INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 3, Issue 2, 2012 pp.195-208
Journal homepage: www.IJEE.IEEFoundation.org

Evaluation of different weather files on energy analysis of buildings

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Abstract
The building energy demand simulation tools consist the compass of the roadmap towards the energy efficient building. Apart from the software itself, the result of the simulation strongly depends on the degree the data used represent the actual situation, among which the climate data of the area are a key factor. In this work, the energy demand of a large building complex is estimated, using the widely accepted EnergyPlus building simulation software in combination with two, also widely accepted, weather files. The simulation results for heating are compared with the actual fuel consumption of a three-year operation period. The comparison reveals that the weather file and the size of the simulation domain significantly affect the simulation representativeness.

Keywords: Building simulation; Energy consumption; Climate data; Weather files; Typical meteorological years.

1. Introduction
The share of total final energy consumed by the household and service sectors in the European Union (EU-27) was reduced from 42.5% in 1996 to 37.2% in 2008, while the corresponding figures for Greece were 35.5% (1996) and 34.7% (2008) [1, 2]. Space heating and cooling are the major energy consumers in buildings, accounting for about 63% to 70% (residential and tertiary sector, respectively) in Greece, the remaining 37 to 30% being used for space illumination, appliances and electromechanical equipment operation [3, 4].
Obviously, the energy consumption is directly related to both the operational cost of buildings and to their negative effect on the environment. There is therefore a growing interest on the energy efficient design, significantly intensified by the implementation of the European Directive 2002/91/EC [5] and the recast of it, European Directive 2010/31/EC [6], concerning the energy performance of buildings. To this direction, taking into account the aforementioned fact that the major energy consumers of a building are the heating and cooling systems, the evaluation of the relevant energy demands becomes the first step towards reducing the corresponding energy consumption. To this purpose, the long-term simulation of the building and of its systems is required, with the dynamic simulation programs being the main tool for the energy performance prediction [7-10]. A number of such tools has been developed over the last 20 years, used for both the design of new buildings and for the improvement of existing ones [11-14].
The building-specific data required for the prediction include details about: (1) construction (design and materials), (2) design and control characteristics of the HVAC system and (3) usage patterns. These data,

combined with detailed weather description, allow for energy demand estimation, the accuracy of which obviously depends on both the quality of the data and on the sophistication of the simulation.
Of these data, those concerning the construction of the building and of the HVAC system are well defined in existing constructions or they can be detailed in the design phase. The ones, however, concerning the usage of the building, on which the estimation of internal loads depends on, and the weather details, on which the external loads depend on, are less certain.
The influence of the internal loads uncertainty on the final result depends on the time scale of the simulation and on the size of the simulation domain, since the increase of either or both results in reducing the statistical error involved.
The effect the climate data have on the simulation result is rather obvious, since they affect not only the energy losses estimation through the envelope [15, 16], in most cases being the major load, but also the efficiency of RES based systems, e.g. solar thermal systems, which in many cases are installed in order to cover building's heating and cooling energy demands [17, 18].
This paper attempts to quantify the effect the simulation domain size and the climate data have on the accuracy of the energy demands of a rather large complex of buildings. To this aim, the energy demands of the buildings of the Aristotle University of Thessaloniki Campus were calculated and compared to the actual fuel consumption for heating. The energy demands of the buildings were calculated with the aid of the EnergyPlus software, using climate data from two different weather file databases.

2. Details of the simulation exercise

2.1 The university and the buildings

The Aristotle University of Thessaloniki is the largest in the Southeast Europe, with 42 Departments and about 80,000 students. It is located at the city centre and the campus covers an area of 230,000 m^2, with 36 buildings of 275,500 m^2 covered area.
The older building was built in 1880 and the newer ones in 2003. As a result, all types of buildings are found: from stone built to modern concrete ones, with various degrees of thermal insulation, single or double glazing depending on the year of construction, and with or without shading elements. All the buildings however have central heating installation, while cooling is provided mainly by split type local air-to-air heat pumps.

Table 1. The heated area and the insulation category of building complexes

Group of Buildings	Heated area [m^2]	Insulation category
Kindergarten	1,110	II
Faculty of Education	6,670	III
Central Library	6,370	0.72/I – 0.28/III
Administrative Building	11,120	I
Faculty of Veterinary Medicine	15,210	0.75/I – 0.25/III
Faculty of Philosophy	25,140	0.92/I – 0.08/III
Faculty of Engineering	55,200	0.57/I – 0.34/II – 0.09/III
Faculty of Natural Sciences	48,310	0.61/I – 0.29/II – 0.10/III
Chemistry Department	15,845	I
Meteorology Department	860	I
Faculty of Law, Economic and Political Sciences	18,420	I
Faculty of Medicine	19,440	0.80/I – 0.20/II
Faculty of Dentistry	14,345	0.86/I – 0.14/III
Observatory	715	I
Faculty of Theology	7,620	0.87/I – 0.13/II
Total	246,375	

The thermal insulation characteristics strongly depend on the construction year of the building. Buildings built before 1975 have no insulation at all, and for the purposes of this study they are characterized as Category I. Buildings built between 1975 and 1990 are partially insulated, and they are characterized as Category II. Finally, the newer buildings (construction year 1990 onwards) are insulated according to the Greek Thermal Insulation Regulation and they are characterized as Category III. Based on this categorization, 66.3% of built area is Category I, 23.2% Category II and 10.5% Category III. For the purposes of this study, the buildings of the campus are grouped, the grouping accounting for the shadowing between buildings which affects the thermal gains. The groups of buildings identified are listed in Table 1.

2.2 The parameters of the energy analysis

The campus buildings include offices, classrooms and auditoriums, laboratories, libraries, refreshment rooms and other auxiliary spaces.

With the aid of in-situ inspection in every space, the internal heat sources (people, lights, appliances) and ventilation habits were recorded, in order to reflect as accurately as possible the real conditions.

Following the ASHRAE suggestions [19, 20], the required temperature of each space was defined, according to the space usage and the time of the year (heating or cooling period). The simulation performed with 1 h time step and accounted for vacations and legislated holidays, considered as non-operation periods of the facilities. The basic parameters of the simulation are listed in Table 2.

Table 2. Basic simulation parameters

Latitude / Longitude	40° 36' / 22° 59'
Operating hours	08:00 – 21:00
Heating period	16 October – 15 May
Desired indoor temperature during heating period (operating/non-operating hours)	22°C / 18°C
Cooling period	16 May – 15 October
Desired indoor temperature during heating period (operating/non-operating hours)	26°C / 30°C
Air changes at Auditoriums, Classrooms, Laboratories, Refreshment rooms (operating/non-operating hours)	2 arch / 0.3 arch
Air changes at Offices, Libraries (operating/non-operating hours)	1 arch / 0.3 arch

2.3 Description of the weather files

As already mentioned, climate data are required for energy simulation of buildings. Typically, these data consist of 8760 (the hours of a year) sets of characteristic values, such as wet and dry bulb temperatures, solar radiation, wind speed and direction etc., grouped in 12 typical months, finally forming the typical year of the area. In order to derive the typical year of an area, long term actual climate data and/or climate modelling results are statistically evaluated and weighted. A number of evaluation methodologies and sets of weighing factors are reported [21-24]. As a result and for each area, a number of different typical years can be found, such as the Typical Reference Year (TRY), the Weather Year for Energy Calculations (WYEC, WYEC2), the Typical Meteorological Year (TMY, TMY2, TMY3) and the International Weather for Energy Calculations (IWEC) [25]. Despite their differences, all these variations constitute a set of 12 months that are representative of the past. As such, the typical year is unlikely to include climate extremes and therefore it is suitable for the prediction of energy consumption but unsuitable for sizing the HVAC systems [26].

