.2952445	9.5049126	8.7903319
Building total	367.6353951		319.6829523	166.2875510	153.3954013

Figure 7.5: Cooling Design Results in a grid form, page 1 out of 3.

Comfort					
	12:00	**14:00**	**16:00**	**18:00**	**20:00**
Air temperature (°C)	26.00000	26.00000	26.00000	31.66341	31.26437
Radiant temperature	30.71078	30.74126	30.62097	30.95585	31.55825
Operative temperature	28.35539	28.37063	28.31049	31.30963	31.41131
Outside dry bulb	32.64400	34.10000	33.42800	31.41200	28.50000
Relative humidity (%)	52.5931390	52.2602786	52.6272761	42.7591847	45.3509469
Mech vent + nat vent +	1.46742	1.46049	1.46367	1.50254	1.51423
Fabric and ventilation, Gains					
Glazing (kW)	35.6309074	38.4561971	28.1349693	-0.1919328	-2.6367575
Walls (kW)	5.0864973	5.0803986	6.0125524	-7.1081367	-6.7719679
Floors (kW)	-8.2217482	-9.2675078	-3.3700027	-24.2849409	-16.8511508
Ceilings (kW)	0.0450468	0.4864906	2.2367528	-0.9544870	-1.8256002
External Infiltration (kW)	-9.1753993	-11.1346144	-10.2326737	0.6032348	4.5725637
Ventilation (kW)	77.9399128	95.0101120	87.1277090	0.0585140	0.0000000
Zone sensible cooling (kW)	161.6907740	165.7562019	163.3166008	29.3423959	38.4305097
Sensible cooling (kW)	239.7884712	260.9598457	250.6343138	23.9831492	0.0000000
Total cooling (kW)	296.4808637	319.1801122	307.6165778	23.9831492	0.0000000
Computers+Equipment (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Catering (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Process (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Miscellaneous (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
General Lighting (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Task Lighting (kW)	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Occupancy (kW)	68.2838034	68.2838034	68.2838034	30.0140699	30.5981864
Summary	**Air temperature (°C)**	**Humidity (%)**	**Time of max cooling**	**Maximum operative temperature in day (°C)**	
room of multiple use	26.00000	59.2026765	14:30	31.62473	
classroom	26.00000	49.3452246	14:30	32.10103	
office	26.00000	48.3455886	14:30	30.87767	
Building total	26.00000	52.2978299	14:30	31.53448	

Figure 7.6: Cooling Design Results in a grid form, page 2 out of 3.

Comfort	
	24:00
Air temperature (°C)	30.02344
Radiant temperature	30.82533
Operative temperature	30.42439
Outside dry bulb	24.91600
Relative humidity (%)	44.4622005
Mech vent + nat vent +	1.52544
Fabric and ventilation, Gains	
Glazing (kW)	-4.7366224
Walls (kW)	2.5553080
Floors (kW)	2.4890737
Ceilings (kW)	4.5111105
External Infiltration (kW)	7.6846397
Ventilation (kW)	0.0000000
Zone sensible cooling (kW)	0.0000000
Sensible cooling (kW)	0.0000000
Total cooling (kW)	0.0000000
Computers+Equipment (kW)	0.0000000
Catering (kW)	0.0000000
Process (kW)	0.0000000
Miscellaneous (kW)	0.0000000
General Lighting (kW)	0.0000000
Task Lighting (kW)	0.0000000
Occupancy (kW)	0.0000000
Summary	
room of multiple use	
classroom	
office	
Building total	

Figure 7.7: Cooling Design Results in a grid form, page 3 out of 3.

Chapter 8

Simulation

Simulation provides heating and cooling results for a selected period of time. In the context of this thesis, it was considered that a single day simulation would be the best option in order to be better understood by the reader. For this reason two single day simulations are presented, one of the winter period for the 12th of January and one of the summer period for the 12th of July.

