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University buildings in Greece: Energy analysis of heating and cooling demand

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Abstract
The paper presents the energy analysis results of 10 University building blocks, confirmed by in-situ recordings. The results prove that the University buildings present a significant potential for energy consumption reduction, behaving differently than the other constructions of the non-residential sector. Energy consumption and environmental behavior indices are reported for the specific building category, in an attempt to fill the existing gap in the literature.

Keywords: Building simulation; Energy consumption; University facilities; Heating; Cooling.

1. Introduction

One of the major targets set by the EU is the reduction of primary energy consumption of building sector, since it accounts for 35.8% of total consumption (EU-27, 2007) [1]. To this aim, the 2002/91/EU Directive [2] was the basic tool during the last decade, calling the member states to improve the energy efficiency of their buildings. The recent recast of this directive (2010/31/EU) [3] calls the member states to take the necessary measures ensuring that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels. Additionally, the construction of the nearly zero energy building by 2018 for the public sector and by 2020 for all other buildings is set as the future target. This general direction must also be followed by the refurbished buildings and the member states are urged to establish strategies for accomplishing the above mentioned targets.
Adopting energy management and evaluation strategies for buildings at national or European level however presumes the knowledge of the specific characteristics of the building stock and makes imperative need the collection and analysis of energy-related data and indices of the building sector. More specifically, the energy consumption mainly depends on the type, the construction and the profile use of the building, the climate of the area, the efficiency of the heating, cooling and hot water producing systems and lighting. Each individual type of building therefore features specific characteristics and behavior, defined by the operational needs. For the collection and evaluation of the relevant data, a significant number of National and European research projects have been elaborated (e.g. [4, 5]), leading to the formation of databases including field data and measurement results as well as results from simulations. A closer look on these data reveals that the residential buildings have been thoroughly analyzed. Consequently, energy consumption and emission indices are available as a function of the construction year, the thermal insulation level, the topology of the building etc. [6-9]. Obviously, this is due to the fact that this category represents the vast majority of buildings. In Greece for example, 76.97%

of the total number of buildings are residential [10], the corresponding figure for EU-25 being estimated at 80% [11]. In contrast to the residential sector, a recent investigation in the EU-25 has revealed the lack of data for non-residential buildings in many countries and format inconsistencies in the cases such data do exist [12].

The non-residential buildings in Greece represent the 23.03% of the total number of building stock. More specifically, 3.77% of the total are commercial and office buildings, 0.82% are hotel establishments and 0.06% are hospital facilities. Other non-residential buildings include churches, industrial facilities, sport centers, parking buildings etc., summing up to 17.92% [13]. The majority of these buildings is not continuously used and presents a minor participation in total energy consumption. As a result, the non-residential buildings analysis in Greece has been focused on the four major subcategories (commercial/office, hotel, educational, and health care buildings) and a number of independent research groups has published energy consumption data and indices [12, 14, 15].

The subcategory "educational buildings" in fact includes schools (i.e. kindergarten, elementary and high schools) and Universities, despite the existing significant differences (university buildings include offices, classrooms, laboratories etc., while school buildings are mainly classrooms, the operation duration of the university buildings is higher than that of the school buildings, but lower than the rest of the tertiary sector, both during the day and through the year due to vacations). In the literature, a number of studies reports energy indices for school buildings [16, 17], but the relevant indices for university buildings are missing [4].

Aim of this study is to present indicative energy consumption indices and CO_2 footprints for University buildings, based on the results of energy simulation, verified by comparison of real world data for the School of Engineering of the Aristotle University of Thessaloniki.

2. Description of the energy analysis tool

For the purposes of this study, the Energy Plus software was used. Energy Plus is a building energy simulation program for modeling heating, cooling, lighting, ventilating and other energy flows. It is based on the most popular features and capabilities of the existed BLAST and DOE-2 simulation software. The simulation time step can be freely chosen between 1 and 60 h, although the range between 1 to 6 h is the most commonly used. It is a robust software that provides a profile of several outputs (cooling/heating loads, zone temperature, building energy consumption for heating and cooling, etc.), requiring as inputs the geometry of the building, the materials of constructions, the internal heat gains, the HVAC system characteristics and the main weather parameters (dry/wet bulb temperature, direct/diffuse solar radiation, wind speed/direction, etc.) [18].

