ENERGY EFFICIENCY & IAQ ASPECTS OF THE SCHOOL BUILDINGS IN GREECE

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ABSTRACT

The present article deals with the energy classification and the environmental evaluation of the school buildings in Greece. The energy performance of the school buildings, in relation to the normalized annual consumption for heating regarding floor area and climatic conditions, was rated using clustering technique (K-means algorithm) and an energy classification tool developed. The audited school buildings were classified into five energy categories. To investigate the potential for energy savings a methodology for the definition of the characteristics of the typical building for each energy class of the school sector has been developed using multivariate statistical techniques. It is based on a selection of seven variables that influence the energy performance of the building and has been mainly carried out using principal components analysis techniques (PCA). For the evaluation of indoor temperatures, the heating loads and the potential for energy conservation interventions, the typical buildings in each class have been simulated for a typical meteorological year, using TRNSYS. The measurements of indoor air quality concerned in concentrations of monoxide (CO) and carbon dioxide (CO_2), as well as in the organic volatile compounds (TVOCs) in 83 classrooms. Thermal comfort conditions have been calculated using the indoor measurements of the meteorological parameters. The research has shown that school buildings suffer from important IAQ problems while their energy consumption and global environmental quality can be improved considerably. The conclusions obtained promote a general energy and environmental evaluation of the school buildings in Greece.

KEYWORDS
Schools, Energy efficiency, IAQ, Cluster analysis, PCA

1 INTRODUCTION

Energy efficiency and IAQ are key points of environmental policy and energy strategy in Europe. As EPBD came into force, European regulation on buildings has been implemented in different ways in European Union Member States and various techniques have been proposed to develop rating schemes (Roulet 2002, Santamouris 2005, Santamouris 2007, Corgnati S. P.,2008, Gaitani N., 2010).
In Greece, since May 2008 the Law 3661 on "Measures to reduce energy consumption in buildings and other provisions" in line with Directive 2001/91/EC has been adopted. The Regulation for Buildings Energy Performance (KENAK) based primarily in European Standard ISO/EN 13790, has been incorporated within national legislation and expected to comprise an integral part of all future developments in the building sector in Greece.
Greece currently has 15,446 schools of which 4,500 are over 45 years old. The total energy consumption of school buildings is around 270.000 MWh. In parallel, the insular and mountainous character of the country and the resulted student population moving to bigger urban centers constantly generates new school infrastructure demand. The result is the

constant need to build new schools and to implement actions to improve the quality of existing school facilities.
The Greek school buildings are divided into two categories: those that were built before 1960 and are usually stone with a wooden roof and the ones that were built after 1960 and represent typologies of Greek School Buildings Organisation SA (SBO). These typologies generally have similar construction features in all climatic zones of the country; are built with concrete and bricks and have metal frames. The different typologies show many similarities mainly in construction but also in the proportions of classes, corridors and other spaces. Basic differences usually occur in the number and arrangement of classrooms.
The design may be linear or Γ shaped, or less commonly Π shaped. Commonly, the schools encountered in compact arrangement, with rooms arranged around a central inner space.
The linear buildings and those that are arranged in Γ shaped, showing the rooms face in the yard, or outdoor with an enclosed hallway toward the rear or, more rarely, open hallway from the main side. The typologies appear with 1, 2, or 3 floors according to the school building program.
The research is based on data collection using energy audits of secondary education public school buildings. The distribution of questionnaires to all the prefectures of Greece conducted in collaboration with the SBO and the Greek Ministry of Education. The method of free sample (Haphazard sampling) was used. The data set represents 33% of the entire population of secondary education school buildings and is distributed in all the prefectures of Greece, while 23% of the sample originates from Attica. The collected data were quantitatively and qualitatively.
The present article deals with the energy classification and the environmental evaluation of the school buildings in Greece. The energy performance of the school buildings, in relation to the normalized annual consumption for heating regarding floor area and climatic conditions, was rated using a clustering technique (K-means algorithm) and an energy classification tool developed. The audited school buildings were classified into five energy classes. In order to identify best practices, set energy performance goals and predict internal conditions, thermal simulations were applied with TRNSYS software for a year in every typical building of each energy class.
The main contribution of the present study is the assessment of energy conservation potentials in schools taking into account the environmental quality issues.