Location and weather data, solar gains through windows, shading effects, internal gains from lighting equipment, occupants and internal equipment, are all considered for the simulation, according to. Heat conduction and convection between zones of different temperatures are, also, taken into account. Simulation continues until temperatures in each zone have converged. The calculations of the simulation are based on the selected schedules. [23]

Last, it would be useful to explain some terms in order to be easier to understand the results. Zone air system sensible heating rate is the calculated heat load need. Zone air system sensible cooling rate is the calculated cooling load need. Supply air sensible cooling represents the sensible only heat transfer from the cooling coil to the supply air [24]. Supply air sensible heating represents the sensible only heat transfer from the heating coil to the supply air. Supply air total cooling represents the supplied cooling load to the building by cooling coil and the air handling unit, which means that supply air total cooling contains the sensible and the latent cooling load. Supply air total heating represents the supplied heating load to the building by the heating coil (HVAC) and the air handling unit, which means that supply air total heating contains the sensible and the latent heating load.

8.1 Single day simulation for the winter period

Starting with the simulation of the winter period, which simulates the loads of the 12th of January, the results displayed in the Figures 8.1, 8.2, 8.3 and 8.4 are going to be analysed. The simulation was selected to export hourly results.

Figure 8.1 presents the air temperature for the entire day, which is close to the favourable temperature of 20^oC and it slightly overcomes this temperatures at peak time. Additionally, radiant temperature, as well as operative temperature are presented. The outside dry bulb temperature ranges from 4^oC to 6.1^oC and relative humidity ranges in the permitted margin.
At figure 8.2 are visible the heat gains and heat losses which come from the glazing, walls, floors, ceiling and external infiltration. The positive loads represents the heat gains and the negative loads the heat losses. These loads can switch from heat gains to heat losses and from heat losses to heat gains during the day. Furthermore, Figures 8.3 and 8.4 displays heat gains. These come from the computers and equipment, general lighting and occupancy. The greatest contribution to the total load comes from the occupancy, but this depends on the schedule of the building.

Zone air system sensible heating rate, zone air system sensible cooling rate, supply air sensible cooling, supply air total cooling, supply air sensible heating and supply air total heating are presented at Figures 8.2 and 8.3.

The need of the building for heating load depends on the schedule and the condition of the building. Furthermore it is visible that there is no supplied cooling load and this is obvious since the simulation refers to a winter day.

Last, the supply air sensible heating and the supply air total heating are equals, which means that there is no latent load. This is logical, because the simulation is for a day of the winter period and the latent load refers to dehumidification.

Time	Air temperature (°C)	Radiant temperature (°C)	Operative temperature (°C)	Outside dry bulb temperature (°C)	Relative humidity (%)	Mech vent + nat vent + Infiltration (ac/h)
12/1 00:00	16.72292	17.79271	17.25782	5.90000	38.9504260	1.75735
12/1 01:00	16.14325	17.35404	16.74865	5.00000	40.9286195	1.56077
12/1 02:00	15.75616	17.01327	16.38471	4.40000	42.3322727	1.56187
12/1 03:00	15.36591	16.80747	16.08669	4.20000	43.6627615	1.56083
12/1 04:00	15.12839	16.58408	15.85623	4.00000	44.3613614	1.56023
12/1 05:00	15.01062	16.40249	15.70656	4.40000	44.2223752	1.55730
12/1 06:00	14.87817	16.24497	15.56157	4.20000	44.0691885	1.55774
12/1 07:00	19.91896	16.13036	18.02466	4.00000	32.1636886	1.98607
12/1 08:00	20.00000	17.06056	18.53028	4.40000	32.3327138	2.78589
12/1 09:00	20.00000	17.64097	18.82049	4.00000	33.6476055	11.40215
12/1 10:00	20.07849	18.06134	19.06991	5.00000	34.1702075	12.60351
12/1 11:00	20.21706	18.35947	19.28827	5.40000	33.6565767	12.58543
12/1 12:00	20.26431	18.71369	19.48900	5.00000	34.3609545	11.82018
12/1 13:00	20.33655	18.91791	19.62723	5.60000	35.1435403	11.83187
12/1 14:00	20.45664	19.09446	19.77555	6.20000	35.1221293	11.82296
12/1 15:00	20.52718	19.23821	19.88269	6.10000	35.2953605	11.84790
12/1 16:00	20.82020	19.27349	20.04684	6.10000	35.3413295	9.01011
12/1 17:00	20.63399	19.35716	19.99558	6.00000	36.2727052	6.60221
12/1 18:00	20.93550	19.24716	20.09133	6.00000	36.8160196	3.18722
12/1 19:00	20.07122	19.17235	19.62179	6.00000	36.5170113	3.18091
12/1 20:00	20.00000	18.82234	19.41117	6.00000	35.1564833	3.58728
12/1 21:00	20.00000	18.74362	19.37181	6.00000	33.3816155	3.58822
12/1 22:00	20.00000	18.63060	19.31530	5.90000	32.6577121	2.78336
12/1 23:00	17.63717	18.47047	18.05382	5.80000	37.4090525	1.76317