For the purposes of this study the IWEC from ASHRAE (GRC - IWEC 166220 WMO) and the METEONORM TMY2 (TMY-2 16622 WMO) were used.

For the development of IWEC [27] weather file, the nine climatic parameters selected are the maximum, minimum and mean daily dry bulb and dew point temperature, the maximum and average daily wind speed, and total daily solar radiation. The weighting factors are: 1/20 for the maximum and minimum dry bulb temperature, 6/20 for the mean dry bulb temperature, 0.5/20 for the maximum and minimum dew point temperature, 1/20 for the mean dew point temperature, 1/20 for the maximum and average wind speed, and 8/20 for the total global solar radiation.

The TMY2 [28] weather file is based on the same parameters, with the addition of the direct normal solar radiation, and the weighting factors are: 1/20 for the maximum and minimum dry bulb and dew point temperature, 2/20 for the average dry bulb and dew point temperature, 1/20 for the maximum and average wind speeds, and 5/20 for the average daily solar and direct normal radiation.

3. Assessment of the weather files

The two weather files of the Thessaloniki used in this work are based on measurements of the Micra Meteorological Station, situated at the Macedonia International Airport of Thessaloniki at a suburban area, 14 km from the city centre.

The first of these weather files (GRC - IWEC 166220 WMO) has been produced by ASHRAE, IWEC hereafter, in the framework of the 1015 research project for the development of International Weather Year for Energy Calculation (IWEC) weather files [27] and it is available at the USA Department of Energy (DOE) site.

The second weather file is from the METEONORM, version 5.0, database. It is a type 2 Typical Meteorological Year (reference code TMY-2 16622 WMO), TMY-2 hereafter.

Despite the fact that both files are based on data from the same meteorological station, they are not identical, due to the different weighing factors mentioned. Figure 1 presents the monthly variation of minimum, maximum and average dry bulb temperatures resulting from the two weather files. The TMY-2 weather file results in systematically higher mean temperatures, with the exceptions of January and December, higher maximum temperatures, with the exception of May, and lower minimum temperatures, with the exception of May and November.

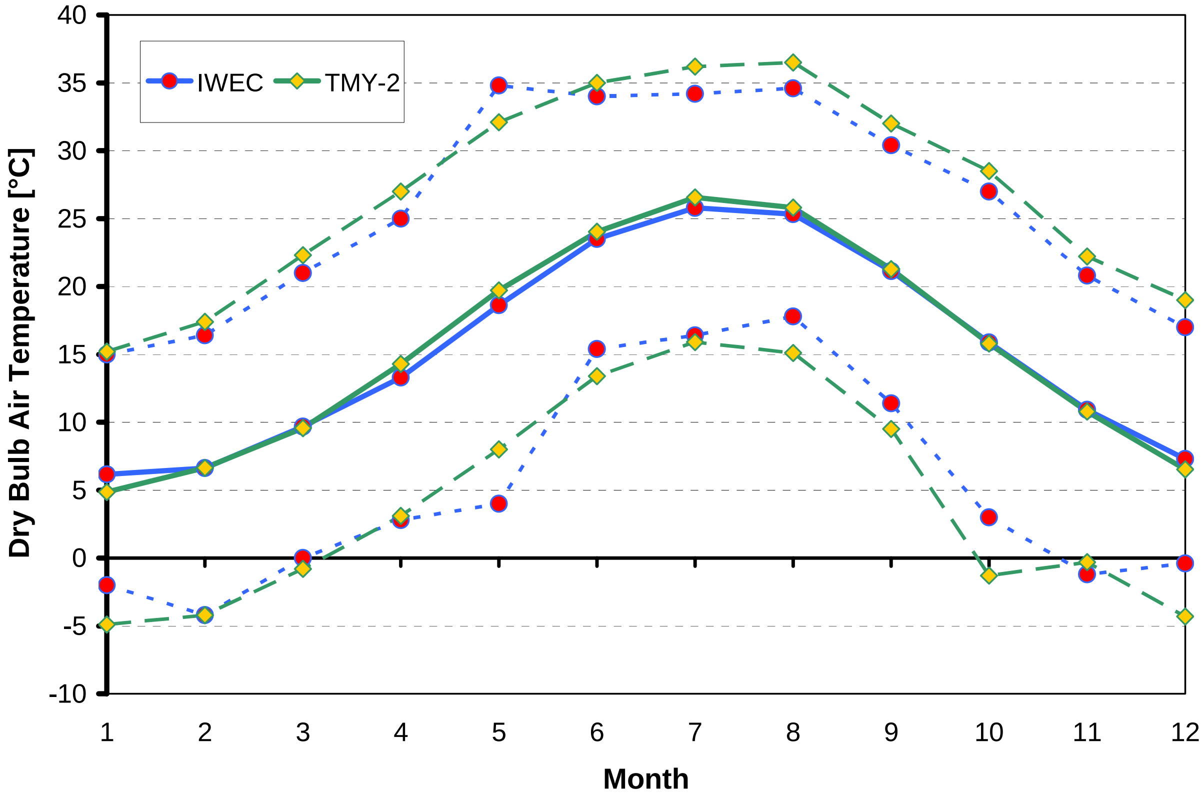

Figure 1. The distribution of the air temperature based on the TMY-2 and IWEC weather files - maximum, minimum and monthly average

Figure 2 shows the cumulative temperature distribution according to the two files. As it can be seen, at temperatures below 9°C the frequency of lower temperatures is higher in the TMY-2 case. At temperatures higher than 20°C the IWEC weather file shows higher frequency of higher temperatures, while the frequency of mid-range temperatures (9-20°C) is more or less identical in both files.

These observations mean that the TMY-2 weather file suggests colder winter and probably hotter summer, it is expected therefore that the energy consumption predictions of a building will be higher in both winter and summer when they are based on TMY-2 weather file.

