Energy audit certification and environmental evaluation of school buildings

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ABSTRACT

The present paper presents the results of the energy and environmental evaluation of ten school buildings in the Greater Athens Area. The research included measurements of the indoor air quality, evaluation of the situation of the building envelope, recording of energy and ventilation systems and generally all the systems that influence the energy output of the school buildings. Experimental investigations were performed in ten different schools and the concentration levels of CO_2, CO and VOC's were measured. The analysis of the educational buildings included measurements of several environmental parameters such as temperature, relative humidity and air velocity inside each classroom, while ventilation was examined by estimating the air changes using the tracer gas technique. The thermal comfort conditions have been calculated using two different thermal comfort bioclimatic indices developed to be used for indoor spaces. The investigation of the above parameters was assessed in relation to the energy consumption of the school buildings. Finally the energy performance of school buildings was rated using a kmeans clustering technique.

KEYWORDS

Energy performance, indoor air quality, thermal comfort, school buildings

1. INTRODUCTION

Energy efficiency, indoor air quality and thermal comfort conditions are the three main factors influencing the school buildings environment (Argiriou et al., 1994; Papadopoulos and Avgelis, 2003).

The concentration levels of various pollutants such as CO_2, CO, HCHO were measured in ten school buildings located in the Greater Athens Area and the results were presented and analyzed in (Synnefa et al., 2003). The experimental investigation included measurements of several environmental parameters such as temperature, relative humidity and air velocity inside each classroom while ventilation was examined by estimating the air changes using the tracer gas technique. In order to evaluate the energy performance of the school buildings, the energy consumed for heating, cooling, lighting, mechanical and electrical systems, has been measured and analysed. The thermal behaviour has also been simulated using a dynamic simulation program and various energy conservation scenarios have been proposed in order to improve the buildings' energy efficiency. Finally, the thermal comfort conditions have been calculated using a thermal comfort bioclimatic index developed to be used for indoor and outdoor spaces.

2. SCHOOL BUILDINGS' DESCRIPTION

Measurements were carried out in ten school buildings. Seven of them are located at the centre of Athens while the remaining three school buildings in the Greater Athens Area. Various classrooms in each school building were provided for measuring the indoor air quality. All measurements were performed during the month of October and November 2004. All ten schools were equipped with central heating systems for

Table 1: Description of the ten school buildings.

A/a	Year of Construction	Number of students	Number of Classrooms	Working hours
1	1980	100	20	8:00-20:00
2	1981	215	11	8:00-16:00
3	1980	200	7	8:00-20:00
4	1980	260	12	8:00-22:00
5	1989	297	12	8:00-14:00
6	1980	210	13	8:00-17:30
7	1979	218	11	8:00-19:00
8	1980	140	6	8:00-16:00
9	1985	280	7	8:00-16:00
10	1982 & 1996	340	19	8:00-14:00 & 18:30-23:30

the winter period.

Table 1 shows a brief description of the ten experimented school buildings.

3. RESULTS AND DISCUSSION

3.1 Analysis of physical parameters

In Tables 2 and 3 can be seen the minimum, maximum, and mean measured indoor air temperature and relatively humidity values respectively for the ten school buildings as well as the mean ambient air temperature and the relative humidity. As shown, the mean indoor temperature and relative humidity values do not present significant differences from those of the ambient air. However, the maximum indoor relative humidity values are in some cases remarkably

Table 2: Minimum, mean and maximum measured indoor air temperature values for the ten school buildings.

A/a	Minimum indoor air temperature, (°C)	Mean indoor air temperature, (°C)	Maximum indoor air temperature, (°C)	Mean ambient air temperature, (°C)
1	23.0	25.8	27.2	27.5
2	19.5	20.2	21.0	19.0
3	20.1	21.9	23.0	17.5
4	22.0	24.4	26.1	23.5
5	22.6	25.3	27.1	26.7
6	19.3	22.7	24.3	21.1
7	17.3	19.4	21.1	19.0
8	23.0	24.5	26.5	23.0
9	22.0	24.7	25.7	25.7
10	23.3	26.0	27.8	26.9

Table 3: Minimum, mean and maximum measured indoor relative humidity values for the ten school buildings.

A/a	Minimum indoor relative humidity, (%)	Mean indoor relative humidity, (%)	Maximum indoor relative humidity, (%)	Mean ambient relative humidity, (%)
1	60	66	76	57
2	40	43	48	24
3	51	53	56	49
4	56	65	70	59
5	47	57	66	42
6	61	66	75	63
7	56	61	69	54
8	54	60	70	59
9	60	68	86	52
10	50	53	57	48

Table 4: Minimum, mean and maximum measured indoor air velocity values for the ten school buildings.

