energies

Article

Energy Assessment of Building Physics Principles in Secondary Education Buildings

Georgios Martinopoulos [1,*], Vasiliki Kikidou [1] and Dimitrios Bozis [2]

[1] School of Science & Technology, International Hellenic University, EL57001 Thermi, Greece; v.kikidou@ihu.edu.gr
[2] MEP Engineering Design and Consulting Services, EL54633 Thessaloniki, Greece; dmbozis@otenet.gr
* Correspondence: g.martinopoulos@ihu.edu.gr; Tel.: +30-231-080-7533

Received: 27 September 2018; Accepted: 25 October 2018; Published: 26 October 2018

Abstract: Educational buildings comprise a considerable portion of the public non-residential building stock. In order to assess the influence of the main parameters involved in the design and possible retrofitting of educational buildings, a secondary school building was selected and investigated with respect to its thermal behavior using EnergyPlus. Designing factors, as well as construction and operational solutions are examined individually and compared with each other, in order to find the best solution for either designing from scratch or retrofitting an educational building. In particular, the orientation of the openings, the thermal mass of the building and alternative insulation solutions, such as the thickness and location of the insulation layers in the building components, are compared. The simulation confirms, that the best orientation for educational buildings is the one in which their long axis coincides with the east-west one. The internally insulated building requires less energy but the difference is too small to be considered cost efficient. Regarding the heating system, from the alternative scenarios examined a one or two hour morning reheat strategy reduces the needed installed capacity for heating by up to 10%.

Keywords: educational buildings; energy demand; simulation; EnergyPlus; insulation; heating

1. Introduction

Buildings are nowadays responsible for as much as 32% of the total final energy consumption, constituting one of the biggest energy consumers. In terms of primary energy consumption, they are responsible for more than 40% in most OECD countries [1]. Educational buildings comprise a considerable portion of the public non-residential building stock. Secondary education schools constitute important energy consumers and are highly distinguished among public buildings by their great diversity, due to the different time periods of their construction, and their spatial distribution [2]. Education buildings have standard energy requirements and levels of environmental comfort that should be guaranteed, which deeply motivates the interest towards the school sector in the field of energy saving in buildings [3]. Thus, energy refurbishment of the existing stock should be considered a priority for governments worldwide, although estimating the potential for energy saving in the whole sector is very difficult because of several factors that do not allow a reliable overall assessment. One such factor is the heterogeneity in the existing situation; both in terms of building construction and heating, ventilation and air conditioning (HVAC) systems. Thermal insulation in educational buildings, depends mainly on the construction year of the school building and, in most cases, is either insufficiently or totally absent [4]. In addition, the existing heating systems are usually over-dimensioned, and their scheduled use is insufficient or even absent [5]. According to previous studies, energy consumption in schools varies depending on their age, state of repair, occupancy hours and equipment installed. A breakdown of energy use and costs in a typical school indicated that space heating is the dominant consumer with 60% of the total energy demand and 50% of the total cost [6].

As far as energy consumption is concerned, a study in the UK indicated very high consumption in secondary schools, which can be higher than 235 kWh/m^2 annually. Moreover, according to official estimations of the Energy Efficiency Office in Great Britain, the whole school sector produces approximately 6 million tons of CO_2 annually, which accounts for about 1% of the total emissions in Great Britain [7].

The same trend is seen in Irish schools as well, which have energy consumption for heating between 50 and 200 kWh/m^2, with a median value of 96 kWh/m^2 [8]. These values do not differ much when compared with available data from other central European countries, as evidenced in Figure 1. In Slovenia for instance, the average total energy consumption in schools is estimated at 192 kWh/m^2, from which 100 kWh/m^2 corresponds to heating alone [9]. In Germany, a study conducted on 105 schools showed that the final energy consumption ranges from 31 to 205 kWh/m^2, with an average annual consumption of 93 kWh/m^2 [10]. Even in Cyprus, in southern Europe, studies indicate an annual average consumption of 63 kWh/m^2 [11].

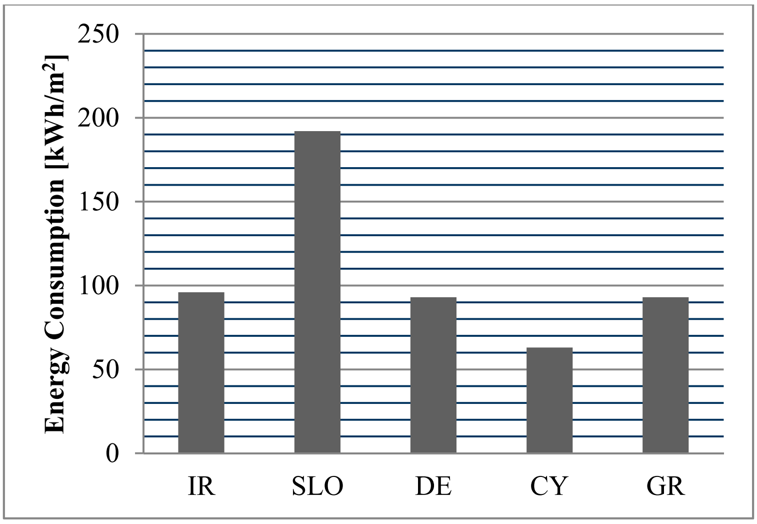

Figure 1. Comparison between average total energy consumption in schools of five European countries.

In Greece, researchers have tried to identify the energy consumption of buildings from early on; in a study published back in 1994 [12], the mean annual energy consumption of various types of buildings was estimated to be 407 kWh/m^2 in hospitals, 273 kWh/m^2 in hotels, 187 kWh/m^2 in offices, 152 kWh/m^2 in commercial buildings and 93 kWh/m^2 in schools [13]. Another similar study reported that the estimated average energy consumption for heating in schools was 92 kWh/m^2, and often reached 200 kWh/m^2 [14]. In a more recent study, the mean annual energy consumption for heating purposes in schools was estimated at 68 kWh/m^2 according to energy surveys performed in 320 schools [15].

As the need for energy conservation and energy efficiency measures intensified, researchers focused on the impact of different climatic zones and structure of the buildings on their energy consumption. By analyzing the data of a sample of 135 Greek schools, researchers concluded that their average annual total energy consumption in climatic zones A, B and C, was 49.5 kWh/m^2, 57.1 kWh/m^2 and 90.8 kWh/m^2 respectively [16].