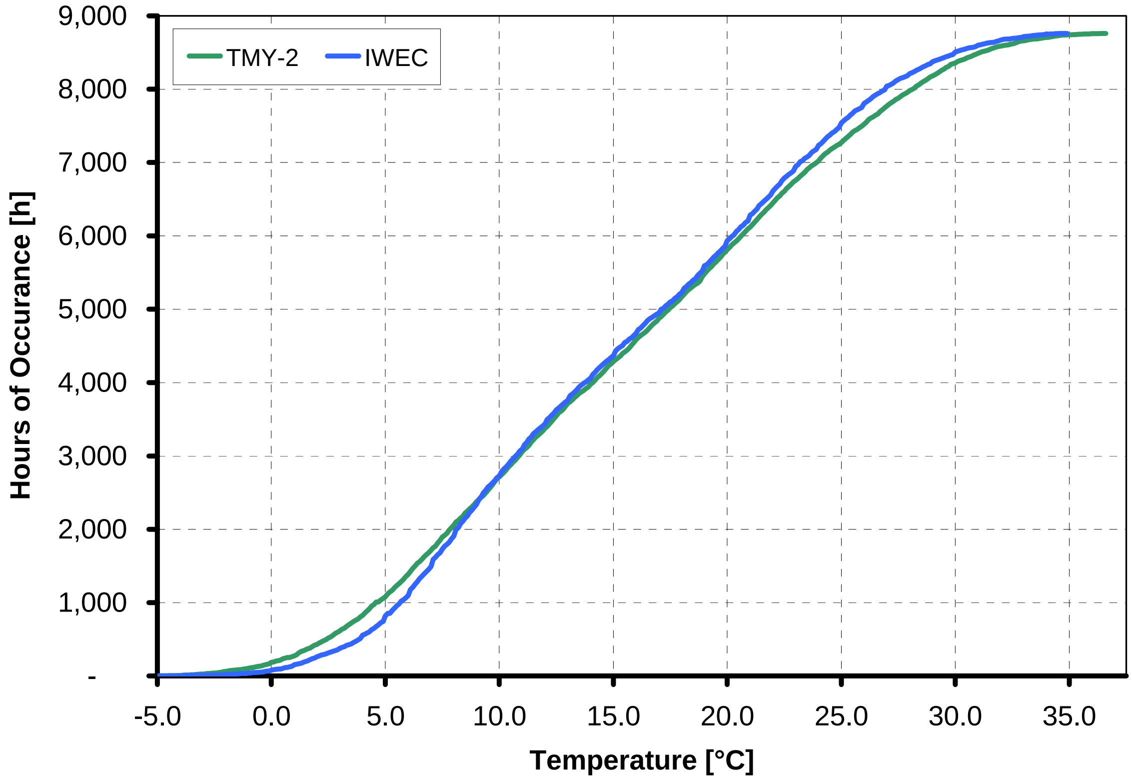

Figure 2. Cumulative distribution of the dry bulb temperature based on the TMY-2 and IWEC weather files

In order to further investigate the differences between the two weather files, the heating and cooling degree-days (HDD and CDD, respectively) for base temperatures 15°C, 18°C and 22°C, 24°C respectively were determined. The results are shown in Figures 3-6.

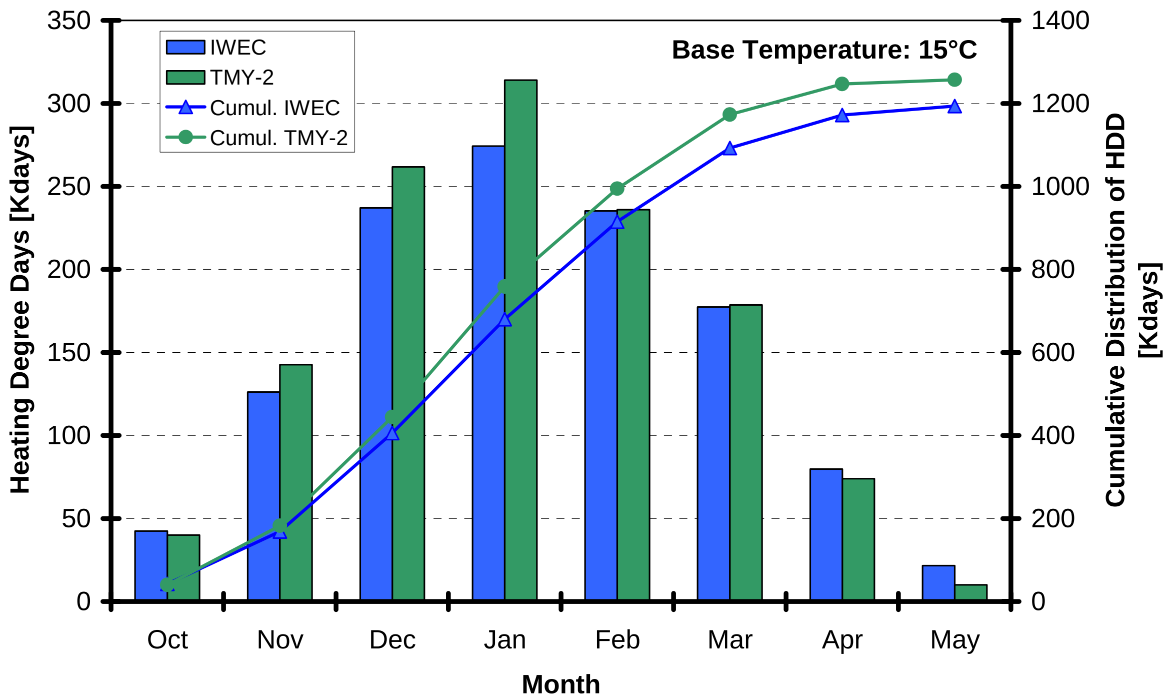

Figure 3. Monthly and cumulative distribution of the HDD, based on the TMY-2 and IWEC weather files. Base Temperature: 15°C