A/a	Minimum indoor air velocity, (m/sec)	Mean indoor air velocity, (m/sec)	Maximum indoor air velocity, (m/sec)
1	0.07	0.18	0.60
2	0.05	0.15	0.31
3	0.07	0.10	0.17
4	0.05	0.07	0.10
5	0.05	0.09	0.20
6	0.01	0.09	0.30
7	0.03	0.10	0.25
8	0.07	0.12	0.20
9	0.00	0.12	0.31
10	0.05	0.13	0.23

higher than those of the ambient environment, while frequently exceed the 65%, which is a limit value for achieving thermal comfort conditions. The observed high indoor relative humidity values could be related to condensations in the building shell.

In Table 4 it can be seen the mean, maximum and minimum measured indoor air velocity values for the ten school buildings. The mean indoor air velocity values could be regarded as acceptable. However, the maximum values in several cases are considered to be significantly high and they do not contribute to the achievement of thermal comfort conditions.

3.2 Analysis of chemical parameters

Measurements of the most important pollutants

Table 5: Minimum, mean and maximum measured CO_2 concentration values for the ten school buildings.

A/a	Minimum CO_2 concentration, (ppm)	Mean CO_2 concentration, (ppm)	Maximum CO_2 concentration, (ppm)	Percentage of classrooms in which concentrations are higher than the limit, (%)
1	408	600	1246	38
2	867	1258	1628	100
3	446	833	1373	57
4	367	602	1040	33
5	363	576	786	70
6	105	661	1133	50
7	772	1070	1873	100
8	413	675	1298	50
9	424	813	1664	100
10	396	598	846	45

Table 6: Minimum, mean and maximum measured CO concentration values for the ten school buildings.

A/a	Minimum CO concentration, (ppm)	Mean CO concentration, (ppm)	Maximum CO concentration, (ppm)	Percentage of classrooms in which concentrations are higher than the limit, (%)
1	1.27	1.70	2.25	0
2	0.74	1.42	2.67	0
3	0.28	0.88	1.70	0
4	0.25	0.36	0.44	0
5	0.19	0.32	0.61	0
6	0.52	0.92	1.45	0
7	3.80	4.08	4.47	0
8	0.28	0.67	1.05	0
9	0.30	1.09	3.10	0
10	0.14	0.57	1.15	0

concentration levels were carried out. Thus, the concentration levels of CO_2, CO and VOCs have been measured in the classrooms of the ten investigated schools. Analytically:

For CO_2: Table 5 shows the minimum, mean and maximum CO_2 concentration values for the ten school buildings. There is also the percentage of each school classrooms where the concentrations are higher than the health and comfort limit. This limit according to ASHRAE is 1001 ppm for an eight hours continuous exposure. However, CO_2 concentration values higher than 600 ppm are usually regarded as nearly the limit. As shown, the CO_2 concentration values are very close or higher than the limit ones. The inadequate ventilation mainly causes this. All measured values of CO_2 are not considered to impose healthy risks, however, the observed CO_2 concentration values can be responsible for a serious reduction of productivity and mental activity, which are very important especially in schools.

For CO: In Table 6 it can be seen the minimum, mean and maximum CO concentration values for the ten school buildings. As shown, the maximum measured value in all classrooms was equal to 4.47 ppm, a value much lower than the limit of 35 ppm of ASHRAE, the limit of 26 ppm defined by WHO, (World Health Organisation), or the limit of 50 ppm recommended by the Technical Chamber of Greece. Thus, it was not observed any risk for the health of students and staff.

For VOCs: Table 7 shows the minimum, mean and maximum VOCs concentration values for the ten school buildings as well as the percentage of each school classrooms where the concentrations are higher than the health and comfort limit. As shown, the maximum concentration values fluctuated between 0.21 and 5.34 ppm. VOCs concentration levels between 0.80 and 6.64 ppm could be responsible for some health problems such as headaches. Concentrations above the limit of 6.64 ppm could cause

Table 7: Minimum, mean and maximum measured VOCs concentration values for the ten school buildings.

A/a	Minimum VOCs concentration, (ppm)	Mean VOCs concentration, (ppm)	Maximum VOCs concentration, (ppm)	Percentage of classrooms in which concentrations are higher than the limit, (%)
1	0.58	1.28	2.29	100
2	0.0	0.60	1.32	100
3	0.02	0.74	2.55	71
4	0.24	0.93	2.15	100
5	0.02	0.08	0.21	90
6	0.01	0.76	1.53	92
7	1.42	2.45	5.34	100
8	0.14	0.40	0.78	100
9	0.23	1.34	3.62	100
10	0.05	0.60	1.68	100

more serious than headaches neurological problems.