Figure 8.1: Simulation results for the 12th of January in a grid form, page 1 out of 4

Time	Glazing (kWh)	Walls (kWh)	Floors (kWh)	Ceilings (kWh)	External Infiltration (kWh)	Zone air system sensible heating rate
12/1 00:00	-6.8047928	0.8891789	17.0436429	0.9972219	16.2456174	0.0000000
12/1 01:00	-9.8730587	0.4632130	14.9045261	1.6559736	16.7017796	0.0000000
12/1 02:00	-9.5563945	0.5389349	17.0320314	2.9700799	17.0369993	0.0000000
12/1 03:00	-6.5306434	-0.3005645	15.6753435	3.3209453	16.7215549	0.0000000
12/1 04:00	-6.8645041	-0.1476428	15.4830327	3.7898968	16.6648975	0.0000000
12/1 05:00	-6.4937757	-0.0379662	15.0883954	4.0542703	15.8487962	0.0000000
12/1 06:00	-6.5830438	-0.1499604	14.4621116	4.1766715	15.9287054	0.0000000
12/1 07:00	-6.7624650	-0.3854870	14.0266172	4.2855544	24.3633759	78.3083825
12/1 08:00	-10.1236883	-16.8352191	-10.8076172	-5.0110857	23.8710455	25.1288984
12/1 09:00	-5.7837349	-21.2708929	-19.5651533	-8.8536788	24.5183955	5.5510244
12/1 10:00	-3.4662646	-22.9453561	-22.3328611	-11.3495593	23.1861128	2.7685760
12/1 11:00	-1.2486425	-22.5174004	-21.0974096	-12.5204853	23.0404883	1.9590472
12/1 12:00	-0.8120735	-22.8335119	-20.8187873	-13.5309525	23.8308864	0.0000000
12/1 13:00	0.0092570	-21.6797192	-19.8360508	-13.7971700	23.1033206	0.0000000
12/1 14:00	-0.1521873	-21.0732153	-19.3347497	-14.2244839	22.5015005	0.0000000
12/1 15:00	-1.5534059	-20.6941014	-18.9060736	-14.6343151	22.8721437	0.0000000
12/1 16:00	-3.8782109	-18.1459018	-13.7235609	-13.0928517	22.7978509	0.0000000
12/1 17:00	-6.4384620	-16.1003676	-9.1513127	-11.0287689	22.3636905	0.0000000
12/1 18:00	-7.4036664	-13.7261244	-6.5386092	-9.3292950	21.9897008	0.1903438
12/1 19:00	-7.4103751	-11.6651767	-2.5394021	-7.2423817	21.2645451	9.4566277
12/1 20:00	-7.1397201	-10.1978099	-2.7789836	-7.0940838	21.2185086	7.2783545
12/1 21:00	-7.1247208	-10.1023361	-2.2257137	-6.6445555	21.1946862	9.8521528
12/1 22:00	-7.3631322	-8.6696172	1.2565757	-5.1746807	21.3546975	22.1277434
12/1 23:00	-7.6266470	-7.5057081	3.3102938	-4.1349133	17.6243740	0.0000000

Figure 8.2: Simulation results for the 12th of January in a grid form, page 2 out of 4

Figures 8.5 and 8.6 present the zone sensible heating and cooling for every zone with summary results, calculated by the software, for the simulation. These refer to the design load, design air flow, design day, date and time of peak, temperature and humidity at peak load and air flow rate, all of them for every zone individually.