Although different analyses demonstrate that school buildings require large amounts of energy [17], the problems that emerge when it comes to evaluating the energy performance of such buildings cannot be disregarded. The first challenge is bridging the gap between predicted and actual energy performance, as recent studies highlight the inconsistency between design estimates and actual energy use due to operational issues and occupant behavior, which strongly influences the energy performance of schools [18]. The second challenge is benchmarking of energy consumption in school buildings. A recent study focuses on the discrepancy of the energy needs and the variety of the occupation profiles between different school levels, the possibility of misleading results when utilizing small sample sizes and the importance of accurate conversion of the required energy demand to final energy and, then, into primary energy [19].

Improving the energy efficiency of school buildings is an issue of high significance, as it bounds adequate thermal comfort with internal air quality conditions. In the context of understanding the factors affecting energy consumption and, by extension, the parameters that need to be specifically designed in school buildings, a lot of studies have been carried out [20–22]. In general, they conclude that the most important design principles and goals can be summed up in the following 10 categories [20]:

(1) site selection,
(2) daylighting and windows,
(3) energy-efficient building shell,
(4) lighting and electrical systems,
(5) mechanical and ventilation systems,
(6) renewable energy systems,
(7) water conservation,
(8) recycling systems and waste management,
(9) transportation, and
(10) resource-efficient building products.

Santamouris et al. investigated several passive energy conservation measures in school buildings in Greece. Adding insulation led to a possible reduction of the energy consumption for heating by 43.9%, while using double glass windows led to a further reduction of 6.1% [12]. In a more recent study in the coldest area (climatic zone C) of Greece, the improvement in thermal insulation led to a decrease of 13.3% to the energy consumption [23].

The paper provides a systematic assessment of the main parameters involved in the design and possible retrofitting of educational buildings. As a case study, a typical secondary school building in Thessaloniki, Greece, was selected and investigated with respect to its thermal behavior. To that end, designing factors, as well as construction and operational solutions are examined individually and compared with each other, in order to find the best solution for either designing from scratch or retrofitting an educational building.

In particular, the orientation of the openings, the thermal mass of the building and alternative insulation solutions, such as the thickness and location of the insulation layers in the building components, are compared. That comparison is achieved in terms of annual heating and ventilation requirements as well as for the maximum required power of the heating system. As far as the heating system is concerned, alternative scenarios of its operation to meet peak demands are examined. Such scenarios include particular set point temperatures or reheating in the first morning hours. For the investigation of the scenarios, the widely used EnergyPlus [24–26], an energy analysis and thermal load simulation program, is used with an hourly simulation of the thermal behavior of the building for a reference year.

2. Materials and Methods

Greece is located in the southeastern part of Europe, confined between the 34th and the 42nd parallel N, with a meridional extent from 19th to 28th E and borders with the Aegean, the Ionian and the south Mediterranean Sea. Greece exhibits a typical Mediterranean climate, with mild and rainy winters, warm and dry summers and long sunshine during the most part of the year. The latter can be broadly divided into two periods: the heating period, from October until the end of March and the cooling period, from April until September [27].

In Greece there are 15,446 schools catering to the needs of more than 1,600,000 pupils. The total amount of energy required for heating and the electrifications of schools is estimated at around 270,000 MWh annually [14,28].

There are two main categories of school buildings in Greece: those built before 1960, which are of stone construction, and those built after 1960, which are constructed of concrete and bricks and are either uninsulated or partially insulated. Those built after 1960 are similar in design and differ mainly in size and configuration. Classrooms are usually organized in a linear formation or in L-shape, while U-shaped or schools around a central space are rare. Depending on their layout school buildings have one, two or three floors [14]. In 2010, researchers noted that most of the existing school building stock is obsolete, having been constructed before 1964. About 41% of the schools are over 30 years of age, while about 42% is considered relatively new, having been constructed after 1985 [16]. Out of the 15,446 schools, 4500 are more than 45 years old with the bill-based annual average energy consumption in secondary schools estimated at 16 kWh/m^2 for electricity and at 68 kWh/m^2 for space heating [28]. Almost 25% of the existing educational building stock is considered poorly insulated, and furthermore 70% is considered as having an adequate heating system, consisting mainly of either central oil-fired boilers coupled with radiators, or local heat pumps [16].

The building that was selected for the energy modeling is a secondary education building, located in the city of Thessaloniki, which is situated in Northern Greece. The city's climate is Mediterranean, characterized by hot and dry summers and mild and wet winters. According to the Hellenic National Meteorological Service's data of 38 years, the annual mean temperature is 15.9 °C, the annual mean values of relative humidity and precipitation are 62.4% and 448.7 mm respectively, while the annual mean wind speed is 5.6 m/s, with a dominant north-west direction [27,29]. The school was constructed in 1978, as a part of a school complex. It is a three-floor building, with a total area of 1647 m^2. It comprises of a basement, presented in Figure 2, with the lower part of its walls buried in the ground, as well as a ground and a first floor, both fully exposed to the outside air, as presented in Figure 3. All levels include classrooms, labs, offices, corridors and restrooms, in a general layout of "open corridor" school building type. The height, area and volume of the building analyzed per floor area are provided in Table 1.

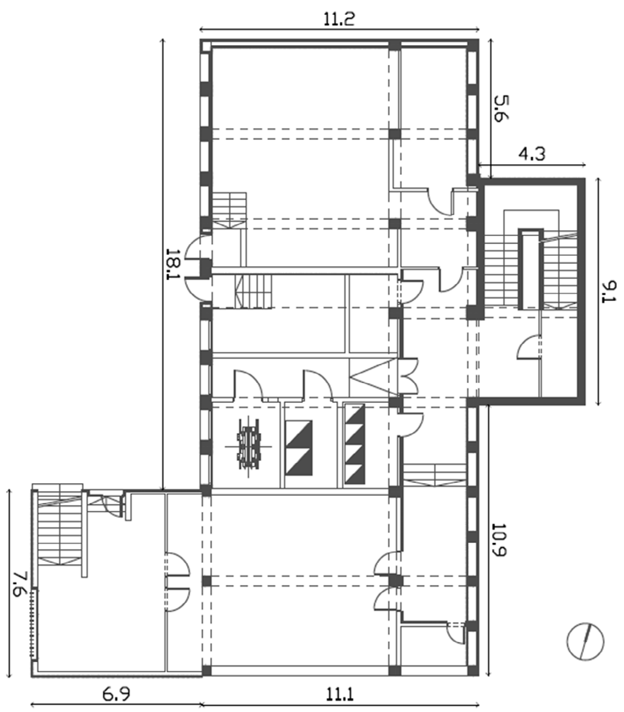

Figure 2. Basement plan.