3. Description of the buildings

This study focuses on the building blocks of the Engineering School complex of the Aristotle University of Thessaloniki – Figure 1. The complex consists of 10 buildings, with 62,200 m^2 total covered area, 55,200 m^2 of which are heated. These buildings cover the needs of the 7 Departments of the School. 16% of the covered area is classrooms, 21% is in common use (corridors, staircases etc.), 30% is laboratories and the remaining 33% is staff offices. The construction of the complex started in late 50's, the older 4 buildings being in operation since 1961. A second group of buildings was finished in 70's and the complex was completed in late 90's.

This long construction period, combined with the complete absence of major renovation works, results in a wide range of characteristics, as for example the thermal insulation level and the total area and quality of windows, reflecting the common practice and the legislation of 5 decades.

The prevailing orientation is SE (139°) – NW (319°), with the majority of windows NE (49°) or SW (229°) oriented. Four of the buildings are free-standing and of high height (more than 8 floors), while the rest are of lower height (less than 10 m), located close to the tall ones, partially or completely shadowed by them.

4. Definition of the energy analysis parameters

The energy analysis and simulation of buildings requires the definition of a number of parameters, related to construction characteristics (geometry and structural elements), the operation time distribution on day, week, month and year basis, the efficiency of the heating, cooling and ventilating systems and the desirable indoor comfort conditions. The proper definition of these parameters has been the subject of many studies over the years [e.g. 19, 20]. In most cases and for the existing buildings, a combination of literature suggestions and in-situ audit results is used, while for new buildings the audit results are substituted by the design details.

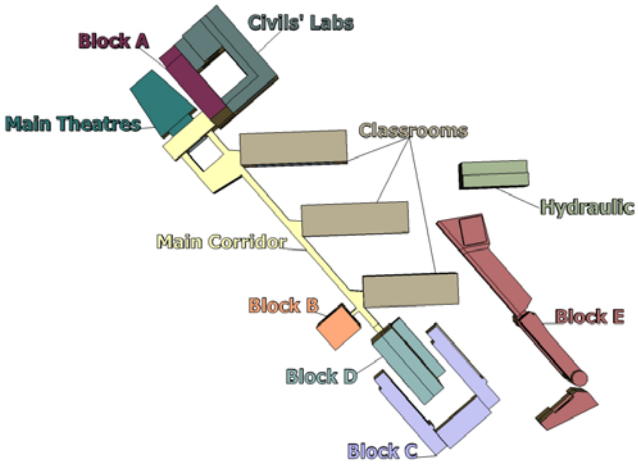

Figure 1. Engineering School. Ground plan of building blocks

In-situ audit results and the ASHRAE recommendations for classrooms, laboratories offices etc, as appropriate, [21, 22] were used for the purposes of this study. More specifically, the internal heat sources (people, lights, equipment) and ventilation were simulated in order to reflect as accurately as possible the actual operating conditions of the buildings. The required space temperatures were set according to the ASHRAE suggestions [23], taking into account the season (heating or cooling period) and the time of the day (operation or non-operation period of the building). Finally, the official holidays as well as the vacation periods were accounted for. Table 1 lists the major simulation parameters.

Table 1. Basic simulation characterists of building's blocks

Latitude / Longitude	40° 36' / 22° 59'
Operation Period	08:00 – 21:00
Heating Period	16 October – 15 May
Desired Temperature During Heating Operation/Non-Operation Period	22°C / 18°C
Cooling Period	16 May – 15 October
Desired Temperature During Cooling Operation/Non-Operation Period	26°C / 30°C
Air Changes of Auditoriums, Classrooms, Laboratories, Refreshment rooms Operation/Non-Operation Period	2 ach / 0.3 ach
Air Changes of Offices, Libraries Operation/Non-Operation Period	1 ach / 0.3 ach

The geometry of the buildings and the construction details were taken from the relevant blueprints, confirmed however by in-situ inspections. Based on these data, the quantities listed in Table 2 were determined. It is worth noticing that the ratio of area over volume (F/V) for the higher buildings ranges between 0.17 and 0.22, while for lower buildings between 0.31 and 0.34. Both ranges are significantly lower than those found in the relevant literature [24], suggesting in principle that reduced energy requirements should be expected.