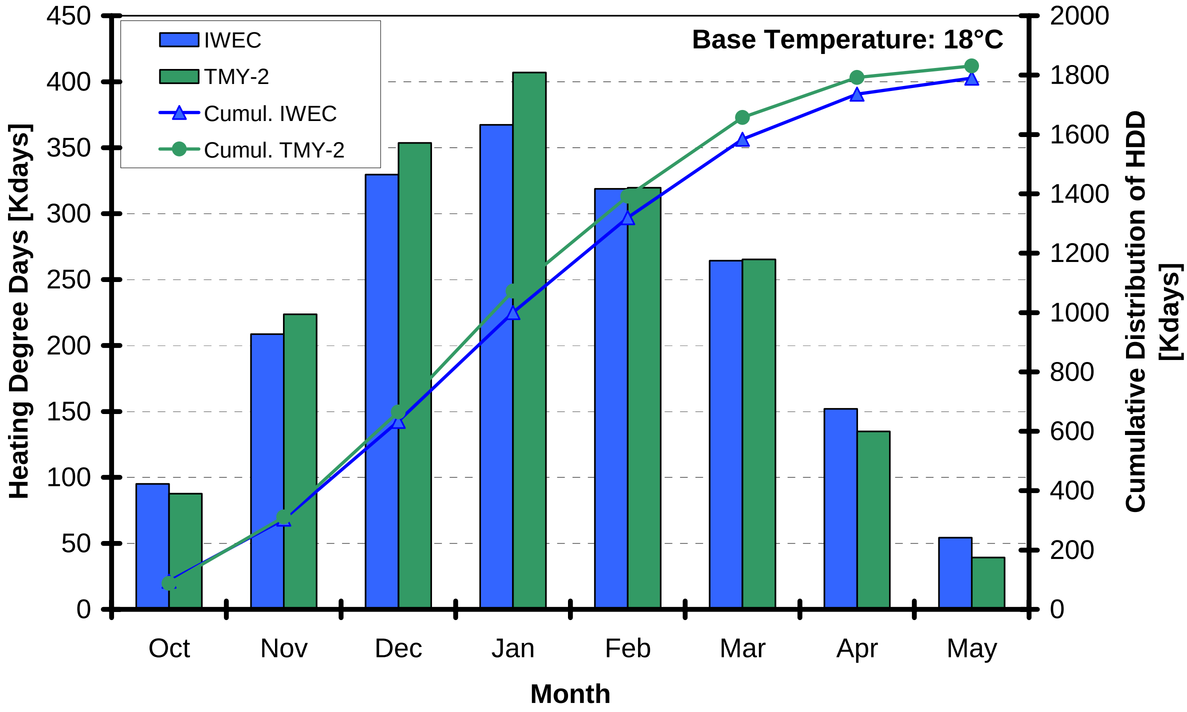

Figure 4. Monthly and cumulative distribution of the HDD, based on the TMY-2 and IWEC weather files. Base Temperature: 18°C

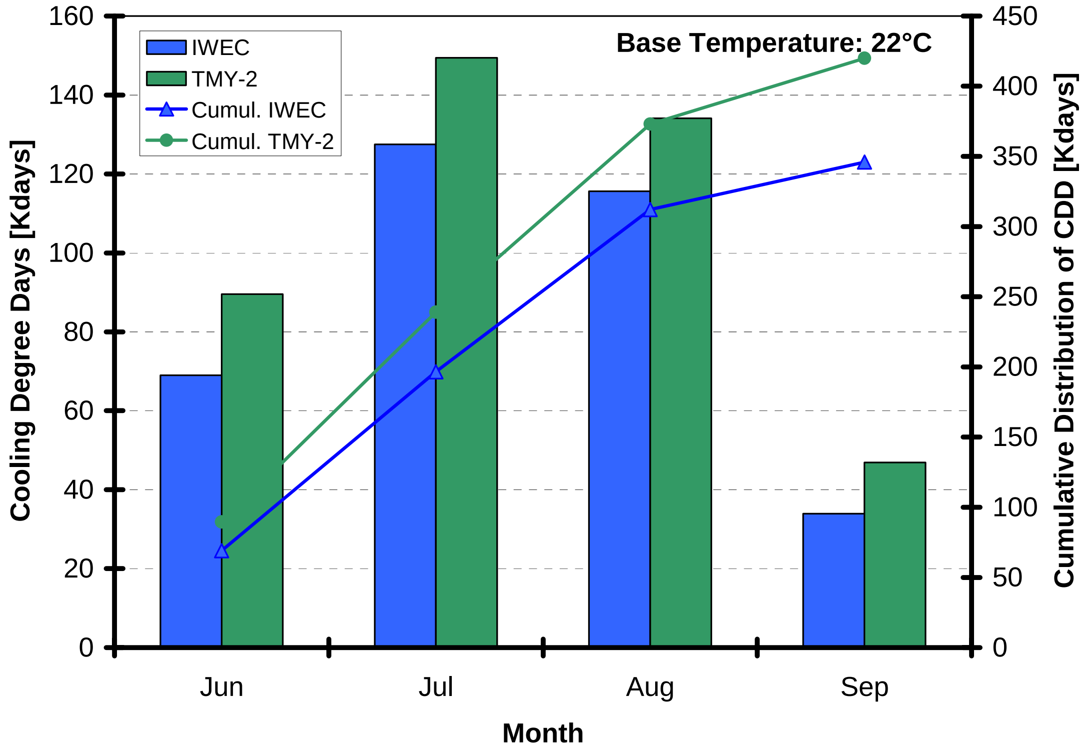

Figure 5. Monthly and cumulative distribution of the CDD, based on TMY-2 and IWEC weather files. Base Temperature: 22°C

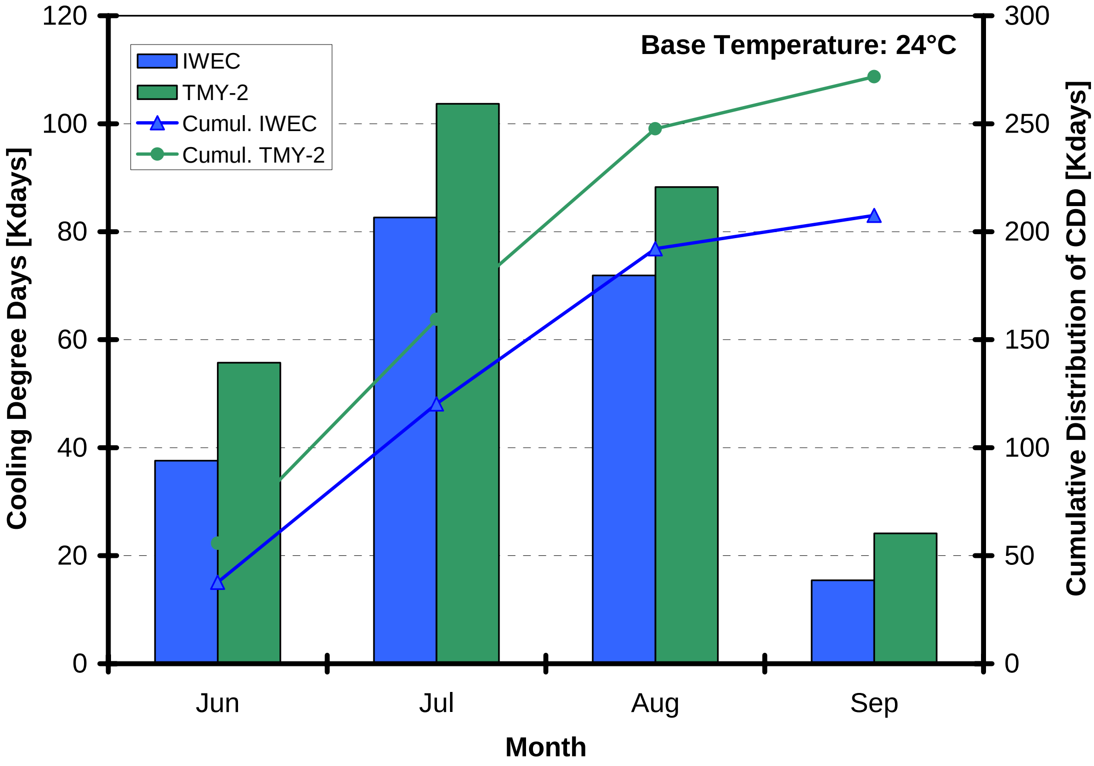

Figure 6. Monthly and cumulative distribution of the CDD, based on TMY-2 and IWEC weather files. Base Temperature: 24°C