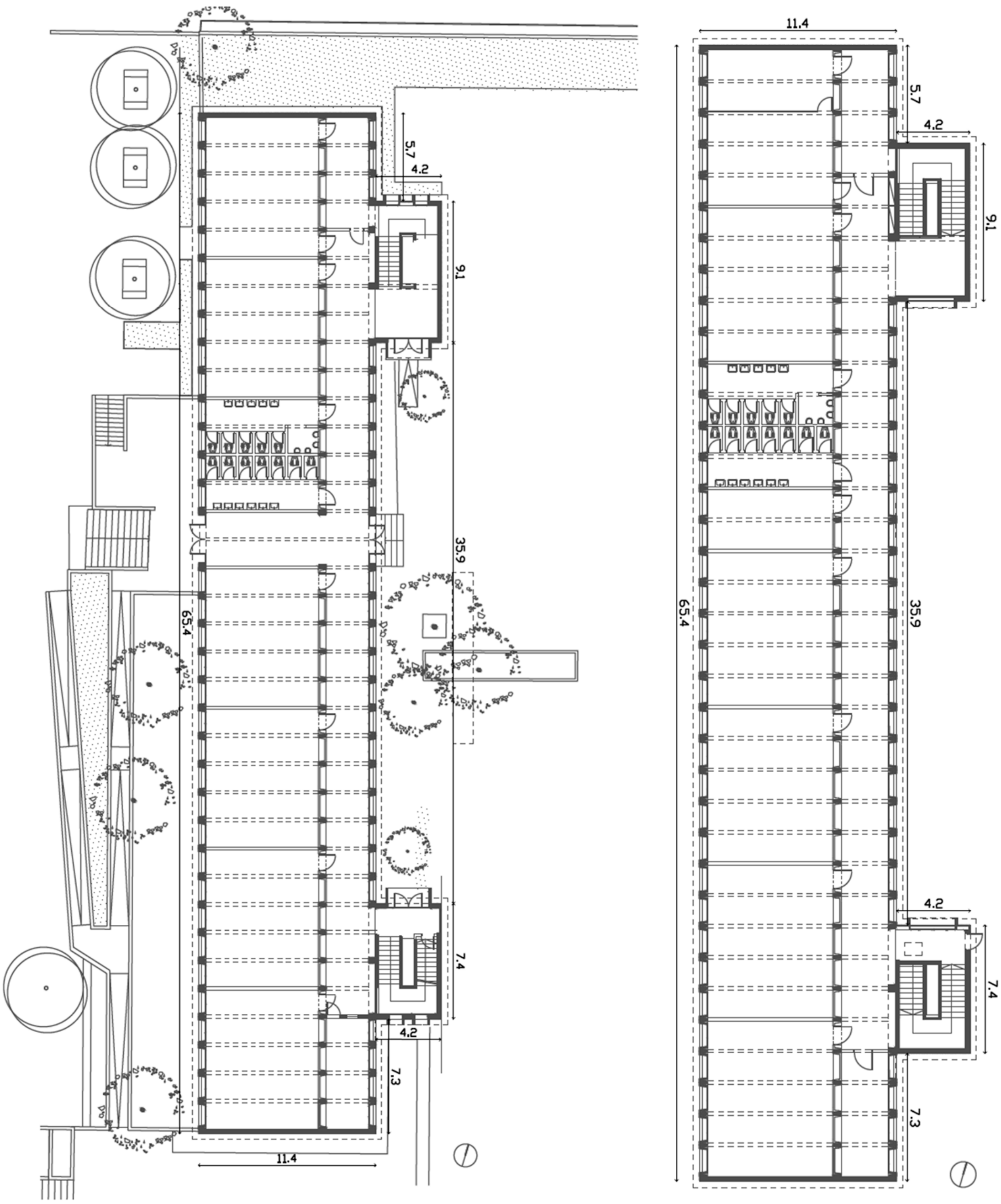

Figure 3. Ground floor (**left**) and first floor (**right**) plan.

Table 1. Building Specifications per floor.

Description	Height (m)	Heated Area (m^2)	Heated Volume (m^3)
Basement	3.4	297	1010
Ground Floor/1st Floor	3.7	675	2498

The building is basically a heavy construction made of concrete, without thermal insulation, except for a 5 cm layer of rock wool in the internal side of the basement walls. It has a tiled roof of 675 m^2 and large windows in both facades of the long axis of the building.

For the calculation of the energy consumption of the case study, a 3D model was constructed in Google "Sketchup" [30], as illustrated in Figure 4, and then "EnergyPlus 8.3.0" [31] and "OpenStudio

2.2.0" [32] were used for the energy simulation. EnergyPlus software was used with an hourly simulation of the thermal behavior of the building for a reference year.

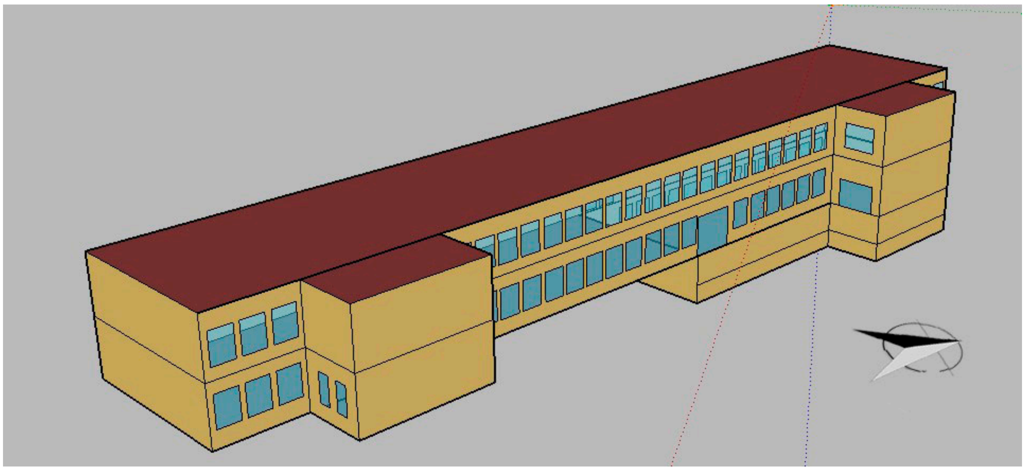

Figure 4. Three dimensional illustration of the building.

For the simulation, several assumptions were necessary. The climatic data for the city of Thessaloniki was retrieved in the form of an EnergyPlus Weather Data file [31]. For the initial simulation a set of 100 "warm up" days was selected in order for the temperature convergence tolerance values to be satisfied. Apart from the outside air temperatures that were used, the custom monthly average ground temperatures were calculated with the basement utility program of EnergyPlus. The winter, or heating period, of the year is considered to be from the 1st of January until the 20th of April and from the 20th of October until the 31st of December. As far as the school's specific operating schedule is concerned, along with the weekends of the reference year, the days when school is closed, as well as bank holidays were taken into consideration. As the operational use of this type of buildings is limited between mid-September to late May, only the heating systems operation was considered.