2 ENERGY PERFORMANCE

The research was based principally on data collection using energy audits in a sample of 1190 secondary education public school buildings. The auditing techniques were used to create a database on the energy use for heating in the school field and contained data such as the annual consumption for heating and lighting, the area of the building, the number of students and professors, the installed power of the boiler, the manufacturing year of the building and the schedule of operation.
The majority of the school buildings in Greece (98%) are not heated with other carriers than oil. Furthermore, the classrooms in Greek schools are not equipped with electrical heating or cooling systems. For general lighting the interior school spaces rely mainly on daylight during daily operation. The percentage of electricity refers to the energy consumption by office and other electrical energy-consuming equipment. Most schools of the sample were 25 years of age and the heating system on average calculated 18 years.
The oil values for space heating of the school buildings measured in litters converted in kWh multiplied by the factor 11.2 kWh/L) according to the Greek legislation. The schools on an

average have 18 internal spaces (classes, workshops and offices), 246 students and 32 students.

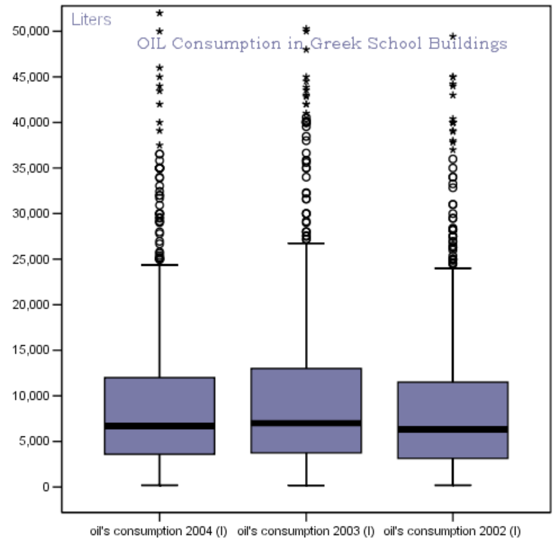

Figure 1: Box plot of energy consumption for space heating with oil [three school years]

As shown in Fig 1 the median values of energy consumption for space heating with oil ranged between 6300-7000 L.

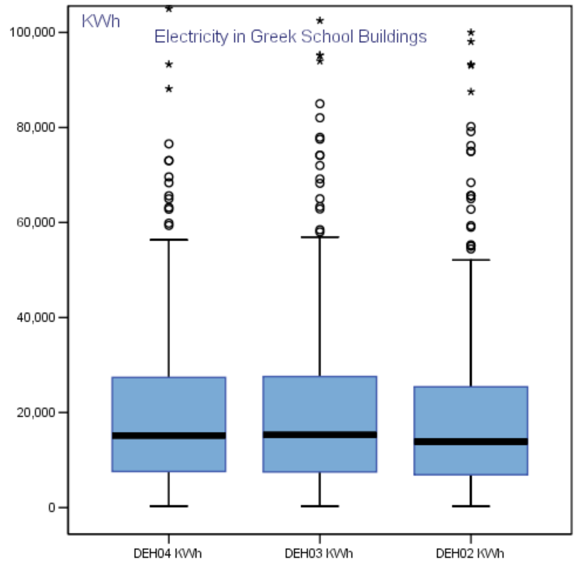

Figure 2: Box plot of energy consumption for electricity [three school years]

The median values of energy consumption for electricity ranged between 13.925-15.252 kWh (see Fig 2). The average power of the boiler was calculated 350 kW and the average heated area of the schools was 1772m^2. Also, the average power of the lamps was found to be 387kW.