Of the important factors, significantly affecting the energy consumption of a building, are the thermal insulation of the construction elements and the physical properties of the embrasures. For this reason, these characteristics, main inputs of the energy model, were in-situ determined and verified. Concerning the thermal insulation of the construction elements, it was decided to group the buildings in three categories: Category I, with the older ones, constructed till 1975, without any insulation, Category II, with the buildings built from 1975 to 1990, partially insulated mainly with expanded polystyrene and Category III, the buildings of which were built after 1990 and they are insulated in order to comply with the Greek Regulation for Thermal Insulation of Buildings. It was revealed that 55.1% of the buildings are of the Category I, 35.9% of the Category II and only 9% of the Category III.

The thermal insulation is characterized by the overall thermal transmittance coefficient, which, for the buildings of this work, is listed in Table 2. As it can be seen, it is in the range 2.35 – 3.10 W/m^{2}K (Category I), 1.41 – 2.10 W/m^{2}K (Category II) and 1.03 W/m^{2}K (Category III), the corresponding average values found in the Greek literature being 2.22 W/m^{2}K, 1.57 W/m2K and 0.7 W/m^{2}K, respectively [4]. The comparison of these values reveals that the insulation of the buildings of the sample is poor, therefore increased energy requirements should be expected, despite the low F/V ratio, which in principle suggests the opposite.

As already mentioned, the weather files are of the most significant inputs for the energy simulation of buildings, seriously affecting the results of the simulation [25, 26]. A number of weather files is available in the literature, developed according to different methodologies [27-33]. The files IWEC of ASHRAE (GRC - IWEC 166220 WMO), IWEC hereafter, and the METEONORM TMY-2 (TMY-2 16622 WMO), TMY-2 hereafter, were used in the present study.

Table 2. Heat area and volume, insulation category and overall thermal transmittance coefficient per building

Building – Construction Year	Air-conditioned Area [m^2]	Air-conditioned Volume [m^3]	Insulation Category	Overall Thermal Transmittance Coefficient [W/m^{2}K]	F/V [m^2/m^3]
Classrooms - 1961	16,945	79,305	I	2.99	0.17
Block A – 1961	7,560	32,300	I	2.79	0.20
Main Corridor - 1961	2,410	13,965	I	2.89	0.34
Civils' Labs - 1961	945	10,440	I	2.35	0.18
Hydraulic - 1966	2,575	11,710	I	3.10	0.22
Block B - 1970	2,985	12,885	II	2.10	0.20
Main Theatres – 1975	1,940	8,875	II	1.87	0.17
Block C – 1976	6,080	21,410	II	1.41	0.31
Block D – 1978	8,790	30,760	II	1.59	0.17
Block E - 1999	4,970	20,090	III	1.03	0.16
Total	55,200	241,740			

5. Results

Figure 2 presents the daily profile of energy consumption of an office building of the Engineering School for four characteristic days of the heating period, according to TMY-2 weather data. It can be clearly seen that the maximum energy consumption occurs at 08:00 hours, when the daily operation of the building starts and the internal temperature is required to reach 22°C. During the day (08:00-16:00), the energy consumption continuously reduces, because of the combined effect of the increasing ambient temperature and the internal and solar gains. During the afternoon (16:00-21:00), the operation intenseness of the building is gradually reduced to reach zero. Consequently, the internal gains are reducing, as well as the ambient temperature and the solar gains. As a result, the energy consumption is increasing to a local maximum, after which it decreases, approaching or even reaching zero over the nocturnal non-operation period of the building, because of the required lower internal temperature (18°C) and the heat capacity of the building. The shape of the curve is typical for all days and all buildings, the absolute values however depending on the day (same building – different days) or on the building characteristics (same day – different buildings). It should be noticed that the use of the IWEC weather file leads to similar curve shapes, but with slightly different absolute values.