The building components used, along with a brief description and their thermal properties are listed in Table 2. The layering of the construction elements is a combination of the preexisting and either external or internal insulation in such a way as to meet the requirements of the current Greek Legislation was considered [33].

Table 2. Building components.

Description	U-Value
External wall of 40 cm concrete and 7 cm external insulation of extruded polystyrene	0.41 W/m^{2}K
External wall of 40 cm concrete and 8 cm internal insulation of rock wool	0.41 W/m^{2}K
External wall of 30 cm concrete, 5 cm internal insulation of rock wool and 7 cm external insulation of extruded polystyrene	0.26 W/m^{2}K
External wall of 30 cm concrete and 13 cm internal insulation of rock wool	0.26 W/m^{2}K
External wall of 30 cm concrete and 5 cm internal insulation of rock wool, in contact with the ground	0.59 W/m^{2}K
External tile roof with 7 cm insulation of extruded polystyrene	0.36 W/m^{2}K
Floor of concrete and 4 cm insulation of extruded polystyrene, in contact with the ground	0.64 W/m^{2}K
Exterior fenestration of aluminum frame with 6 mm glazing-16 mm air gap-6 mm glazing and shading coefficient 0.7	2.67 W/m^{2}K

The entire building was treated as a single thermal zone, taking though into consideration the internal thermal exchanges, by inserting internal mass. The walls and floors composing the internal mass, as well as the area of the surfaces that exchange heat are presented in Table 3.

Table 3. Internal mass components.

Description	Area
Internal wall of plaster and 10 cm brick	2100 m^2
Internal floor of mosaic, 20 cm concrete and plaster	1944 m^2

Some additional information was used for the energy modeling of the particular school building, as follows: The total number of teachers, students and staff of the school was set at 180 people. The lighting of the building is achieved through luminaires with electronic ballast and fluorescent lamps. The total installed power is estimated at 11,690 W. The total power of the electrical equipment, i.e., printers, personal computers and interactive boards, is estimated at 9400 W.

Regarding air changes, for the fresh air calculation, 80% of the school population in the fully occupied mode of the building is taken into account. Then, the minimum value of demand for fresh air per person is set at 22 m^3/h, in compliance with the relevant regulation [33], resulting in a total demand of fresh air of 3168 m^3/h; considering that the total volume of the building is 6006 m^3, it amounts to 1.9 air changes per hour (ACH). As the air-tightness of the openings is never ideal, and the building does not use mechanical ventilation (as normal practice for educational buildings in Greece), this amount of fresh air is considered to be an intake through infiltration as well as through the manual opening of the fenestration. Thus, the value of 1.9 ACH is set as infiltration in the energy simulation model.

The operation hours of the school are those between 07:00 a.m. and 15:00 p.m. Classes take place during 08:00 a.m.–15:00 p.m. The detailed operation profiles of the people, the lighting level, the electrical equipment and the infiltration are presented in Table 4, as a percentage of the full value in each case, for every hour of a typical day. The initial analysis is conducted for the initial orientation of the building as shown in Figures 2 and 3.

Table 4. Operation profiles.

Hour	People %	Lighting %	Equipment %	Infiltration %
0–7	0	0	0	15
8	10	40	10	25
9	78	100	100	100
10	78	80	100	100
11	85	40	100	100
12	85	40	100	100
13	85	40	100	100
14	93	40	100	100
15	50	40	50	100
16	0	0	0	100
17–24	0	0	0	15

Note: hour 1 corresponds to the period from 24:00 to 1:00, etc.

Finally, for the needs of the heating system simulation, the "Ideal Loads Air System" in EnergyPlus was used, as per usual practice [34–37] in order to calculate loads without modeling a full HVAC system. All that is required for the ideal system are zone controls, zone equipment configurations, and the ideal loads system component. This component can be thought of an ideal unit that mixes zone air with the specified amount of outdoor air and then adds or removes heat at 100% efficiency in order to meet the specified controls. The maximum heating supply air temperature is set at 35 °C.

Although dynamic simulation models have been used in many studies, in order to validate the model the energy consumption results of the initial model have been compared with the energy required during the previous years for heating purposes as derived from the utility bills of the educational building with good agreement.

3. Results

3.1. Orientation

The first part of this study concerns the ideal orientation that should be adopted at the design stage of a school building. In the case of the particular building, all major windows are located in its two opposite large facades. Therefore, studying the building's behavior in four different orientations is enough to draw adequate conclusions.

The comparison that follows is based in the simulation of the building's behavior during the hours of operation, when being oriented with the long axis running north/south, north-east/south-west, east/west and north-west/south-east. At this point, it should be noted that the building that took part into the simulation is considered externally insulated.

In a typical November day, east and west orientation compete with north-east and south-west for the last place in energy consumption, while north and south orientation dominate during most of the day, having even almost 10 kWh difference in energy consumption in comparison with east and west orientation, as shown in Figure 5.

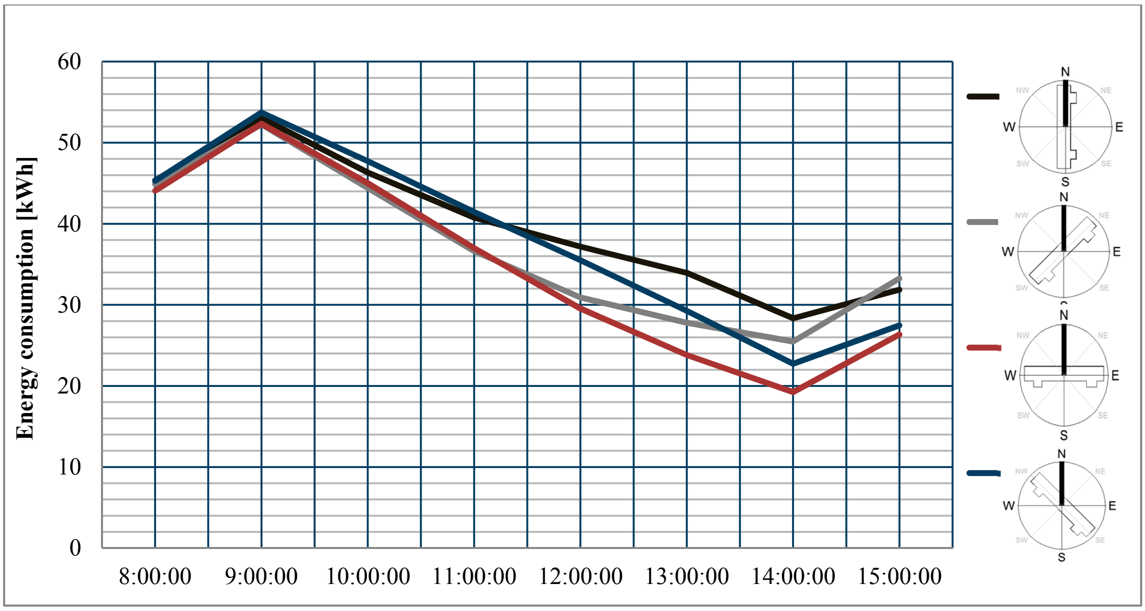

Figure 5. Effect of orientation in energy consumption, in a typical day of November.