Figures 3 and 4 present the monthly and the cumulative distribution of heating degree-days for base temperatures 15°C and 18°C respectively. The conclusion drawn from Figure 2 is confirmed: the TMY-2 weather file results in higher HDD values for the colder months (November to January) and similar values for the months with intermediate temperatures (February and March) while the IWEC weather file results in higher values for the hotter months (April, May and October).
The cumulative distribution of heating degree-days resulting from the TMY-2 weather file is always higher than the one from the IWEC for both base temperatures, the difference being more enhanced at lower base temperatures (base temperature 15°C: 1194 HDD from IWEC, 1257 HDD from TMY-2 – 5% deviation; base temperature 18°C: 1790 HDD from IWEC, 1831 HDD from TMY-2 – 2.2% deviation). This reduction of percentage deviation confirms the aforementioned overall colder climate of TMY-2.
Figures 5 and 6 present the monthly and cumulative distribution of cooling degree-days for 22°C and 24°C base temperatures according to the two weather files.
The cooling degree-days resulting from TMY-2 weather file for all months and both base temperatures are always higher. As a result, the cumulative distribution is also always higher in the TMY-2 case, with the sum of CDD being 346 for the IWEC weather file and 420 CDD for the TMY-2 (17.6% deviation) in the 22°C base temperature case and 208 and 272 - deviation 23.6% - in the 24°C base temperature case. This increase in percentage deviation confirms the aforementioned conclusion that the TMY-2 weather file results in hotter summer.

4. Simulation results and discussion

Figure 7 presents the annual energy consumption of all building groups, as it resulted from the simulation with both weather files. As it was expected, the adoption of TMY-2 weather file results in higher energy demands for all building groups and both heating and cooling periods.
The higher energy consumption group of buildings is that of the Engineering School, followed by that of the School of Natural Sciences and of Philosophy. This was expected, since these groups are the largest ones in terms of temperature regulated area (see Table 1).
In order to eliminate the effect of the size of buildings, the energy consumption according to both climate files, reduced to the respective temperature regulated area (kWh/m^2/a), is calculated and presented in Figure 8.

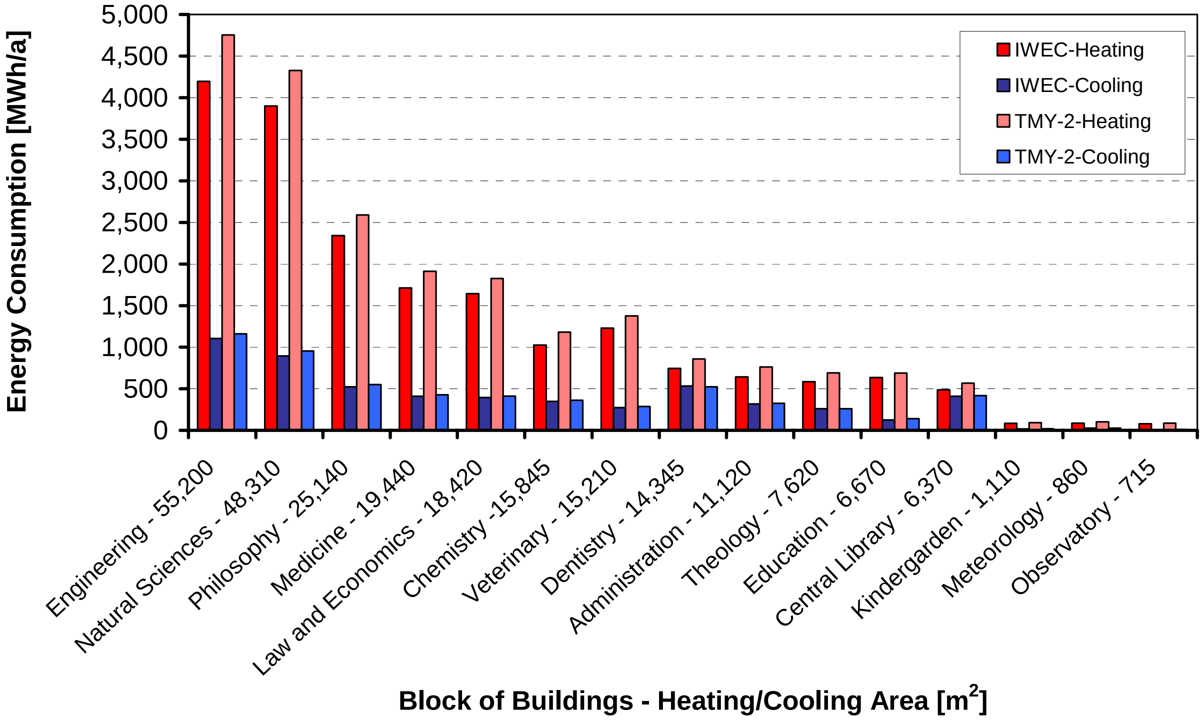

Figure 7. Energy consumption of the buildings' groups of the A.U.Th. on annual basis

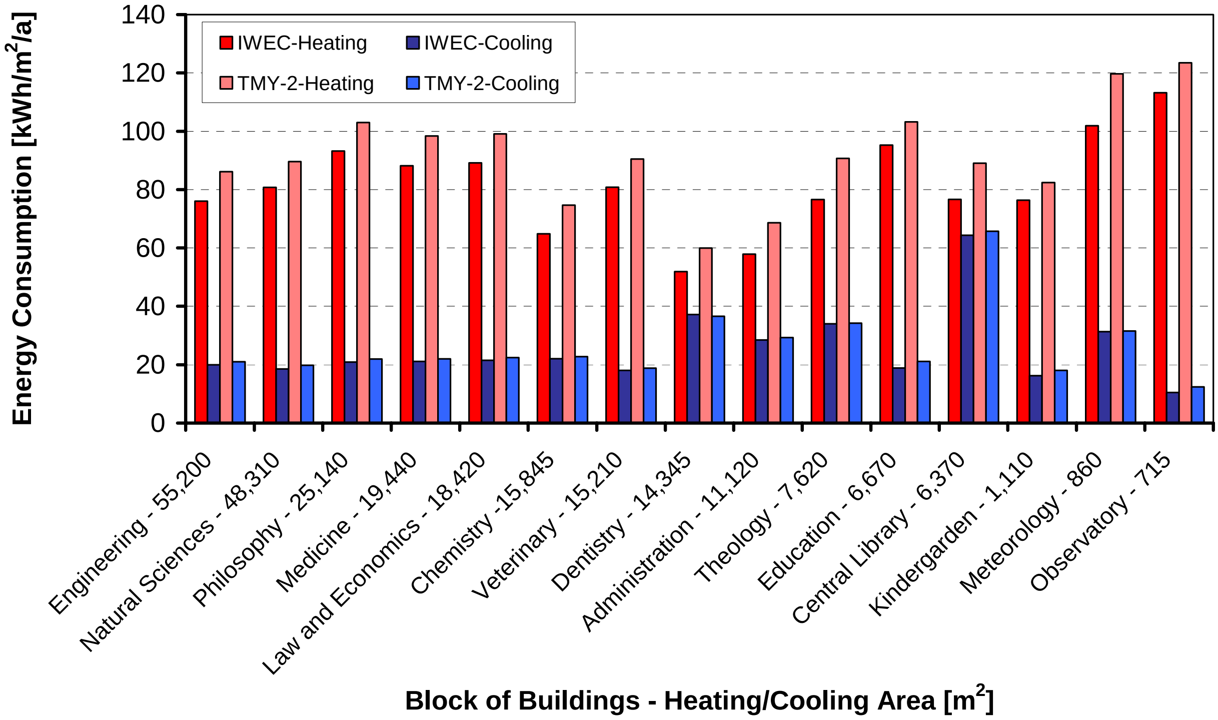

Figure 8. Energy Consumption per temperature regulated area of the buildings' groups of the A.U.Th. on annual basis

The highest heating specific energy consumption results for the Meteorology and Observatory buildings, followed by the Education School, the Philosophy School and the Medicine School groups, with significant differences however.