Time	Zone air system sensible cooling rate	Supply air sensible cooling (kWh)	Supply air total cooling (kWh)	Supply air sensible heating (kWh)	Supply air total heating (kWh)	Computers+ Equipment (kWh)
12/1 00:00	0.4211143	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/1 01:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/1 02:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/1 03:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/1 04:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/1 05:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/1 06:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/1 07:00	0.0818795	0.0000000	0.0000000	84.9101208	84.9101208	0.0000000
12/1 08:00	0.0000000	0.0000000	0.0000000	28.3755747	28.3755747	12.6878832
12/1 09:00	15.9726389	0.0000000	0.0000000	32.0713289	32.0713289	12.6878832
12/1 10:00	38.8494681	0.0000000	0.0000000	13.0326565	13.0326565	12.6878832
12/1 11:00	39.1224514	0.0000000	0.0000000	11.9486311	11.9486311	12.6878832
12/1 12:00	39.8398205	0.0000000	0.0000000	4.2568137	4.2568137	12.6878832
12/1 13:00	40.7514412	0.0000000	0.0000000	3.1910045	3.1910045	12.6878832
12/1 14:00	40.7072573	0.0000000	0.0000000	2.2329267	2.2329267	12.6878832
12/1 15:00	40.7684119	0.0000000	0.0000000	2.1166245	2.1166245	12.6878832
12/1 16:00	23.0889513	0.0000000	0.0000000	2.0154008	2.0154008	12.6878832
12/1 17:00	10.7424793	0.0000000	0.0000000	1.9874153	1.9874153	12.6878832
12/1 18:00	4.8307336	0.0000000	0.0000000	1.5244522	1.5244522	12.6878832
12/1 19:00	0.6177885	0.0000000	0.0000000	16.2930940	16.2930940	0.0000000
12/1 20:00	0.0000000	0.0000000	0.0000000	16.7074256	16.7074256	0.0000000
12/1 21:00	0.0000000	0.0000000	0.0000000	19.2611715	19.2611715	0.0000000
12/1 22:00	0.0000000	0.0000000	0.0000000	27.0215091	27.0215091	0.0000000
12/1 23:00	0.4443579	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

Figure 8.3: Simulation results for the 12th of January in a grid form, page 3 out of 4

Time	Catering (kWh)	Process (kWh)	Miscellaneous (kWh)	General Lighting (kWh)	Task Lighting (kWh)	Occupancy (kWh)
12/1 00:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0781665
12/1 01:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/1 02:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/1 03:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/1 04:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/1 05:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/1 06:00	0.0000000	0.0000000	0.0000000	2.1777464	0.0000000	0.0000000
12/1 07:00	0.0000000	0.0000000	0.0000000	3.3006683	0.0000000	0.1619020
12/1 08:00	0.0000000	0.0000000	0.0000000	9.0737929	0.0000000	4.2832067
12/1 09:00	0.0000000	0.0000000	0.0000000	21.1777669	0.0000000	64.3378834
12/1 10:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	76.3379973
12/1 11:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	75.6588008
12/1 12:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	75.2657001
12/1 13:00	0.0000000	0.0000000	0.0000000	35.9295584	0.0000000	75.2397439
12/1 14:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	74.6519440
12/1 15:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	73.4743241
12/1 16:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	47.0245789
12/1 17:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	23.9010407
12/1 18:00	0.0000000	0.0000000	0.0000000	35.0929709	0.0000000	15.6974096
12/1 19:00	0.0000000	0.0000000	0.0000000	20.6275138	0.0000000	14.6539775
12/1 20:00	0.0000000	0.0000000	0.0000000	24.1044469	0.0000000	19.1339989
12/1 21:00	0.0000000	0.0000000	0.0000000	20.3486514	0.0000000	17.6378675
12/1 22:00	0.0000000	0.0000000	0.0000000	9.9178523	0.0000000	9.6377916
12/1 23:00	0.0000000	0.0000000	0.0000000	2.8194161	0.0000000	1.5669236

Figure 8.4: Simulation results for the 12th of January in a grid form, page 4 out of 4.

Zone Sensible Heating

	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]	Design Day Name	Date/Time Of Peak {TIMESTAMP}	Thermostat Setpoint Temperature at Peak Load [C]	Indoor Temperature at Peak Load [C]	Indoor Humidity Ratio at Peak Load [kgWater/kgAir]	Outdoor Temperature at Peak Load [C]	Outdoor Humidity Ratio at Peak Load [kgWater/kgAir]	Minimum Outdoor Air Flow Rate [m3/s]	Heat Gain Rate from DOAS [W]
ZONE 1	16936.08	21170.10	87.10	0.809	1.422	WINTER DESIGN DAY IN UNTITLED	1/15 10:00:00	20.00	20.00	0.01287	-3.20	0.00289	1.422	0.00
ZONE 2	96747.32	120934.15	62.03	4.674	7.467	WINTER DESIGN DAY IN UNTITLED	1/15 10:00:00	20.00	20.00	0.01311	-3.20	0.00289	7.467	0.00
ZONE 3	9173.43	11466.79	66.47	0.491	0.621	WINTER DESIGN DAY IN UNTITLED	1/15 11:00:00	20.00	19.98	0.01450	-3.20	0.00289	0.621	0.00