The effect of the building's orientation in energy consumption, for a typical day of December January and February are presented in Table 5.

During December, no significant fluctuations between different orientations are apparent, with the north and south orientations requiring the lowest amount of energy. On the other hand during January, when the major openings face east and west results in the highest energy consumption, with a peak hourly consumption of about 84 kWh.

Slightly different results are presented during February. What is interesting is that orientation starts playing a key role in energy consumption, only after 11:00 a.m., due to the position of the sun at this time of the year. However, north and south orientation seems to be best in this case, too.

Hence, the suggestions that buildings should be oriented in such a way that major windows face either north or south, maximizing solar gains during winter, are found correct. Also, the implication that north orientation offers low heat gains and increased heat losses during winter is proved right, too.

Table 5. Effect of orientation in average daily energy consumption (November to March).

Month	Orientation	Energy Consumption (kWh)
November	E	317
	SE	296
	S	277
	SW	303
December	E	301
	SE	294
	S	286
	SW	296
January	E	494
	SE	480
	S	451
	SW	472
February	E	483
	SE	473
	S	460
	SW	474
March	E	352
	SE	350
	S	346
	SW	353

3.2. Envelope

As far as the envelope of the building is concerned, the installation of thermal insulation internally or externally of the building's shell was examined.

The non-insulated building exhibits an annual consumption of 58,555 kWh, with a peak demand of 209 kWh during the coldest day of the year, in February. The same building, externally insulated, presents an annual consumption of only 57% compared to the non-insulated case, with an annual energy consumption of 33,618 kWh and peak demand of 141 kWh. The breakdown of these numbers into the monthly energy consumption in both cases is presented in Figure 6.

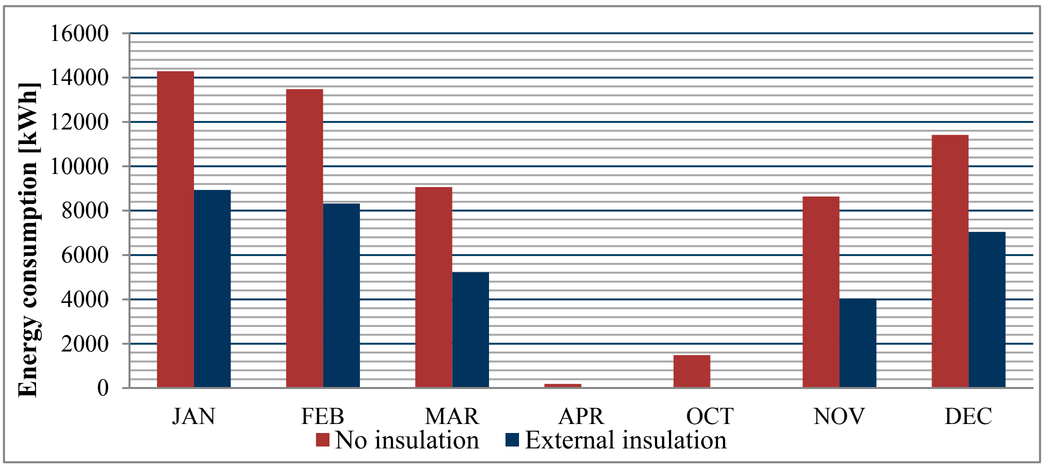

Figure 6. Effect of thermal insulation in monthly energy consumption.

The fluctuation of the mean air temperature of the zone during the first day of the school's operation, after being closed for Christmas holidays, for both insulated and non-insulated buildings, is presented in Figure 7. In Figure 8 the energy consumption of both buildings during the same day of operation in January is shown.

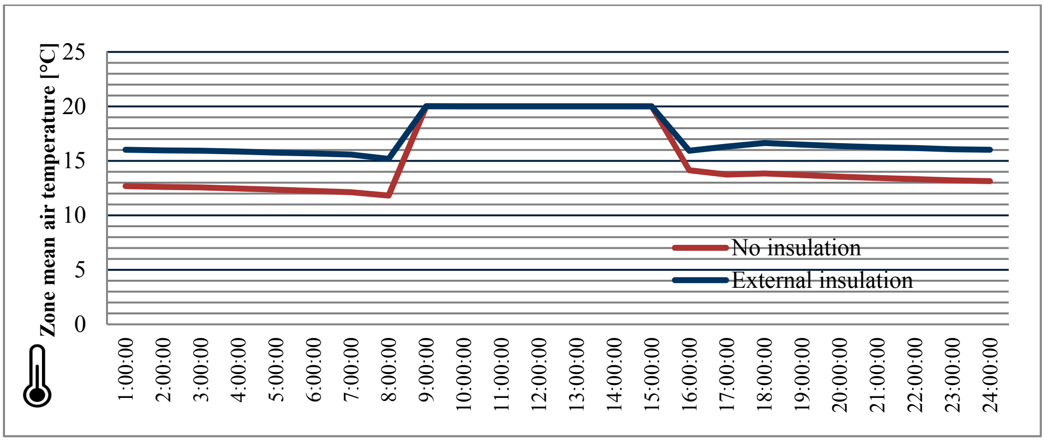

Figure 7. Zone temperature in the first day of operation after fortnightly holidays, in January.

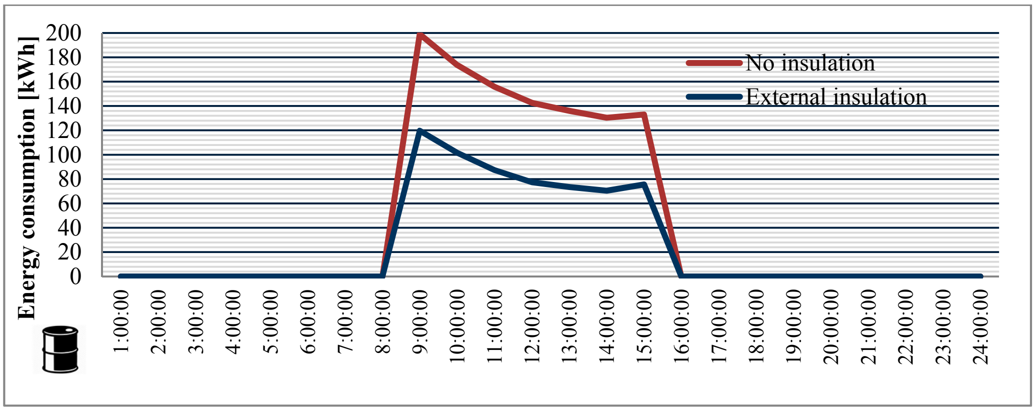

Figure 8. Energy consumption in the first day of operation after fortnightly holidays, in January.