2.1 Energy consumption for heating

The majority of schools in Greece (98%) were not heated with other carriers than oil. The classrooms were not equipped with electrical heating (nor cooling) systems. The focus was on oil conservation used for space heating. The energy performance of the school buildings, in relation to the normalized annual consumption for heating regarding floor area and climatic conditions, was rated using a clustering technique (K-means algorithm, Afifi AA., Clark, 1996.) and an energy classification tool developed (Gaitani N., 2010). The annual consumption for space heating has been divided by the total heated floor area, (to get energy per unit area, kWh/m^2) in order to enable a comparison with buildings of different size. In order to normalize the impact of climate on energy consumption the degree-days method was applied on energy use for heating with a base temperature of 18.5°C (Papakostas 2005, Yael 2009).

Table 1: Normalized annual consumption for heating with oil in kWh/m^2y

		$OILN_{04}$ kWh/m^2y	$OILN_{03}$ kWh/m^2y	$OILN_{02}$ kWh/m^2y
N	**Valid**	944	918	901
	Missing	247	273	290
Mean		63.8	65.8	61.0
Median		47.9	49.5	45.7
Std. Deviation		61.9	61.5	59.9
Percentiles	**25**	29.9	31.2	27.7
	50	47.9	49.5	45.7
	75	77.3	79.6	73.7

The mean normalized energy consumption for heating with oil was calculated for three years (Table 1): 61.0 kWh/m^2y, 65.8 kWh/m^2y and 63.8 kWh/m^2y respectively.

As the data set is skewed the median is preferred to other measures of central tendency. Moreover, it is the most appropriate measure of central tendency when the data has outliers (Hoaglin D C., 1986). Here, the median of the normalized energy consumption for heating was calculated for the three years respectively: 45.7kWh/m^2y, 49.5kWh/m^2y, and 47.9kWh/m^2y.

The energy performance of the school buildings, in relation to the normalized annual consumption for heating regarding floor area and climatic conditions, was rated using K-means algorithm and the audited school buildings were classified into five energy classes A–E. The average annual energy consumption for heating in school buildings for the three examined years, in class A was varied in a range of 18-22 kWh/m^2y and the median 19-23kWh/m^2y. For energy class B, the corresponding values were 37-42 kWh/m^2y and 40-42kWh/m^2y, respectively. In class C was calculated 57-62kWh/m^2y (mean) and 58-62kWh/m^2y (median), in class D, 85-89kWh/m^2y and 84-87 kWh/m^2y and finally in class E 119-124kWh/m^2y and 117-123kWh/m^2y, respectively.

The consumption for heating with oil was high, given the limited operation hours of schools and the mild climate of the country. Furthermore, this consumption usually does not cover the actual needs for heating, as most schools do not meet the thermal comfort conditions during operation.

All non-insulated elements (i.e. non-insulated columns, beams, ledges) contributed to increased thermal losses during winter and increased thermal gains during the warm period and intensify the feeling of thermal discomfort. The large air infiltration from cracks and openings uncontrolled ventilation produced excessive fuel consumption and cold conditions in the halls. Also, the random orientation of buildings, according to the available land did not provide the necessary insolation schools, nor to avoid overheating in combination with insufficient shading.

The orientation should be a crucial issue in the creation of a building with low energy efficiency. School buildings with favourable orientation in classrooms (north and south orientation) had a smaller load for heating.