Figure 8.5: Table of the report for the 12th of January simulation presenting the zone sensible heating for every zone. Personal file

Zone Sensible Cooling

	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]	Design Day Name	Date/Time Of Peak {TIMESTAMP}	Thermostat Setpoint Temperature at Peak Load [C]	Indoor Temperature at Peak Load [C]	Indoor Humidity Ratio at Peak Load [kgWater/kgAir]	Outdoor Temperature at Peak Load [C]	Outdoor Humidity Ratio at Peak Load [kgWater/kgAir]	Minimum Outdoor Air Flow Rate [m3/s]	Heat Gain Rate from DOAS [W]
ZONE 1	17929.18	20618.55	84.83	1.046	1.422	SUMMER DESIGN DAY IN UNTITLED JUL	5/15 15:00:00	26.00	25.97	0.01010	34.10	0.01106	1.422	0.00
ZONE 2	130971.80	150617.57	77.26	7.641	8.787	SUMMER DESIGN DAY IN UNTITLED JUL	5/15 16:00:00	26.00	25.97	0.00950	33.43	0.01106	7.467	0.00
ZONE 3	8817.24	10139.83	58.78	0.514	0.621	SUMMER DESIGN DAY IN UNTITLED JUL	5/15 15:00:00	26.00	25.99	0.00849	34.10	0.01106	0.621	0.00

Figure 8.6: Table of the report for the 12th of January simulation presenting the zone sensible cooling for every zone. Personal file

8.2 Single day simulation for the summer period

In this section are going to be analysed the results of the simulation for the summer period. The simulation refers to the 12th of July. Figures 8.7, 8.8, 8.9 and 8.10 display the simulation results.

Figure 8.7 presents the air temperature for the entire day, which is close to the favourable temperature of 26^oC and it is exactly 26^oC at occupancy hours. Furthermore radiant temperature, as well as operative temperature are presented. The outside dry bulb temperature ranges from 19.4^oC to 31.8^oC and relative humidity ranges in the permitted margin.

At figure 8.8 are visible the heat gains and heat losses which come from the glazing, walls, floors, ceiling and external infiltration. These loads can switch from heat gains to heat losses and from heat losses to heat gains during the day. Additional heat gains come from the computers and equipment, general lighting and occupancy, which are displayed at figures 8.9 and 8.10.
Zone air system sensible heating rate, zone air system sensible cooling rate, supply air sensible cooling, supply air total cooling, supply air sensible heating and supply air total heating are presented at figures 8.8 and 8.9. The simulation refers to a summer day, for this reason the zone air system sensible heating rate, supply air sensible heating and supply air total heating are zero. There is need only for cooling load. Zone air system sensible cooling rate represents the building's need of cooling load. Supply air total cooling consists of the sensible and latent load. For this reason supply air total cooling is greater than supply air sensible cooling. As it is, already, stated latent load is the difference between the supply air sensible cooling and supply air total cooling. The occupancy makes the greatest contribution to the total load of the building, but this depends on the schedule of use.

Figures 8.11 and 8.12 present the zone sensible heating and cooling for every zone with summary results, calculated by the software, for the simulation. These refer to the design load, design air flow, design day, date and time of peak, temperature and humidity at peak load and air flow rate, all of them for every zone individually.