3.3 Ventilation measurements

All measurements of the natural ventilation were performed using the tracer decay method. From the measurements the air changes per hour (ACH), have been calculated for all investigated areas. Table 8 presents the results of the experimental investigation concerning the air changes per hour for various experimented classrooms of the ten school buildings for infiltration and for natural ventilation. Values in bold are considered being insufficient ventilation rates.

Table 8: Infiltration and natural ventilation levels, in ACH, in various classrooms of the ten investigated school building.

A/a	Infiltration (ACH)	Infiltration & natural ventilation (ACH)
1 Classroom 1	0.1	3.5
1 Classroom 2	0.2	2.8
2 Classroom 1	0.4	9.0
3 Classroom 1	1.2	4.6
3 Classroom 2	1.9	6.9
4 Classroom 1	0.1	7.4
5 Classroom 1	0.2	1.7
5 Classroom 2	0.3	3.8
6 Classroom 1	0.9	7.3
6 Classroom 2	0.3	2.4
7 Classroom 1	0.5	12.1
7 Classroom 2	0.9	10.2
8 Classroom 1	1.3	5.9
8 Classroom 2	6.2	11.7
9 Classroom 1	0.4	1.3
9 Classroom 2	0.4	1.4
10 Classroom 1	0.3	2.0
10 Classroom 2	0.2	4.8

Table 9: The WBGT-index criterion of heat stress warning specified in order to prevent heat stroke.

WBGT [°C]	Types of warning and required rest
Below 21	Safe (needs occasional supply of water)
21 - 25	Note (needs immediate supply of water)
25 - 28	Caution (needs to take rest)
28 - 31	Warning (Stop active physical exercise)
Above 31	Dangerous (Cancel physical exercise)

3.4 Thermal comfort conditions investigation

Human thermal comfort is defined as a condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 1997), the person would prefer neither warmer nor cooler surroundings, (Fanger, 1972). In the present research the thermal comfort conditions have been investigated using the wet-bulb globe temperature index, which is a heat stress indicator that considers the effects of temperature, humidity and radiant energy.

Wet Bulb Globe Temperature (WBGT) is commonly used as guidance for environmental heat stress to prevent heat stroke during physical exercise or while at work.

The wet bulb globe temperature is calculated using the following equations (Aynsley and Spruill, 1990):

- For outdoor environment with direct sun exposure:

$$WBGT=0.7*T_w+0.2*T_g+0.1*T_{air}$$

- For indoor environment or outdoor without direct sun exposure:

$$WBGT=0.7*T_w+0.3*T_g$$

where: T_w is the wet bulb temperature, T_g is the temperature measured using a black globe thermometer and T_{air} is the ambient air temperature (conventional thermometer). All temperatures should be expressed in °C.

Table 9 shows the WBGT-index criterion of heat stress warning specified in order to prevent heat stroke. WBGT index has been calculated for the ten examined school buildings. In Table 10 it can be seen the minimum, mean and maximum values of the calculated index for the ten school buildings. As shown, all values are lower than the considered limits, thus, the occupants of the investigated buildings do not experience any heat stress.

3.5 Energy performance investigation

Furthermore, the energy behaviour of the ten school buildings was calculated using the transient simulation program TRNSYS (TRNSYS, 2002). These calculations aim primarily at the buildings energy evaluation and assessment and secondly at improving the thermal comfort conditions and minimizing the energy consumption

Table 10: Minimum, mean and maximum WBGT-index values for the ten school buildings.

School Number	Minimum WBGT, (°C)	Mean WBGT, (°C)	Maximum WBGT, (°C)
1	22	22	23
2	14	15	16
3	16	18	19
4	19	21	23
5	19	21	23
6	18	20	21
7	14	16	18
8	19	21	22
9	21	22	22
10	19	21	22

especially during the heating period of the year, as school buildings are not occupied during the months of July and August. Energy calculations were performed for the whole set of the ten school buildings using hourly values of climatic data for the city of Athens and for one year. The main inputs to the model were the following:

- The construction elements of the ten school buildings: which mainly are the materials of the external and internal walls, of the roof and floor as well as the openings.
- The geometric elements of the examined buildings including dimensions and orientations
- The climatic data including air temperature, relative humidity, solar radiation, and wind velocity
- The internal gains including lighting, occupancy and electric equipment.
- Infiltration and ventilation of the each building.