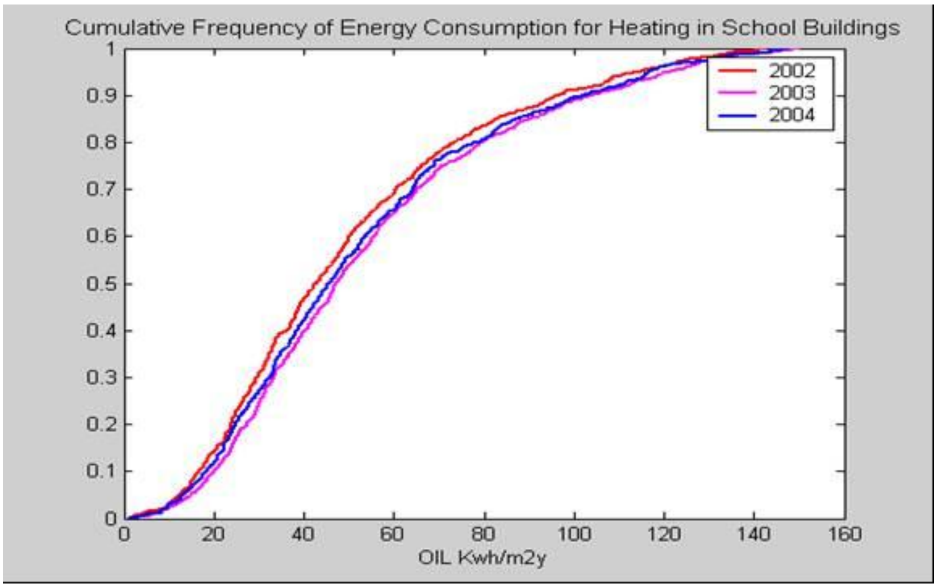

Figure 3: Cumulative frequency distribution of the normalized energy consumption for heating with oil in kWh/m²y (after the removal of outliers-Tukey method)

Fig 3 illustrates the cumulative frequency curve of the normalized energy consumption for heating with oil in kWh/m^2y. 50% of schools consume for space heating with oil, less than 50 kWh per square meter annually.

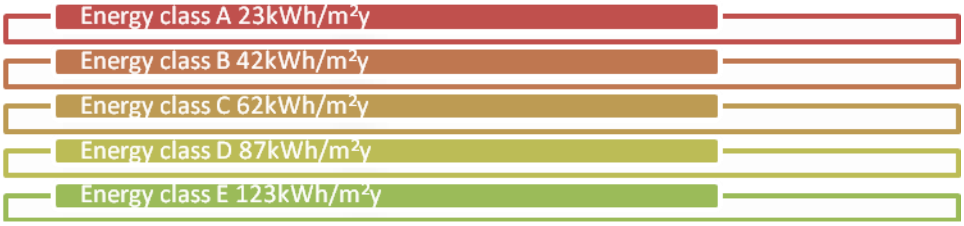

Figure 4: Benchmarks of the normalized energy consumption for heating with oil in kWh/m²y in each energy class

In order to acquire in-depth data on energy consumption levels the benchmarks for each class were calculated as shown in Fig 4. To evaluate the potential energy conservation, the typical characteristics of school buildings belonging to an energy class have to be identified. A methodology based on the use of the principal components analysis (PCA, Jolliffe IT., 1993) has been developed. The method allows to define in an accurate way the typical building of each energy class and thus to perform analysis on the potential energy savings for the specific group of school buildings.

For the definition of the typical building in each one of the five energy classes, seven variables have been selected:

- Heated surface (m^2)
- Age of the building (years)
- Insulation of the building (0 for non-insulated, 1 for insulated)
- Number of classrooms
- Number of students
- School's operating hours per day
- Age of the heating system (years)

The characterization of the typical school among a seven variables sample, has being performed as the closest to the medians in the principal components' coordinate system. The Euclidian distance performed in the seven dimensional PCs coordinate system and the five reference schools are presented in Fig 5.

Figure 5: The examined reference school buildings (A-E class)

2.2 Best practices for energy efficiency

In order to set energy performance goals and predict internal conditions, thermal simulations were applied with TRNSYS 15.1 software for a year in every typical building of each energy class. The models have been calibrated to the real consumption as obtained from the bills. The simulated heating load varied in the range of 22.3-50.7 kWh/m^2y while the corresponding cooling load, in case of AC fluctuated between 6.9-18.9 kWh/m^2y. Several scenarios were examined.