Figure 3 presents the cooling energy profile of the same building for five characteristic days of the cooling period, based on TMY-2 weather file. Overnight (21:00-08:00), the energy demand is zero, with the exception of the two early in the morning hours of the hottest months (July – August), when some cooling is needed to maintain internal temperature 30°C. During the day, the cooling energy demand constantly increases, reaching a maximum at 12:00, after which it remains practically constant for about five hours and it starts reducing, to reach zero at night. As in the heating energy demand case, the absolute values of this profile depend on both the day (i.e. climate conditions) and the building characteristics (construction, orientation, usage).

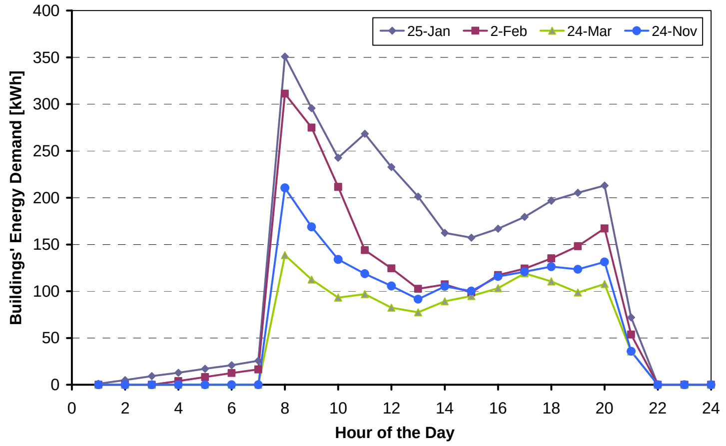

Figure 2. Typical daily energy consumption profiles for the university office building. Heating period - TMY-2 weather file

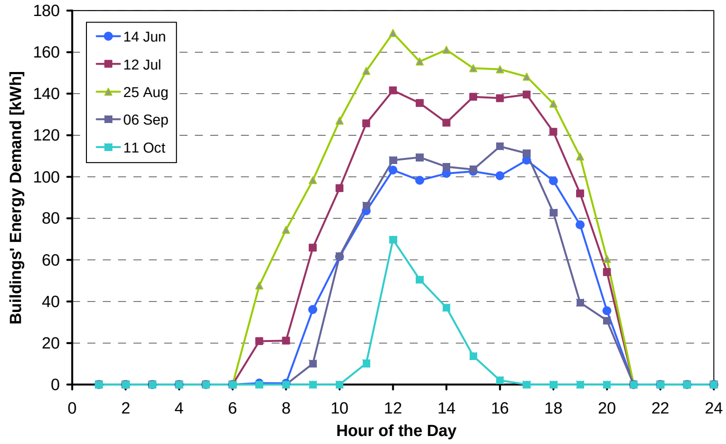

Figure 3. Typical daily energy consumption profiles for the university office building. Cooling period - TMY-2 weather file

Figure 4 presents the energy demand for heating of a classroom building, for the same days and weather file as in Figure 2. The overall trend of the classroom building remains the same with the one of the office building, it has to be noted however that the reduction of heating energy demand during the day in the classroom case is much sharper, because of the increased internal gains resulting from the presence of significantly higher number of people in the spaces.

The comparison of cooling energy demand profiles of classroom (Figure 5) and office buildings (Figure 3) reveals more enhanced differences. Due to the increased number of occupants in the classroom building case, the cooling energy demand in October remains significant. On the other hand, the energy demand of the same building in July and August is significantly lower, because the building is practically not in operation, due to the summer vacations of the students. It should be noticed that the profile of the curves presented in Figures 2-5 remains similar when IWEC weather file is used.

Figure 6 shows the annual energy consumption reduced to the heated/cooled area, as this energy resulted using the two weather files. Clearly, the results for both heating and cooling with TMY-2 are always higher than the IWEC corresponding ones. It has to be noted however that: (a) regardless of the weather file used, there are significant differences in heating energy demand between buildings – up to a factor of more than 5 – depending on both the age and the usage of the building, (b) the energy demand for heating is significantly higher than for cooling, a result of both the climate of the area and the usage of the buildings, and (c) the difference of the results with the two weather files is very small, practically negligible, in the case of cooling energy demand.