Time	Air temperature (°C)	Radiant temperature (°C)	Operative temperature (°C)	Outside dry bulb temperature (°C)	Relative humidity (%)	Mech vent + nat vent + Infiltration (ac/h)
12/7 00:00	27.82333	28.50780	28.16557	25.30000	38.3023508	1.51295
12/7 01:00	27.75163	28.38337	28.06750	23.90000	38.6752665	1.51936
12/7 02:00	27.59237	28.31928	27.95582	22.80000	38.5415174	1.52416
12/7 03:00	27.36505	28.22843	27.79674	21.70000	38.4783615	1.52877
12/7 04:00	27.12255	28.10765	27.61510	20.50000	38.7965301	1.53385
12/7 05:00	26.90136	27.97326	27.43731	19.40000	39.4310825	1.53852
12/7 06:00	26.01546	27.91224	26.96385	21.20000	41.3063228	1.93637
12/7 07:00	26.00000	27.90040	26.95020	23.00000	40.9211807	2.75152
12/7 08:00	26.00000	28.29137	27.14569	24.80000	41.2643897	11.60260
12/7 09:00	26.00000	28.67246	27.33623	25.90000	41.7145355	12.83561
12/7 10:00	26.00000	28.91862	27.45931	27.00000	41.9218969	12.83097
12/7 11:00	26.00000	29.20248	27.60124	28.20000	43.4689330	12.00572
12/7 12:00	26.00000	29.31888	27.65944	28.70000	44.3955424	12.00643
12/7 13:00	26.00000	29.36075	27.68037	29.30000	44.5121072	12.01444
12/7 14:00	26.00000	29.45240	27.72620	29.80000	44.5412613	12.02276
12/7 15:00	26.00000	29.48472	27.74236	30.50000	44.3331146	9.12279
12/7 16:00	26.00000	29.47516	27.73758	31.10000	43.0095490	6.63593
12/7 17:00	26.00000	29.43719	27.71859	31.80000	41.4183835	3.12388
12/7 18:00	26.00000	29.14861	27.57431	30.90000	40.1700265	3.12873
12/7 19:00	26.00000	28.94370	27.47185	29.90000	39.6878893	3.54653
12/7 20:00	26.00000	28.68644	27.34322	29.00000	39.5417090	3.55085
12/7 21:00	26.00000	28.48451	27.24226	28.00000	39.5485362	2.72943
12/7 22:00	27.86630	28.26479	28.06555	27.00000	36.5538022	1.71210
12/7 23:00	27.82764	28.52144	28.17454	26.00000	37.2489527	1.71707

Figure 8.7: Simulation results for the 12th of July in a grid form, page 1 out of 4

Time	Glazing (kWh)	Walls (kWh)	Floors (kWh)	Ceilings (kWh)	External Infiltration (kWh)	Zone air system sensible heating rate
12/7 00:00	-2.6163252	2.3045966	-1.9687553	5.4650272	3.7731017	0.0000000
12/7 01:00	-3.4295413	2.1610011	-0.6073677	5.3972298	5.6912967	0.0000000
12/7 02:00	-4.1692841	1.8631609	-0.0775145	5.4107157	7.0330558	0.0000000
12/7 03:00	-4.6279572	1.8502922	0.9495240	5.6024529	8.2800171	0.0000000
12/7 04:00	-5.1232667	2.0097067	2.1428799	5.8902086	9.6661257	0.0000000
12/7 05:00	-5.5128450	2.1411974	3.1992549	6.1758768	10.9237750	0.0000000
12/7 06:00	-3.8464556	1.7625109	3.1026882	6.1520014	6.9399673	0.0000000
12/7 07:00	6.0042030	1.3202269	0.6096803	5.1004451	4.3041953	0.0000000
12/7 08:00	20.5532897	-4.6832365	-14.6330345	-0.0678459	1.7156681	0.0000000
12/7 09:00	30.4900678	-6.9081594	-20.5385258	-3.3611141	0.1488604	0.0000000
12/7 10:00	34.8234318	-5.3013755	-18.8281244	-4.3858831	0.0000000	0.0000000
12/7 11:00	36.4378294	-3.4086707	-17.2687595	-4.8386787	0.0000000	0.0000000
12/7 12:00	35.2200806	-1.0562530	-15.2731256	-4.8837421	0.0000000	0.0000000
12/7 13:00	28.6732731	0.9837373	-11.5634498	-4.0471954	0.0000000	0.0000000
12/7 14:00	32.1048216	0.8908769	-13.4277400	-4.0822962	0.0000000	0.0000000
12/7 15:00	32.9261192	2.0072492	-11.0016185	-2.8506101	0.0000000	0.0000000
12/7 16:00	33.2389730	3.0096257	-9.3685007	-1.6617437	0.0000000	0.0000000
12/7 17:00	35.4446446	3.3671542	-10.0840980	-1.0072497	0.0000000	0.0000000
12/7 18:00	27.0420025	6.5630160	-1.6778673	1.7018706	0.0000000	0.0000000
12/7 19:00	12.9789678	7.0879269	2.3572039	3.2240064	0.0000000	0.0000000
12/7 20:00	0.6201851	8.4736228	7.0416778	5.5034149	0.0000000	0.0000000
12/7 21:00	-0.8493601	8.9740001	8.2092344	7.1882932	0.0000000	0.0000000
12/7 22:00	-1.4003149	9.1340328	8.6529131	8.2658273	1.3109222	0.0016499
12/7 23:00	-2.1802963	1.9345831	-4.2707474	5.2838842	2.7033579	0.0000000

Figure 8.8: Simulation results for the 12th of July in a grid form, page 2 out of 4.