In relation to the way a school building should be insulated, a widely shared claim is that internal insulation in education buildings is more energy-efficient. The argument is based on the notion that faster reheating of the building is feasible with internal insulation in combination with the limited hours of operation. To that end the use of internal insulation was examined as well, and the results are similar with the use of external insulation, as total energy consumption was calculated at 33,489 kWh, a mere 0.4% less and is in agreement with the results found in the literature [38].

3.3. Heating Operation

An important issue, besides the way a school building should be insulated, is what the best way of the heating system operation is. To that end, three alternative scenarios of heating system operation, concerning the temperature set points, were modelled.

The first scenario is the simplest possible way for the heating system to operate. That is accomplished by setting a lower limit of the thermostat temperature at 20 °C, during the 7 h of the school's operation; the rest of the day the heating system is shut down. The second scenario contains the same set point temperature of 20 °C, during the 7 h of the school's operation in addition to a second set point of 15 °C during the rest of the day, which intends to prevent the building of being extremely cooled down, requiring a higher energy demand in the first hours of operation in the morning. The third scenario also aims at eliminating the possibility of an extreme energy demand during the first hours of operation in the morning; but without the constant need of the heating system to operate during the night. That is made possible by setting a two-hour morning reheat, which allows the building to reach the desirable temperature of 20 °C gradually. For the needs of the energy simulation, the thermostat is set at 16 °C between 06:00 and 07:00 a.m. and at 18 °C between

07:00 and 08:00 a.m. In Table 6 the temperature set points of the three different scenarios of the heating system operation are summarized.

Table 6. Temperature set points of the three heating system operation scenarios.

Hour	Heating Temperature Set Point (°C)		
	Scenario 1	Scenario 2	Scenario 3
1–6	No set	15	No set
7	No set	15	16
8	No set	15	18
9–15	20	20	20
16–24	No set	15	No set

In the following analysis, two different types of buildings are compared (the first is the externally insulated building, with the construction components; the second is the internally insulated building), in relation to each of the three operating case scenarios.

Except for the total energy consumption of the building in several cases and the monthly breakdown of that amount, some typical days of the year are examined, in order to draw more accurate conclusions. These are:

- The first day of school operation, after Christmas holidays, in January
- The coldest day of the reference year, in February
- Typical Mondays of January, February, November and December
- Typical Fridays of January, February, November and December

At this point, it should be noted that the "typical" days are assumed to be some random days in the middle of each month. Mondays are selected since the building is closed during the weekend and the energy demand for heating it up should be important. Fridays are selected for the opposite reason; the school has operated for a whole week and the energy demand for its reheating is expected to be less significant.

4. Discussion

The analysis concerning the three selected heating system operation scenarios when applied to the two different types of buildings, the internally and the externally insulated, is summarized in Table 7, in terms of monthly and annual energy consumption values, in kWh, along with the maximum values of demand that were calculated for the whole heating period of the simulation. Annual energy demands, as well as individual values for each month, present an increase from the first to the second operation scenario and a further increase in the third one. This is quite reasonable, given that the minimum heating system operating hours are observed in the first and the maximum in the third scenario.

Regarding the comparison between the internally and externally insulated buildings, the first appears to perform better during February, March and April in all three scenarios, as well as in December in scenarios 1 and 2. For the rest of the months, the externally insulated building appears to be slightly more energy efficient.

Nevertheless, it is worth mentioning that in the months presenting the most notable values of energy consumption, the difference of the energy demand of the internally, compared to the externally insulated building is from 3 to 5% less. The maximum observed annual difference recorded between the two types of buildings, favoring the internally insulated, is 129 kWh, which is a relatively minor difference, bearing in mind that the application of external insulation in a building's envelope is much more cost effective. This can be attributed to the high thermal inertia of the building due to the high mass of the internal walls and floor plates of the building in comparison to the mass of the external walls.

Table 7. Monthly, annual and peak values of energy consumption for all operation scenarios and building types.

Month	Energy Consumption (kWh)					
	Scenario 1: 8 a.m.–15 p.m. Set		Scenario 2: 24 h Set		Scenario 3: 2 h Reheat	
	Internal Insulation	External Insulation	Internal Insulation	External Insulation	Internal Insulation	External Insulation
JAN	9037	8930	9075	8948	9399	9188
FEB	7993	8318	8003	8318	8249	8488
MAR	4968	5227	4968	5227	5073	5278
APR	21	41	21	41	22	40
OCT	190	16	190	16	200	16
NOV	4243	4042	4243	4042	4353	4106
DEC	7037	7044	7039	7045	7279	7220
TOTAL	33,489	33,618	33,539	33,637	34,575	34,336
PEAK	140	141	140	141	130	131

In Figures 9 and 10 the three operation scenarios of the most important months in reference to energy consumption are compared for the case of the internally and the externally insulated building, respectively. The fact that the building is very well insulated makes it extremely rare to present a drop of temperature below the set point of 15 °C. Consequently, the building performs quite similarly in both scenarios 1 and 2. In general, annual and monthly energy demand values present a slight increase from the first to the second operation scenario and a further increase in the third one. This performance is quite reasonable, given that the minimum heating system operating hours are observed in the first scenario, and the maximum ones in the third. Although scenario 3 displays increased overall energy consumption, a substantial decrease in the peak energy demand values is observed, rendering it an efficient option. In conclusion, the most efficient heating operating scenario is the first, with minimum hours of operation, unless the differences displayed between the peak demand values are enormous. In that case, the implementation of operating scenario 3, with morning reheat, may contribute in avoiding the selection of an over dimensioned heating system.