Because of the different usage of the spaces of the various buildings, the internal height can be very different. As a result, the heated/cooled volume per heated/cooled area ranges between 11.1:1 (laboratories) and 3.5:1 (classrooms). In order to account for the effect of this parameter, the annual energy demand per heated/cooled volume is plotted in Figure 7 for both weather files.

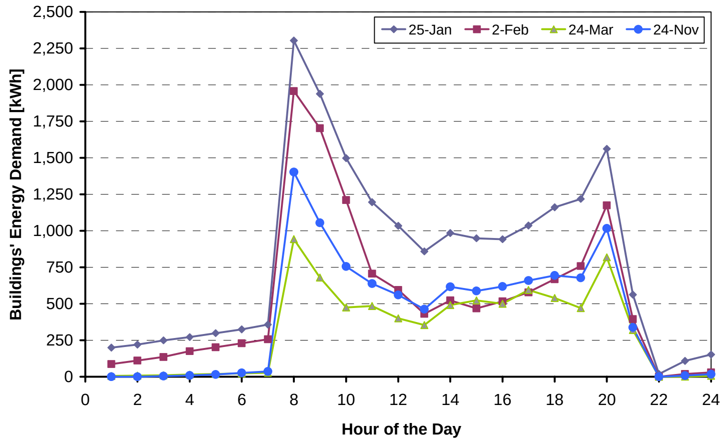

Figure 4. Typical daily energy consumption profiles for the university classroom building. Heating period - TMY-2 weather file

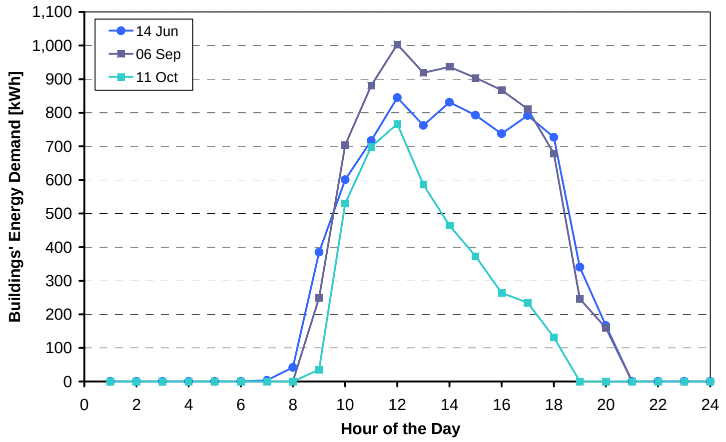

Figure 5. Typical daily energy consumption profiles for the university classroom building. Cooling period - TMY-2 weather file

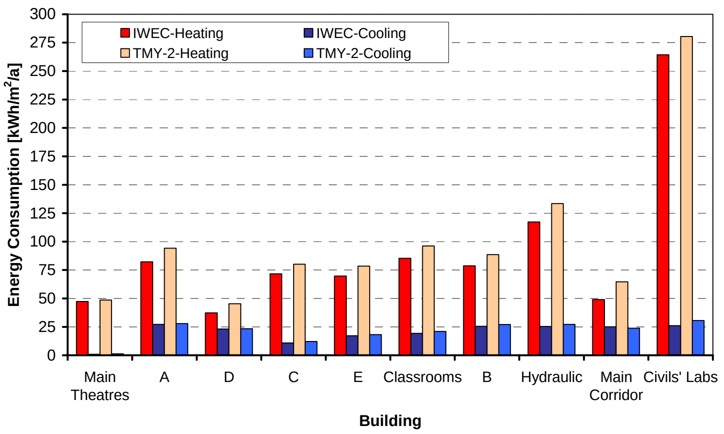

Figure 6. Energy Consumption per heating/cooling area of the buildings on annual basis

Based on Figures 6 & 7, it can be stated that the bigger energy consumers are the Civil's Labs and the Hydraulic buildings, while the Main Corridor, the Main Theaters and Block D are the less consuming buildings. At this point it must be reminded that the energy demand of a building depends on a number of parameters, including the insulation level but also the use profile, shadowing of nearby taller constructions etc. The combined effect of all these parameters has can explain some "abnormalities" observed in Figures 6 & 7. For example, despite the fact that Block E is newer, and hence better insulated, than Block D, it presents higher heating and lower cooling energy demand, even though they are both office buildings with equivalent usage profiles and internal gains. Block E however is a low building and the shadows of the nearby much taller constructions significantly reduce solar gains, resulting thus in lower cooling and higher heating energy demand.