The main output is the energy consumption, (heating and cooling load), of the building in kWh/m^2. Primarily, the thermal performance of the ten buildings in their existing situation was simulated. Figure 1 shows the calculated energy consumption values, (heating and cooling load), of the ten schools in their existing situation. These values represent the heating load and the cooling load that corresponds to the months of May, June, and September, (July and August schools are closed). As it can be seen the heating load varied in the range of 22.3 to 50.7 kWh/m^2 while the cooling load fluctuated between 6.9 and 18.9 kWh/m^2. In order to improve thermal comfort conditions and to reduce the energy consumption levels several improving scenarios have been proposed.

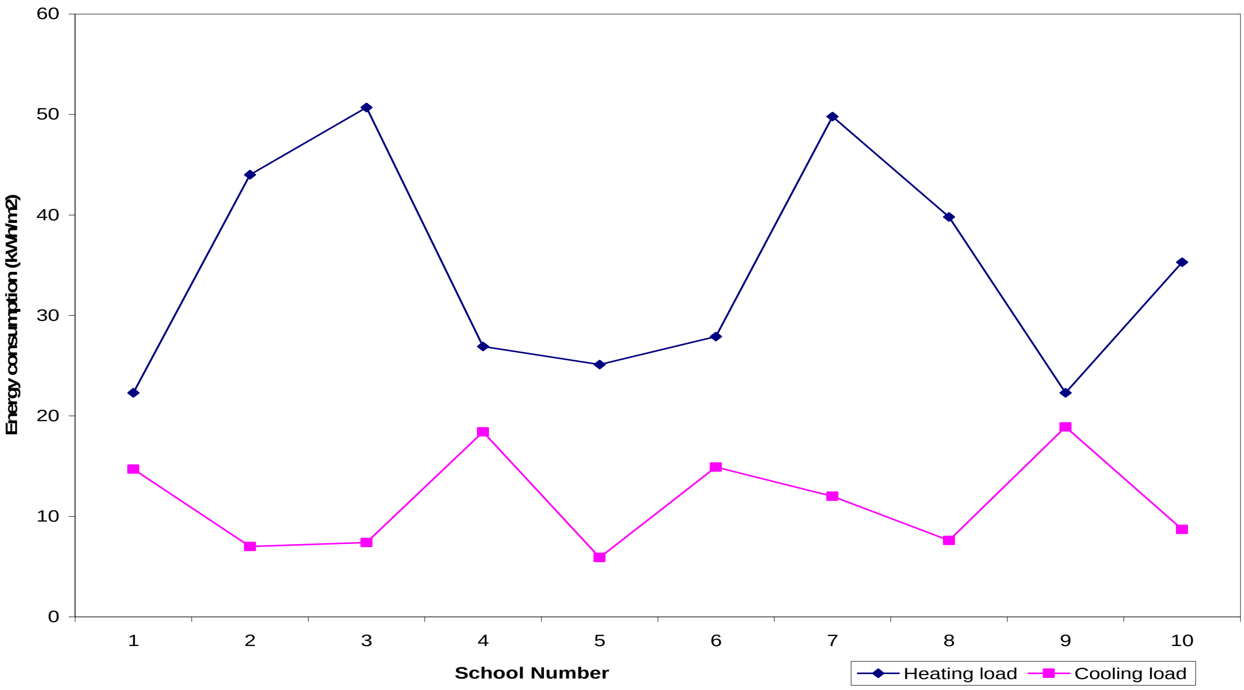

Figure 1: Energy consumption values for heating and cooling for the ten investigated school buildings in their existing situation.

4. CONCLUDING REMARKS

The indoor air quality, the energy behaviour and the thermal comfort conditions in ten school buildings, located in the greater Athens area, were investigated in the present paper. The main concluding remarks from the above research are the following:

Regarding the indoor air quality, the CO_2 concentration values are usually higher than the comfort limit values. The CO concentrations are lower than the limit and do not present any danger for the occupants health. VOCs concentrations are, in a high percentage, higher than the limits. Moreover, ventilation levels are insufficient.

As regards the thermal behavior, the ten investigated school buildings were simulated using a dynamic simulation program, in order to calculate the buildings' energy consumption. After calculating the energy consumption various improvements were proposed and the energy saving was estimated. Improving scenarios such as external walls and roof insulation, ceiling fan, and night ventilation present a significant contribution to the energy consumption reduction.

The WBGT-index was used for calculating the thermal comfort conditions inside the classrooms. From the calculations it was found that the thermal comfort values were lower than the considered limits.

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