The highest cooling specific energy consumption results for the Central Library, followed by the Dentistry School and Theology School groups.
The observed differences in both heating and cooling specific energy consumptions are due to the differences in construction and main orientation of the buildings as well as to the different usage profiles.
Summarizing the results of Figure 8 and for the IWEC weather file, the heating specific energy consumption of University Campus building groups varies from 52 up to 113.2 kWh/m^2/a, while for the TMY-2 weather file from 60 to 123.5 kWh/m^2/a.
The ranges for the cooling specific energy consumption are 10.5 – 64.3 kWh/m^2/a and 12.4 – 65.7 kWh/m^2/a, for the IWEC and TMY-2 weather files, respectively.
Based on the specific energy consumptions shown in Figure 8, a strong deviation between heating and cooling periods is observed, with ratios as high as 11. This is attributed to the fact that the majority of the University buildings is not in operation in the second half of July and in the first half of August, which is the worst period from the energy consumption for cooling point of view. During winter, the holiday period is significantly short; therefore it can't strongly affect the heating specific energy consumption.
The simulation results based on the two weather files are compared in Figure 9. As it can be seen, the results with the TMY-2 weather file in all but one case are higher, from 7.8% to 18.6% for heating and from 0.5% to 18.5% for cooling.
A more detailed picture of the total energy demand for heating is given in Figure 10. As it can be seen, the demand resulting with the TMY-2 weather file for the months November to March is always higher than the one with the IWEC weather file. The comparison is inversed for October, April and May, with the IWEC file resulting in higher energy consumption. It has to be noted however that these months are the ones with the higher temperatures, therefore with the lower need for heating. Consequently the total energy consumption according to the TMY-2 file results higher. This picture confirms the overall milder character of the IWEC typical weather year, already expected from Figures 2-6.

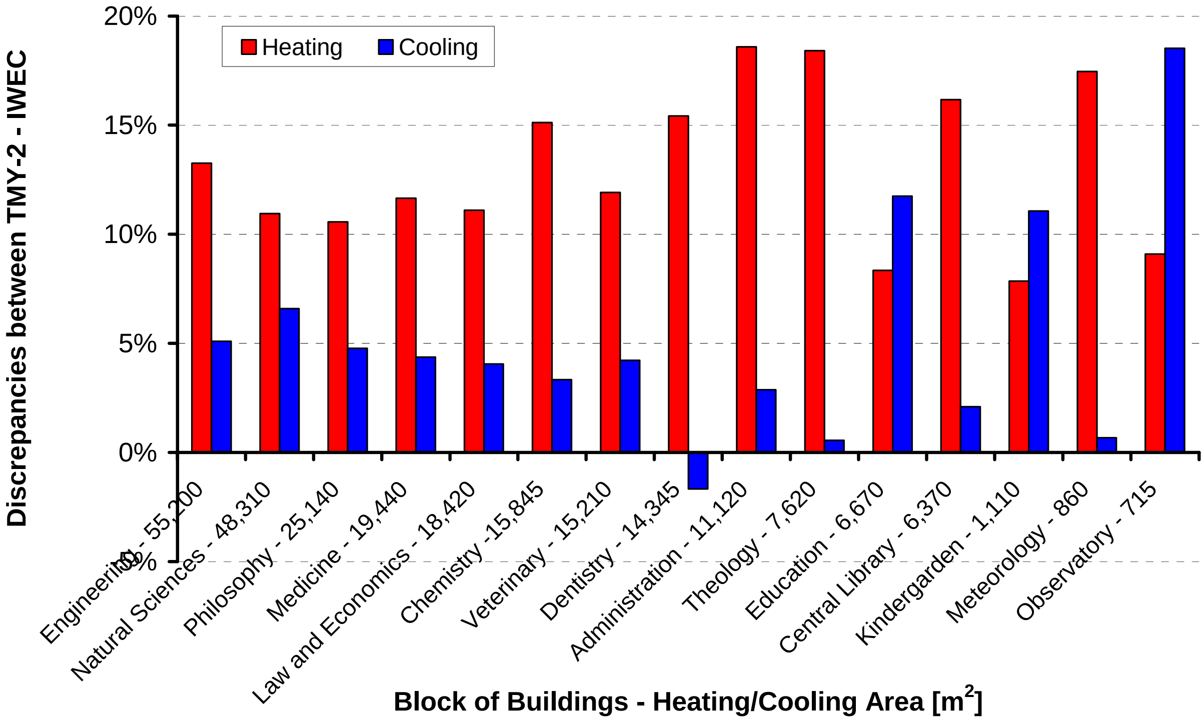

Figure 9. Discrepancies on energy consumption of the building groups using the TMY-2 and IWEC weather files

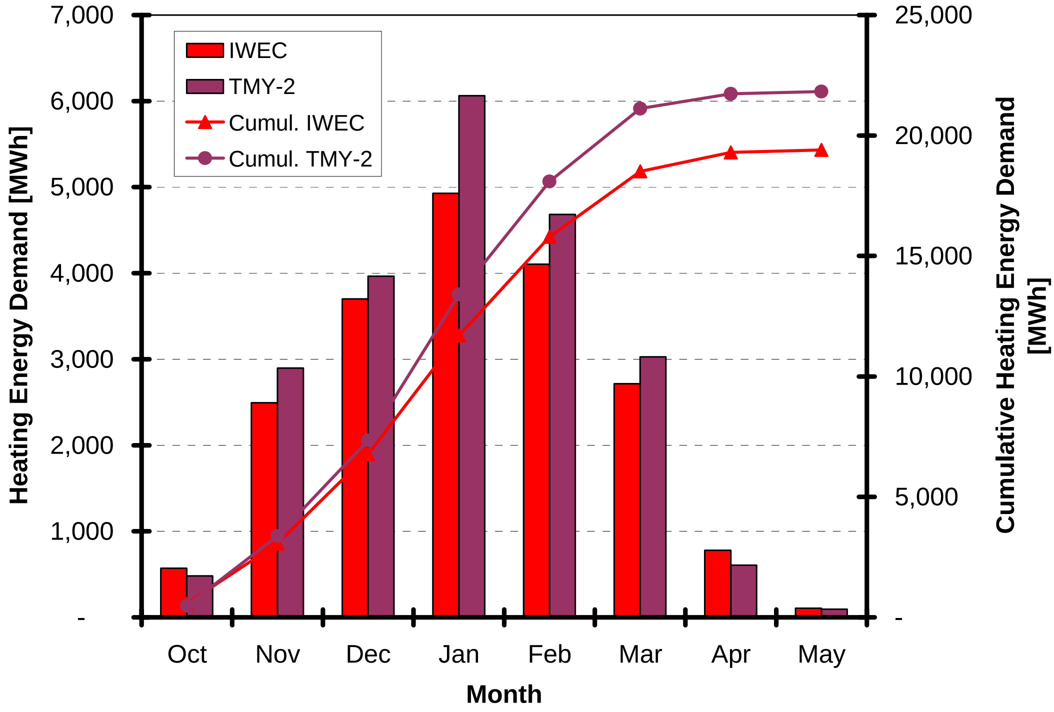

Figure 10. Monthly and cumulative heating energy demand of the University Campus buildings using the TMY-2 and IWEC weather files