Following the adoption of energy choices in class A, the annual heating load was varied in a range of 18kWh/m^2y-27kWh/m^2y. The potential of the reduction of the energy load for heating calculated between 7 and 40%.

For the reference building in class B the annual heating load was varied in a range of 26kWh/m^2y-34kWh/m^2y. Energy savings could be achieved by a combination of interventions, were accounted for 26%.

With implementation of the proposed interventions energy saving class C, the annual heating load for the representative building was varied in a range of 20kWh/m^2y-47kWh/m^2y. The reduction of thermal losses of the cracks proved the most effective method of reducing the thermal load. Specifically, the reduction of thermal exchanges the cracks calculated that can reduce the heat load of 34%. The final examined scenario with all the proposed interventions calculated in savings of 59%.

From the simulations for the reference building in class D emerged annual heating loads by 26kWh/m^2y to 65kWh/m^2y. The largest reduction of annual consumption for heating, with a 63% calculated for the simultaneous implementation of all actions.

Finally, the annual heating load in the representative building of E class was varied in a range of 23kWh/m^2y-110kWh/m^2y. The main reduction of annual consumption for heating, with a change of 80%, calculated for all the scenario of the combined solutions.

A considered efficient intervention was the replacement of the windows with new, better quality with lower U (u-value) and solar heat gains (g-value). More specifically, for the simulation low-e double window glazing was chosen. The efficient thermal insulation through the use of up-to-date double glazing was important, as the blinds covering an average area of 30% on the sides of school buildings contributed at a rate of 10% in energy consumption for heating.

The insulation accounted only for 35% of the buildings in class A, B; C, D, and class E buildings were non-insulated. The remaining surface either created thermal bridges or was covered by window frames. The thermal insulation of the external wall could contribute to energy saving per year to 32%. Furthermore, external insulation may ensure less fluctuation of indoor temperatures and therefore better thermal comfort conditions in classrooms.

Modern boilers and heating systems are designed to have minimal thermal losses and yield 0.8-0.9 means that the losses are on the order of 10-20%. The heat recovery process could contribute to a reduction in consumption for heating ranging from 5 to 15%.
The most effective method of reducing the thermal load was associated with the reduction of heat loss from the cracks. Consequently, the airtightness of frames or replacement of gastight doors and frames should be a technical priority in old school buildings as they were accounted for 23-44% reduction in the heating load.

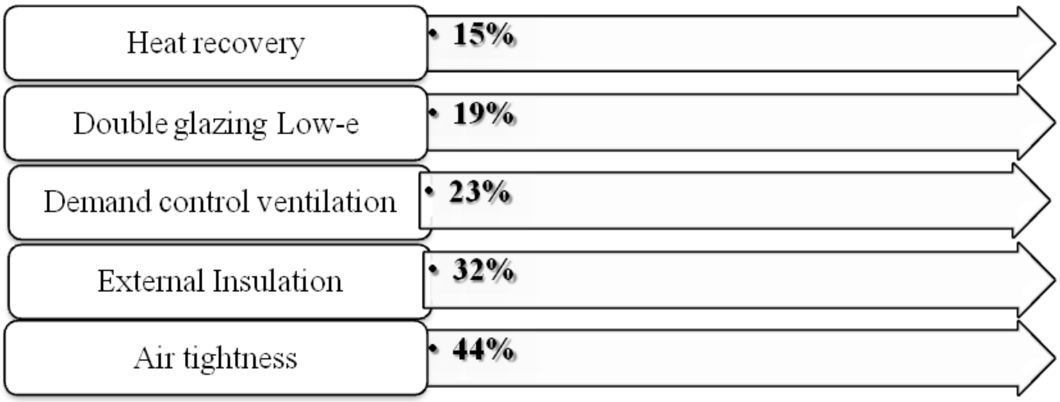

Figure 6: Benchmarks of the normalized energy consumption for heating with oil in kWh/m^2y in each energy class

As it can be seen (Fig 6) the energy saving for heating load may be reduced up to 50% with simple energy measures. The evaluation of various energy saving techniques, revealed an opportunity for an overall reduction in consumption for heating of 15-80%. The rational operation and maintenance of school buildings should be integrated also into a global Action Plan.