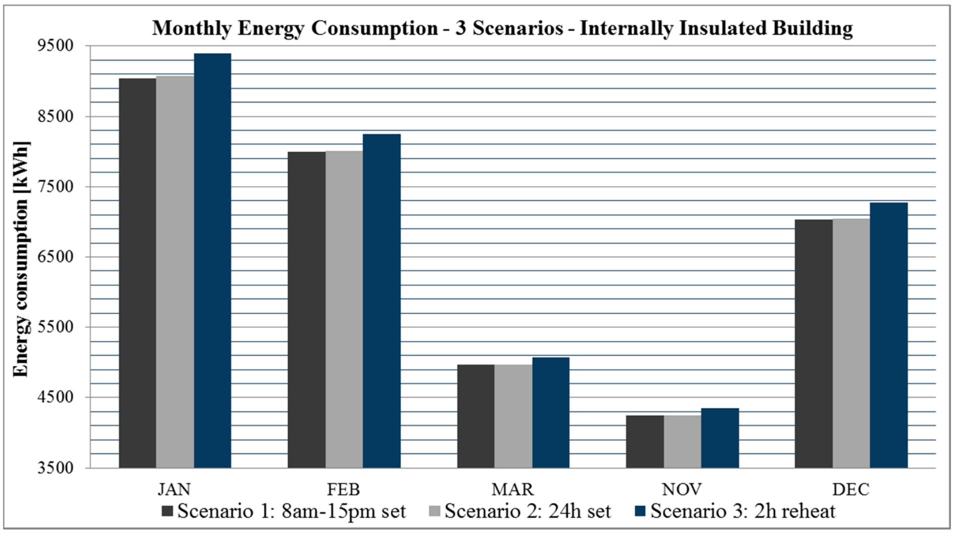

Figure 9. Monthly energy consumption in the internally insulated building.

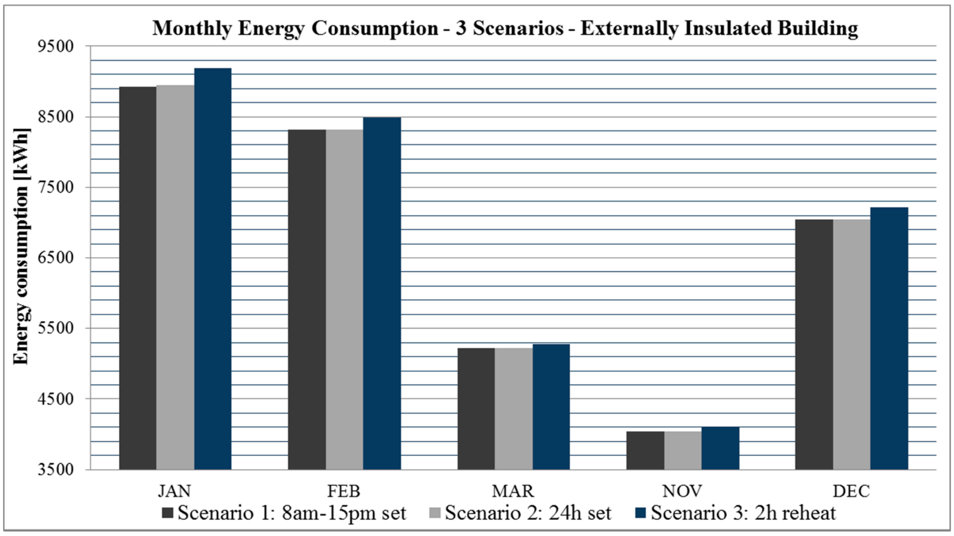

Figure 10. Monthly energy consumption in the externally insulated building.

5. Conclusions

The aim of this study was to provide answers to fundamental questions that arise when designing a school from scratch or retrofitting one, as well as to give solutions to solve more complex quandaries about the selection and operation of its systems. Within this framework, the thermal behavior of a typical Greek secondary education building was studied, aiming to tackle the issues of the ideal orientation of the building, the optimal location of the insulation layers and the most efficient scenario of heating operation in the special climatic conditions of Greece.

The dynamic simulation of the building's energy performance confirms, that the optimal orientation for educational buildings is the one in which their long axis coincides with the east-west one, which should be taken into consideration in the design phase.

Regarding insulation options, although insulating from the inside provides slightly better results than from outside, the difference can be thought of as negligent, taking into consideration the inherently higher initial installation cost. It should be highlighted that the use of insulation, either internal or external, leads to a reduction of energy consumption by more than 55%.

It is interesting to note, that for new buildings that follow current legislation requirements for insulation, the minimum internal temperature rarely drops below 15 °C, regardless of how the heating system operates rendering the operation of the heating system during the night needless. On the other hand, enforcing a one or two hour morning reheat strategy in educational buildings could reduce the needed installed capacity for heating by up to 10%. Although, as the majority of the existing educational buildings is uninsulated or poorly insulated, the results of the study can be used as a guide for their efficient renovation, as well as for the selection of the most appropriate scheduling of their heating system.

Author Contributions: Conceptualization, G.M. and V.K.; Methodology, V.K.; Resources, D.B.; Supervision, G.M.; Writing—review & editing, G.M., V.K. and D.B.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Martinopoulos, G.; Papakostas, K.T.; Papadopoulos, A.M. A comparative review of heating systems in EU countries, based on efficiency and fuel cost. *Renew. Sustain. Energy Rev.* **2018**, *90*, 687–699. [CrossRef]
2. Marrone, P.; Gori, P.; Asdrubali, F.; Evangelisti, L.; Calcagnini, L.; Grazieschi, G. Energy Benchmarking in Educational Buildings through Cluster Analysis of Energy Retrofitting. *Energies* **2018**, *11*, 649. [CrossRef]