The respective results of the cooling period are shown in Figure 11. The energy demand of the months May, June and August results higher according to the TMY-2 weather file, while for July, September and October the energy demands according to IWEC result higher. It is reminded at this point that, belonging to an educational establishment, the majority of the buildings is not in operation during the second half of July and the first half of August. Consequently, the resulting energy demand of these months, the hottest during the cooling period, can be considered as typical only for the university buildings.

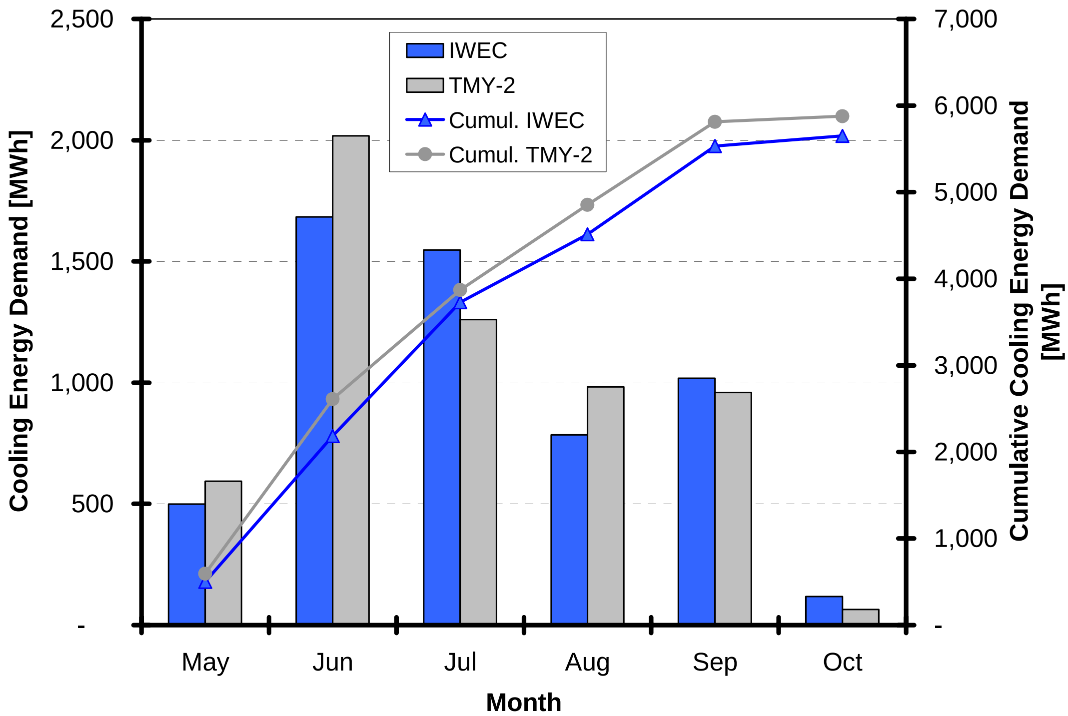

Figure 11. Monthly and cumulative cooling energy demand of the University Campus buildings using the TMY-2 and IWEC weather files

Figure 12 summarizes the annual energy demand estimations for heating and cooling of all buildings of the Aristotle University Campus. It can be clearly seen that the estimations based on the TMY-2 weather file are higher by 11.1% and 3.8%, for heating and cooling respectively. Based on the CDD differences presented in Figures 5-6, the discrepancy for the cooling period was expected higher, the result however being justified considering the fact that the majority of the buildings is not in operation during the hottest period (mid July to mid August) of the year.

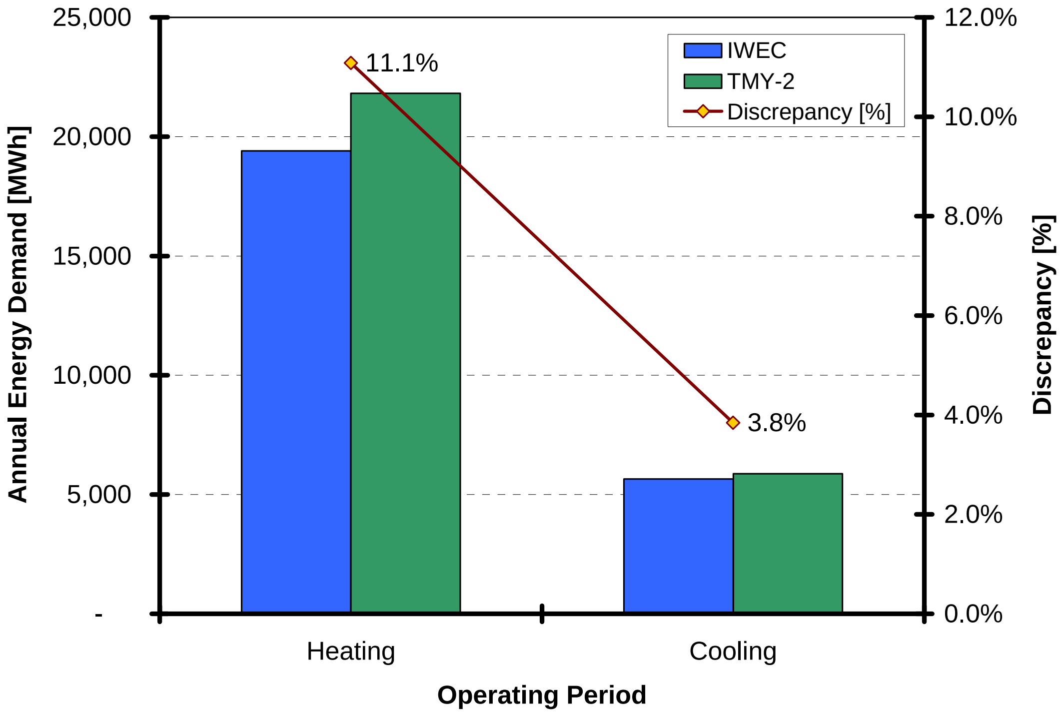

Figure 12. Annual energy demand of the buildings groups using the TMY-2 and IWEC weather files

5. Comparisons with actual data and discussion

As already mentioned, all buildings have central heating installation, the required hot water being produced by boilers. There are three natural gas fired boiler systems: one supplying the Engineering School complex, one for the Education School and a central one, for all other buildings (district heating).