3 INDOOR AIR QUALITY ASPECTS

Together with the energy demand one should consider the general requirements of indoor climate conditions, in order to avoid possible adverse consequences (Santamouris, 2008). The school buildings in general are characterized by a high density of people per unit area, which is associated with increased concentrations of certain pollutants and therefore with reduced attentiveness of students and less ability to learn. Moreover, students are a vulnerable group necessitating a special attention. Characterized by:
• Greater respiratory rate compared with adults
• Lower weight
• Higher levels of physical activity
• The human lung continues to develop until adolescence
Measurements of air quality were conducted within ten school buildings in the Greater Athens area. Hourly measurements of ambient indoor and outdoor temperature and relative humidity have been performed, while indoor air velocity and infiltration have been also monitored. Furthermore, CO_2, CO, TVOCs were measured in 83 examined classrooms.

3.1 Ventilation

The monitoring strategy to evaluate air flow rates in classrooms was the concentration decay method (tracer gas). Measurements of infiltration rate were performed using SF_6 tracer gas when classrooms were empty and the windows closed. Then measurements were repeated during the breaks when most of the windows were opened (opening of windows is very common practice in mild climates) and classrooms were empty. Thus the max & min ventilation rates were estimated. Infiltration in all schools varied between 0.1 to 0.9ACH with a mean value close to 0.4ACH. Combined air flow rates (natural ventilation & infiltration) varied between 1.3-12.1ACH with a mean value of 2.2ACH (see Table 2).

Table 2: Infiltration & ventilation rates

School number	Infiltration (ACH)	Infiltration & natural ventilation (ACH)
1	0.1	3.5
2	0.2	2.8
3	0.4	9.0
4	1.2	4.6
5	1.9	6.9
6	0.1	7.4
7	0.2	1.7
8	0.3	3.8
9	0.9	7.3
10	0.3	2.4
11	0.5	12.1
12	0.9	10.2
13	1.3	6.0
14	0.4	11.7
15	0.4	1.3
16	0.4	1.4
17	0.3	2.0
18	0.2	4.8

3.2 Indoor Air

As it concerns indoor air quality, measurements have been performed according to experimental protocol in 83 classrooms of the examined schools (Table 3).

Table 3: Minimum, average and maximum measured values of CO, CO_2 and TVOC's concentration per school building, number of classrooms and percentage exceeding the threshold limit values

	Min	Average	Max	Number of classrooms & percentage that exceed the acceptable limit	Min	Average	Max	Number of classrooms & percentage that exceed the acceptable limit	Min	Average	Max	Number of classrooms & percentage that exceed the acceptable limit	Number of classrooms & percentage that exceed at least one limit, in total
1	0,28	0,67	1,05	0/8 (0%)	413	675	1298	4/8 (50%)	0,14	0,40	0,78	8/8 (100%)	8/8 (100%)
2	0,74	1,42	2,67	0/9 (0%)	867	1258	1628	9/9 (100%)	0,00	0,60	1,32	8/9 (89%)	9/9 (100%)
3	0,30	1,09	3,10	0/8 (0%)	424	813	1664	5/8 (63%)	0,23	1,34	3,62	8/8 (100%)	8/8 (100%)
4	0,52	0,92	1,45	0/12 (0%)	105	661	1133	6/12 (50%)	0,01	0,76	1,53	11/12 (92%)	11/12 (92%)
5	0,25	0,36	0,44	0/3 (0%)	367	602	1040	1/3 (33%)	0,24	0,93	2,15	3/3(100%)	3/3 (100%)
6	0,14	0,57	1,15	0/11 (0%)	396	598	846	5/11 (45%)	0,05	0,60	1,68	11/11 (100%)	11/11 (100%)
7	0,28	0,88	1,70	0/7 (0%)	446	833	1373	4/7 (57%)	0,02	0,74	2,55	4/7 (57%)	5/7 (71%)
8	0,19	0,32	0,61	0/10 (0%)	363	576	786	7/10 (70%)	0,02	0,08	0,21	9/10 (90%)	9/10 (90%)
9	1,27	1,70	2,25	0/8 (0%)	408	600	1246	3/8 (38%)	0,58	1,28	2,29	8/8 (100%)	8/8 (100%)
10	3,80	4,08	4,47	0/7 (0%)	772	1070	1873	7/7 (100%)	1,42	2,45	5,34	7/7 (100%)	7/7 (100%)
Sum				0/83 (0%)				51/83 (61%)				77/83 (93%)	79/83 (95%)