3. Desideri, U.; Proietti, S. Analysis of energy consumption in the high schools of a province in central Italy. *Energy Build.* **2002**, *34*, 1003–1016. [CrossRef]
4. Zomorodian, Z.S.; Tahsildoost, M.; Hafezi, M. Thermal comfort in educational buildings: A review article. *Renew. Sustain. Energy Rev.* **2016**, *59*, 895–906. [CrossRef]
5. Niemelä, T.; Kosonen, R.; Jokisalo, J. Cost-optimal energy performance renovation measures of educational buildings in cold climate. *Appl. Energy* **2016**, *183*, 1005–1020. [CrossRef]
6. Carbon Trust. Schools: Learning to Improve Energy Efficiency (CTV019). 2012. Available online: https://www.carbontrust.com/ (accessed on 10 August 2017).
7. Filippın, C. Benchmarking the energy efficiency and greenhouse gases emissions of school buildings in central Argentina. *Build. Environ.* **2000**, *35*, 407–414. [CrossRef]
8. Energy Information Administration (US); Government Publications Office. *International Energy Outlook 2016: With Projections to 2040*; Government Printing Office: Washington, DC, USA, 2016.
9. Butala, V.; Novak, P. Energy consumption and potential energy savings in old school buildings. *Energy Build.* **1999**, *29*, 241–246. [CrossRef]
10. Beusker, E.; Stoy, C.; Pollalis, S.N. Estimation model and benchmarks for heating energy consumption of schools and sport facilities in Germany. *Build. Environ.* **2012**, *49*, 324–335. [CrossRef]
11. Katafygiotou, M.C.; Serghides, D.K. Analysis of structural elements and energy consumption of school building stock in Cyprus: Energy simulations and upgrade scenarios of a typical school. *Energy Build.* **2014**, *72*, 8–16. [CrossRef]
12. Santamouris, M.; Balaras, C.A.; Dascalaki, E.; Argiriou, A.; Gaglia, A. Energy consumption and the potential for energy conservation in school buildings in Hellas. *Energy* **1994**, *19*, 653–660. [CrossRef]
13. Vagi, F.; Dimoudi, A. Analysing the energy performance of secondary schools in N. Greece. In Proceedings of the World Renewable Energy Congress-Sweden, Linköping, Sweden, 8–13 May 2011; Linköping University Electronic Press: Linköping, Sweden, 2011; No. 057, pp. 1837–1844.
14. Centre for Renewable Energy Sources (CRES); European Commission Directorate General for Energy (DG XVII). *Guidelines for Thermal-Visual Comfort and Energy Conservation in Public Schools*; Centre for Renewable Energy Sources (CRES): Athens, Greece, 1995.
15. Santamouris, M.; Mihalakakou, G.; Patargias, P.; Gaitani, N.; Sfakianaki, K.; Papaglastra, M.; Pavlou, C.; Doukas, P.; Primikiri, E.; Geros, V.; et al. Using intelligent clustering techniques to classify the energy performance of school buildings. *Energy Build.* **2007**, *39*, 45–51. [CrossRef]
16. Dascalaki, E.G.; Sermpetzoglou, V.G. Energy performance and indoor environmental quality in Hellenic schools. *Energy Build.* **2011**, *43*, 718–727. [CrossRef]
17. Rospi, G.; Cardinale, N.; Intini, F.; Cardinale, T. Analysis of energy consumption of different typologies of school buildings in the city of Matera (Southern Italy). *Energy Procedia* **2015**, *82*, 512–518. [CrossRef]
18. Demanuele, C.; Tweddell, T.; Davies, M. Bridging the gap between predicted and actual energy performance in schools. In Proceedings of the World Renewable Energy Congress XI, Abu Dhabi, UAE, 25–30 September 2010; pp. 25–30.
19. Pereira, L.D.; Raimondo, D.; Corgnati, S.P.; Da Silva, M.G. Energy consumption in schools—A review paper. *Renew. Sustain. Energy Rev.* **2014**, *40*, 911–922. [CrossRef]
20. US Department of Energy, Office of Energy Efficiency and Renewable Energy. *National Best Practices Manual for Building High Performance Schools*; US Department of Energy: Washington, DC, USA, 2007.
21. Orlowski, R.; Loe, D.; Watson, N.; Rowlands, E.; Mansfield, K.; Venning, B.; Seager, A.; Minikin, J.; Hobday, R.; Palmer, J. *Guidelines for Environmental Design in Schools*; Revision of Design Note 170, Building Bulletin 87; School Building and Design Unit, Department for Education and Skills: London, UK, 1997.
22. School Buildings Organisation S.A. Directives for Bioclimatic Design of School Buildings. 2008. Available online: www.osk.gr/UserFiles/File/Bioklimatika.pdf (accessed on 10 July 2017).
23. Dimoudi, A.; Kostarela, P. Energy monitoring and conservation potential in school buildings in the C′ climatic zone of Greece. *Renew. Energy* **2009**, *34*, 289–296. [CrossRef]
24. Hong, S.; Lee, J.; Moon, J.; Lee, K. Thermal Comfort, Energy and Cost Impacts of PMV Control Considering Individual Metabolic Rate Variations in Residential Building. *Energies* **2018**, *11*, 1767. [CrossRef]
25. Lee, K.H.; Schiavon, S. Influence of three dynamic predictive clothing insulation models on building energy use, HVAC sizing and thermal comfort. *Energies* **2014**, *7*, 1917–1934. [CrossRef]

26. Kim, C.H.; Lee, S.E.; Kim, K.S. Analysis of Energy Saving Potential in High-Performance Building Technologies under Korean Climatic Conditions. *Energies* **2018**, *11*, 884. [CrossRef]
27. Martinopoulos, G.; Papakostas, K.T.; Papadopoulos, A.M. Comparative analysis of various heating systems for residential buildings in Mediterranean climate. *Energy Build.* **2016**, *124*, 79–87. [CrossRef]
28. Gaitani, N.; Cases, L.; Mastrapostoli, E.; Eliopoulou, E. Paving the way to nearly zero energy schools in Mediterranean region-ZEMedS project. *Energy Procedia* **2015**, *78*, 3348–3353. [CrossRef]
29. Giannaros, T.M.; Melas, D. Study of the urban heat island in a coastal Mediterranean City: The case study of Thessaloniki, Greece. *Atmosp. Res.* **2012**, *118*, 103–120. [CrossRef]
30. Google, 'SketchUp Pro'. 2017. Available online: https://www.sketchup.com/products/sketchup-pro (accessed on 10 June 2017).
31. EnergyPlus, 'EnergyPlus'. 2017. Available online: https://energyplus.net/ (accessed on 10 June 2017).
32. OpenStudio, 'OpenStudio'. 2017. Available online: https://www.openstudio.net/ (accessed on 10 June 2017).
33. Greek Parliament. *Regulation for the Energy Performance of Buildings (K.EN.A.K.)*; Official Gazette of the Hellenic Republic: Athens, Greece, 2010; pp. 5333–5356.
34. Solmaz, A.Ş. An Approach to Identify the Optimal Solutions in the Context of Energy and Cost Criteria for Buildings in Different Climates. *Megaron* **2016**, *11*, 592–606. [CrossRef]
35. Ordoñez, A.; Carreras, J.; Korolija, I.; Zhang, Y.; Coronas, A. Impact of building geometry on its energy performance depending on climate zones. In Proceedings of the BSO14: Second Building Simulation and Optimization Conference, London, UK, 6–7 June 2014; pp. 23–24.
36. Lee, K.H. Heat Balance Analysis of Low-E Window Impacts on Thermal Load in Buildings. In Proceedings of the Sustainable Building 2013 Conference, Seoul, Korea, 7–10 July 2013.
37. Seong, Y.B.; Lim, J.H. Energy saving potentials of phase change materials applied to lightweight building envelopes. *Energies* **2013**, *6*, 5219–5230. [CrossRef]
38. Androulakis, N.D.; Armen, K.G.; Bozis, D.A.; Papakostas, K.T. Simulation of the thermal performance of a hybrid solar-assisted ground-source heat pump system in a school building. *Int. J. Sustain. Energy* **2018**, *37*, 311–324. [CrossRef]