The above estimated heating energy demands can be translated in estimated natural gas consumption per boiler system, using the appropriate overall annual average efficiency, accounting for both boiler efficiency [29] and distribution system losses [30], and then be compared to the actual natural gas consumption, determined from the relevant invoices. This comparison is shown in Figure 13, the actual consumption being the annual three years average (2005-2007).

As it can be clearly seen, the fuel consumption estimation based on the TMY-2 weather file is always significantly closer to the actual one. Taking into account the area being heated by each boiler system, the deviation between estimated and actual fuel consumption as a fuction of the heated area can be plotted (Figure 14).

Clearly, the fuel consumption is underestimated in all cases. The underestimation is significantly higher in the IWEC weather file case, ranging from 12 to 24%, while in the TMY-2 case it ranges from 1 to 17%. It is of interest to note that the highest underestimation with both weather files results in the smallest boiler system case, that of the Education School, which heats a total of only 6,670 m^2. This finding suggests that, apart from the climate data, the accuracy of estimation depends also on the size of the building, which obviously affects the relative significance of the statistically estimated parameters, namely the internal gains, which depend on the usage profile.

Based on the above, it can be concluded that the results of energy consumption simulations are strongly affected by both the quality of the climate data used and the size of the simulation domain.

Unfortunately, due to the cooling system used in the vast majority of buildings (split-type local air-to-air heat pumps) it was not possible to verify the cooling energy demand estimations.

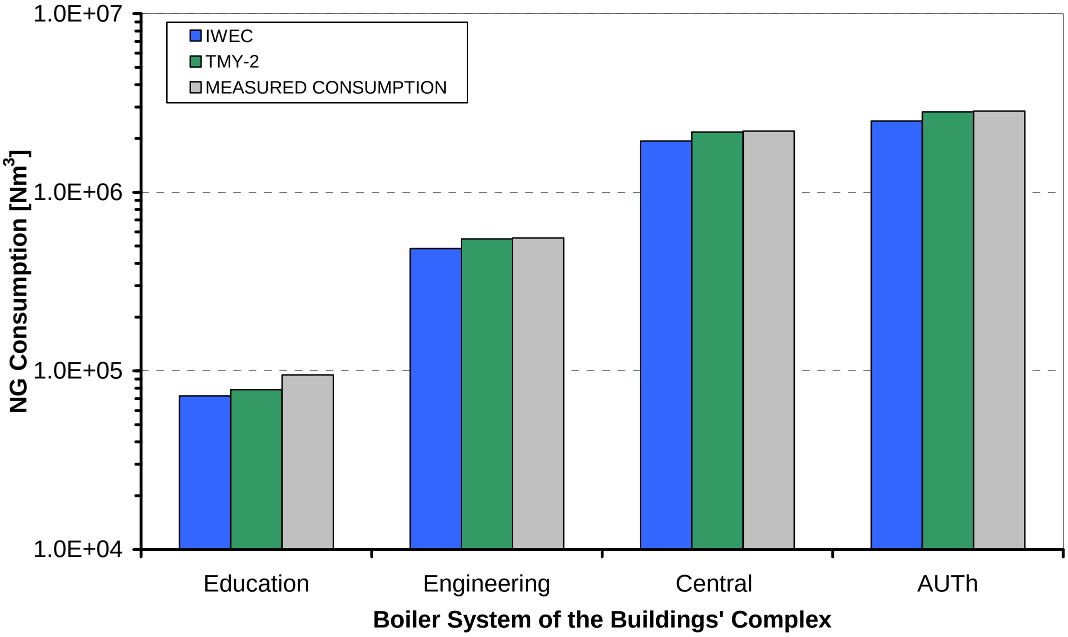

Figure 13. Total and per boiler system actual and estimated annual natural gas consumption for heating

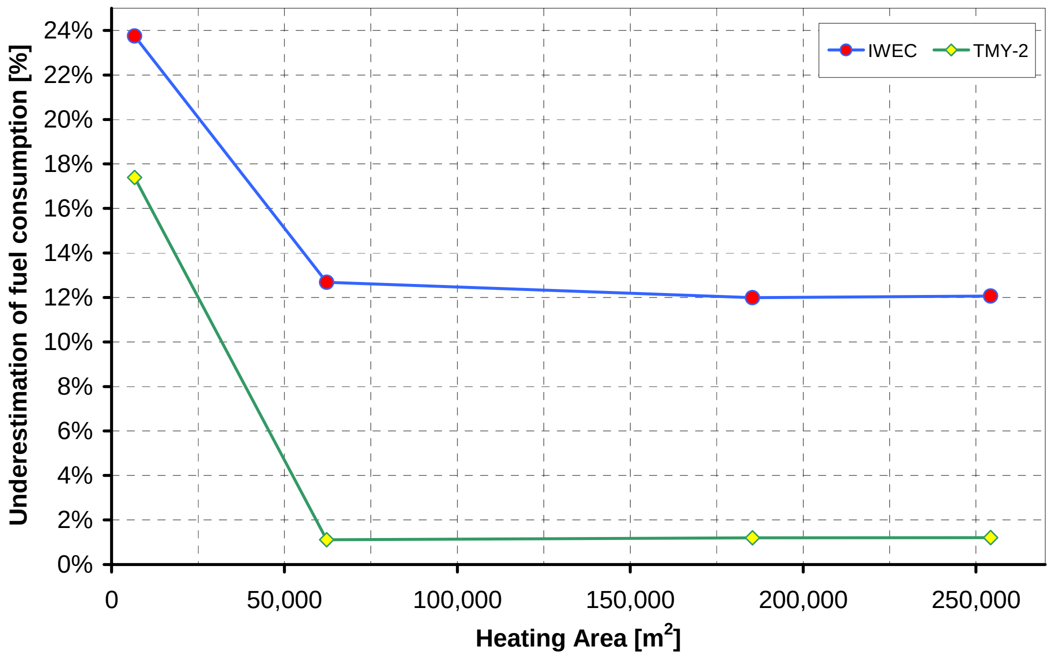

Figure 14. Underestimation of fuel consumption as a function of the area served by the boiler system

6. Conclusion

A large scale simulation of heating and cooling energy demands estimation, concerning educational buildings, is reported. The commercially available EnergyPlus software was used in combination with the ASHRAE IWEC (GRC - IWEC 166220 WMO) and the METEONORM TMY2 (TMY-2 16622 WMO) weather files for Thessaloniki – Greece area.

The exercise showed that for the specific area (Thessaloniki) and the specific use of buildings (educational establishment), the resulting energy consumption for both heating and cooling is lower with the IWEC weather file.

The comparison of the results with the actual fuel consumption for heating showed that the estimations based on the TMY-2 weather file is much closer to reality, with the underestimation depending on the size of the simulation domain, ranging from 1 to 17% - the highest value resulting for the smallest building.

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