Time	Zone air system sensible cooling rate	Supply air sensible cooling (kWh)	Supply air total cooling (kWh)	Supply air sensible heating (kWh)	Supply air total heating (kWh)	Computers+ Equipment (kWh)
12/7 00:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/7 01:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/7 02:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/7 03:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/7 04:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/7 05:00	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/7 06:00	14.4367234	14.5287077	17.1063901	0.0000000	0.0000000	0.0000000
12/7 07:00	30.1525194	28.0647346	34.1295145	0.0000000	0.0000000	12.6878832
12/7 08:00	77.3709673	66.8105144	111.6384033	0.0000000	0.0000000	12.6878832
12/7 09:00	99.7275840	98.9155667	169.4459583	0.0000000	0.0000000	12.6878832
12/7 10:00	108.3001620	111.7366971	188.9540800	0.0000000	0.0000000	12.6878832
12/7 11:00	115.5379806	122.2550479	209.8427357	0.0000000	0.0000000	12.6878832
12/7 12:00	119.2363838	127.4434492	223.0478621	0.0000000	0.0000000	12.6878832
12/7 13:00	120.7562969	130.7018419	230.4396954	0.0000000	0.0000000	12.6878832
12/7 14:00	122.7351202	134.1983974	242.5527320	0.0000000	0.0000000	12.6878832
12/7 15:00	109.9493842	117.8150835	178.3794929	0.0000000	0.0000000	12.6878832
12/7 16:00	98.2007653	101.8422184	133.6990481	0.0000000	0.0000000	12.6878832
12/7 17:00	94.1449446	95.4890973	113.7479317	0.0000000	0.0000000	12.6878832
12/7 18:00	71.6098905	74.1289071	81.2012229	0.0000000	0.0000000	0.0000000
12/7 19:00	68.5272666	71.1638121	76.4022037	0.0000000	0.0000000	0.0000000
12/7 20:00	58.7628270	60.7891717	66.4473969	0.0000000	0.0000000	0.0000000
12/7 21:00	43.3164895	44.0189092	49.6278773	0.0000000	0.0000000	0.0000000
12/7 22:00	0.0272195	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
12/7 23:00	0.0651992	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

Figure 8.9: Simulation results for the 12th of July in a grid form, page 3 out of 4.

Time	Catering (kWh)	Process (kWh)	Miscellaneous (kWh)	General Lighting (kWh)	Task Lighting (kWh)	Occupancy (kWh)
12/7 00:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/7 01:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/7 02:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/7 03:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/7 04:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0000000
12/7 05:00	0.0000000	0.0000000	0.0000000	2.1777464	0.0000000	0.0000000
12/7 06:00	0.0000000	0.0000000	0.0000000	3.3006683	0.0000000	0.0904671
12/7 07:00	0.0000000	0.0000000	0.0000000	9.0737929	0.0000000	3.0346541
12/7 08:00	0.0000000	0.0000000	0.0000000	21.1777669	0.0000000	45.5834235
12/7 09:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	54.0855104
12/7 10:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	54.0855104
12/7 11:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	54.7775116
12/7 12:00	0.0000000	0.0000000	0.0000000	35.9295584	0.0000000	54.7775116
12/7 13:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	54.7775116
12/7 14:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	54.7775116
12/7 15:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	34.9393090
12/7 16:00	0.0000000	0.0000000	0.0000000	36.2084209	0.0000000	17.9351353
12/7 17:00	0.0000000	0.0000000	0.0000000	35.0929709	0.0000000	11.6150455
12/7 18:00	0.0000000	0.0000000	0.0000000	20.6275138	0.0000000	10.7224191
12/7 19:00	0.0000000	0.0000000	0.0000000	24.1044469	0.0000000	13.5564481
12/7 20:00	0.0000000	0.0000000	0.0000000	20.3486514	0.0000000	12.4964382
12/7 21:00	0.0000000	0.0000000	0.0000000	9.9178523	0.0000000	6.8283803
12/7 22:00	0.0000000	0.0000000	0.0000000	2.8194161	0.0000000	1.1101661
12/7 23:00	0.0000000	0.0000000	0.0000000	2.0383152	0.0000000	0.0419400

Figure 8.10: Simulation results for the 12th of July in a grid form, page 4 out of 4.