Regarding the CO_2 concentrations, while the measured values were not considered to impose healthy risks, were measured in high levels related to inadequate ventilation. All CO concentration values were measured below the international limits (concentration limit for CO according to ASHRAE is 9ppm for an eight hour exposure). In 7 out of 10 schools, TVOCs were measured in the classrooms above the recommended limit values.

3.3 Thermal Comfort Conditions

The mean values of the air temperature in the classes, varied in the range of 19.4°C-26.0°C. The majority of the examined school buildings (60%) showed minimum value above 21.0°C and in accordance with the European standard prEN 15251:2006, guarantee an adequate level of thermal comfort. The wet bulb globe temperature is a heat stress indicator that considers the effects of temperature, humidity & radiant energy.

Table 4: WBGT index calculated values

A/α	Minimum WBGT (°C)	Average WBGT (°C)	Maximum WBGT (°C)
1	19	21	22
2	14	15	16
3	21	22	22
4	18	20	21
5	19	21	23
6	19	21	23
7	16	18	19
8	19	21	23
9	22	22	23
10	14	16	18

The average value of the calculated WBGT index was ranged from 15˚C to 22˚C. For the examined schools the WBGT values were lower than the considerate limits (as shown in the Table 4) and therefore persons are not subjected to heat stress.

Table 5: CP index calculated values

A/α	Minimum CP (mcal $cm^{-2}sec^{-1}$)	Average CP (mcal $cm^{-2}sec^{-1}$)	Maximum CP (mcal $cm^{-2}sec^{-1}$)
1	4.30	5.21	5.90
2	6.70	7.07	7.30
3	4.70	5.06	6.10
4	5.30	5.91	7.30
5	4.50	5.20	6.20
6	3.80	4.55	5.70
7	5.80	6.27	7.10
8	4.00	4.78	5.90
9	4.00	4.70	6.40
10	6.60	7.36	8.20

The cooling power calculated values was varied in the range 4.6-7.4mcal*cm^{-2}*sec^{-1} of irritating warm environment to tolerable cold environment, with the majority of the mean values in the range of adequate warm environment (see Table 5).
The same period the outdoor air temperature was varied in the range of 17.5°C-27.5°C. A comparison of the measurements has shown that the mean indoor air temperature did not differ significantly from the corresponding values in the external environment. This is an indication of insufficient heating due to a grade and continuous opening of windows which generates thermal energy losses.

4 CONCLUDING REMARKS

The main objectives of this research included the assessment of energy conservation potentials in schools in view of the environmental quality issues. The research has shown that school buildings feature indoor air quality problems while their energy consumption and global environmental quality could be improved significantly. The energy consumption of school buildings may be reduced up to 50 % with simple energy measures (great potential for energy conservation).The conclusions obtained endorse a general energy evaluation for space heating for the Greek school buildings. The clustering in five classes could be used for energy saving techniques applied from the decision makers.

5 ACKNOWLEDGEMENTS

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