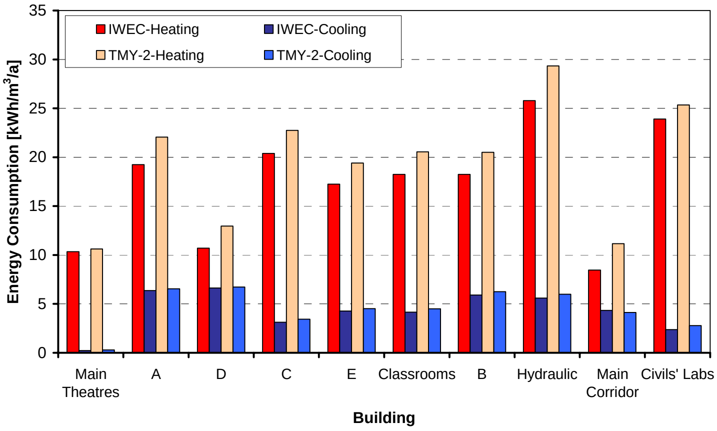

Figure 7. Energy Consumption per heating/cooling volume of the buildings on annual basis

The comparison of Figures 6 & 7 reveals also that the reduction of the energy consumption to the heated/cooled volume instead of area alters the energy classification of the buildings, as expected, since volume accounts for both the area and the internal height of the spaces.

The results of the above presented simulation for heating were translated (assuming 82% overall efficiency of the heating system [34,35]) in fuel consumption (natural gas) and the results were compared to the average actual consumption recorded for the period 2004-09. The results of this comparison are shown in Figure 8.

According to Figure 8, the simulation results with the IWEC weather file underestimate the fuel consumption for heating by 13.2%, while the corresponding figure with TMY-2 is 1.4%. It is reminded at this point that according to the IWEC, the performance of the solar radiation model for the Thessaloniki area is “unknown”, as “the model was not calibrated because there is no data available for this site”, and that “it is an important parameter which should not be overlooked” [36].

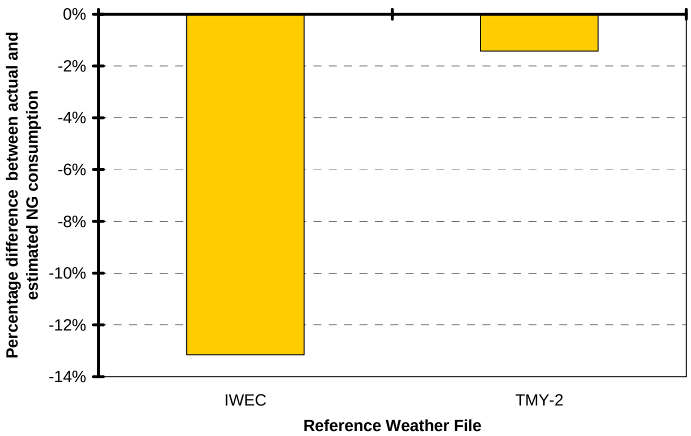

Figure 8. Comparison between actual natural gas consumption and estimated via simulation using the weather files of TMY-2 and IWEC

Using the prescribed in the Greek regulations CO2 emission factor for natural gas systems [37], the CO2 footprint for heating of each building was calculated, using the results of the above described simulation, in CO_2 mass per unit of area and volume. The results are plotted in Figure 9. It can be clearly seen that the annual CO_2 emission ranges between 10.45 and 64.65 kg/m^2 or between 2.45 and 5.85 kg/m^3, depending on the usage and the construction of the building.