Zone Sensible Heating

	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]	Design Day Name	Date/Time Of Peak {TIMESTAMP}	Thermostat Setpoint Temperature at Peak Load [C]	Indoor Temperature at Peak Load [C]	Indoor Humidity Ratio at Peak Load [kgWater/kgAir]	Outdoor Temperature at Peak Load [C]	Outdoor Humidity Ratio at Peak Load [kgWater/kgAir]	Minimum Outdoor Air Flow Rate [m3/s]	Heat Gain Rate from DOAS [W]
ZONE 1	16936.08	21170.10	87.10	0.809	1.422	WINTER DESIGN DAY IN UNTITLED	1/15 10:00:00	20.00	20.00	0.01287	-3.20	0.00289	1.422	0.00
ZONE 2	96747.32	120934.15	62.03	4.674	7.467	WINTER DESIGN DAY IN UNTITLED	1/15 10:00:00	20.00	20.00	0.01311	-3.20	0.00289	7.467	0.00
ZONE 3	9173.43	11466.79	66.47	0.491	0.621	WINTER DESIGN DAY IN UNTITLED	1/15 11:00:00	20.00	19.98	0.01450	-3.20	0.00289	0.621	0.00

Figure 8.11: Table of the report for the 12th of July simulation presenting the zone sensible heating for every zone. Personal file

Zone Sensible Cooling

	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]	Design Day Name	Date/Time Of Peak {TIMESTAMP}	Thermostat Setpoint Temperature at Peak Load [C]	Indoor Temperature at Peak Load [C]	Indoor Humidity Ratio at Peak Load [kgWater/kgAir]	Outdoor Temperature at Peak Load [C]	Outdoor Humidity Ratio at Peak Load [kgWater/kgAir]	Minimum Outdoor Air Flow Rate [m3/s]	Heat Gain Rate from DOAS [W]
ZONE 1	17929.18	20618.55	84.83	1.046	1.422	SUMMER DESIGN DAY IN UNTITLED JUL	5/15 15:00:00	26.00	25.97	0.01010	34.10	0.01106	1.422	0.00
ZONE 2	130971.80	150617.57	77.26	7.641	8.787	SUMMER DESIGN DAY IN UNTITLED JUL	5/15 16:00:00	26.00	25.97	0.00950	33.43	0.01106	7.467	0.00
ZONE 3	8817.24	10139.83	58.78	0.514	0.621	SUMMER DESIGN DAY IN UNTITLED JUL	5/15 15:00:00	26.00	25.99	0.00849	34.10	0.01106	0.621	0.00

Figure 8.12: Table of the report for the 12th of July simulation presenting the zone sensible cooling for every zone. Personal file

Chapter 9

Conclusion

9.1 Recapitulation

To recapitulate, the energy performance of a building depends on various parameters. Firstly, it depends on the location and orientation of the building, the climatic data of this location, the architectural design, the shell and geometry parameters of the building's elements. The glazing, walls, floor, ceiling, external infiltration are basic factors for the heat transfer from the inside to the outside of the building and, conversely,from the outside to the inside of it. Additionally, the building's energy performance depends on the Heating Ventilation and Air Conditioning system of use. Internal heat gains, which come from the occupancy, lighting and internal equipment, contribute to the total load, too. Last, the operating schedule can modify the total energy performance of the building.

9.2 Importance of the energy analysis

The investigation of the energy analysis of a building is significant as for an already existing building as for a new building.

- The energy analysis can energy upgrade an existing building after a major renovation, if necessary.
- In a new building an energy analysis can contribute to the better design of the building and to take the full advantage of energy efficiency. This can be achieved when the energy analysis is considered at the first stage of the design investigation. In that way, not only the appropriate walls, ceiling, shell elements and HVAC system are used, but also the climatic data, location, architectural design and geometry of the building are leveraged.

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