Table 3 summarizes the results of this work, obtained with the TMY-2 weather file, the results of which, at least for the Thessaloniki area, proved to be closer to actual fuel consumption. It is worth noticing that the heating energy demand of University office buildings is in the 45.32 – 133.43 kWh/m^2 or 12.95 – 29.35 kWh/m^3 range. The corresponding range reported in the literature is 83.0 kWh/m^2 to 223.9

kWh/m^2 [38], almost double the results of this work, or 101 kWh/m^2 on average according to another publication [39]. This difference should be attributed to the relatively prolonged non-operation of the University offices in the middle of the heating period (e.g. Christmas vacations) and to the increased density of electronic equipment (i.e. increased internal thermal gains). Referring to the cooling energy demand, it resulted in the 18.19 – 27.93 kWh/m^2 or 4.50 – 6.71 kWh/m^3 range, the relevant literature [39] reporting 36 – 44 kWh/m^2. The observed significant difference is again attributed to the different usage of the University buildings: they are not in operation during the hottest month of the year, due to summer vacations.

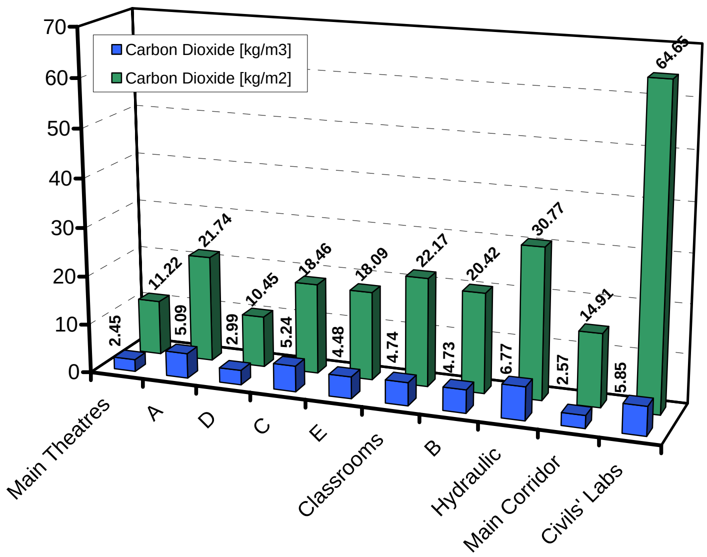

Figure 9. Carbon Dioxide (CO_2) footprint

Table 3. Energy and environmental indices per building type and year of construction

Building Type	Construction Year	Specific Energy Consumption in:				CO_2 Footprint	
		Heating Period		Cooling Period			
		kWh/m^2	kWh/m^3	kWh/m^2	kWh/m^3	kg/m^2	kg/m^3
Classrooms	1961	96.15	20.54	21.03	4.49	22.17	4.74
Offices	1961	94.26	22.06	27.93	6.54	21.74	5.09
Offices	1966	133.43	29.35	27.23	5.99	30.77	6.77
Offices	1970	88.55	20.51	27.00	6.25	20.42	4.73
Offices	1978	45.32	12.95	23.49	6.71	10.45	2.99
Offices	1999	78.44	19.41	18.19	4.50	18.09	4.48
Theatres	1975	48.64	10.62	1.29	0.28	11.22	2.45
Laboratories	1961	280.36	25.35	30.64	2.77	64.65	5.85

6. Conclusion

Aim of this work was to present the simulation results of the energy consumption of 10 University buildings in Greece, covering a total of 62,200 m^2. The simulation exercise results for the heating period were confirmed by comparison with the actual fuel consumption of the 2004-2009 period.

The analysis of the results highlights the effect of the weather data file used for the simulation. In this work, the Meteonorm (TMY-2) and the ASHRAE (IWEC) weather files were used and the deviations of the actual fuel consumption were 1.4% and 13.2%, respectively.

Depending on the office building characteristics, the heating and cooling energy consumptions resulted in the 45.32 – 133.43 kWh/m^2 and 18.19 – 27.93 kWh/m^2 ranges, both significantly lower than the ones reported for the commercial office buildings. These differences are attributed to the different profile use of the University buildings, with the increased vacation days, and to the more intense usage of electronic equipment.

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