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Thermal comfort of a typical secondary school building in Cyprus

Martha C. Katafygiotou*, Despina K. Serghides[1]

Cyprus University of Technology, Department of Environmental Science and Technology, 33 Anexartisias Street, 1st Floor, P.C. 3036, Limassol, Cyprus

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ABSTRACT

A field study is conducted in a secondary school building in Cyprus, to assess the indoor thermal conditions during the students' lesson hours. The survey is carried out in Neapolis Gymnasium which is a typical Cypriot school located in the coastal city of Limassol. Requirements for comfort are critical especially to pupils' performance and welfare.

Classrooms, laboratories and administrative offices are chosen for investigation of indoor and outdoor thermal conditions. Air temperature (AT) and relative humidity (RH) are monitored using indoor and outdoor sensors simultaneously throughout the four seasons of the year. Data analysis compares the results with international standards, ASHRAE Standard 55, ISO Standard 7730, etc.

Thermal comfort variables are measured at the same time when students and teachers completed a questionnaire which focuses on their perception of the indoor climate. Fanger's comfort indicators are calculated (PMV, predicted mean vote and PPD, predicted percentage of dissatisfied people) and the actual people clothing and metabolic rate are estimated in order to conclude to the prevailing indoor thermal conditions of the school.

1. Introduction

The indoor air quality and comfort is a major problem in the developed and industrialized countries. According to several studies in industrialized countries people spend an average of 80–90% of their time in indoor environments Dascalaki and Sermpetzoglou (2011). Therefore the quality control of the indoor environment depends on thermal, visual and air quality parameters. The indoor comfort of buildings is a result of the interaction between the climate, the region and the structural elements of buildings, the heating-ventilation-air-conditioning systems of buildings, several infectious sources and the users' behavior (Article in Greek, 2011).

The importance of maintaining adequate indoor air quality and mostly thermal comfort especially in schools is recognized as being a contributing factor to the learning performance of pupils (Fisk, 2000; Synnefa et al., 2003). Recently, a study based on both a subjective questionnaire survey and objective test scores concluded that learning performance improved with a decrease in the percentage of pupils dissatisfied with the indoor air environment (Mumovic et al., 2009). Another study, based on five independent experiments carried out in mechanically ventilated classrooms, concluded that improving classroom conditions should be an urgent educational priority (Wargocki & Wyon, 2006).

Thermal comfort is a significant factor of the indoor environment, not only because of the comfort sensation that the occupants feel, but also because it is related to the energy consumption of a building, which influences its sustainability (Nicol & Humphreys, 2002). Proper design of school buildings requires the balance of the thermal performance and an acceptable quality of the indoor climate conditions (Allard & Santamouris, 1998). The construction of schools is a major priority in most societies; it is also a complex task since the running costs of heating, cooling, and ventilation seem far less important than the achieved indoor environmental comfort due to the vulnerability of their occupants' health, well-being and ability for attendance. The design of a building determines the environmental comfort conditions and its energy efficiency. Bernardi and Kowaltowski (2006) said that these conditions are also influenced by the activities performed by the occupants and their clothing. To attain ideal comfort conditions, the users' behavior in relation to the environment and spontaneous adjustments to the environment are imperative factors. Buildings are not merely containers in which people act like robots and are placed to receive their thermal effects. There is a dynamic dialog between building

* Corresponding author. Tel.: +357 25002195.
E-mail addresses: martha.katafygiotou@cut.ac.cy, katafiyiotou_martha@hotmail.com (M.C. Katafygiotou), despina.serghides@cut.ac.cy (D.K. Serghides).
[1] Tel.: +357 25002341.

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controls and building use. Furthermore, for the Mediterranean climate it is necessary that some of the employed passive systems for their optimization must be activated by the users in order to be effective (Serghides, 2008).

School buildings constitute a rather special case of building (Theodosiou & Ordoumpozanis, 2008). Thermal conditions in classrooms have to be considered carefully mainly because of the high occupant density in classrooms and because of the negative influences that an unsatisfactory thermal environment has on learning and performance (Coley, Greeves, & Saxby, 2007; Fisk, 2000). Specifically comfort conditions affect users physically as well as psychologically and consequently they have an impact on the performance of their activities. An interesting review of the first scientific studies about the effects of the thermal quality on the students' performances in classrooms is given in the study of Pepler and Warner (1968). As Faustman, Silbernagel, Fenske, Burbacher, and Ponce (2000) stated, indoor environments in schools have been of particular public concern since children have greater vulnerability to some environmental pollutants than adults, because they breathe higher volumes of air relative to their body weights and their tissues and organs are actively rowing. It is also worth mentioning that children spend more time in school environment than at home and therefore the environmental conditions of schools are considerably important. However in many countries, including Cyprus, school buildings are sometimes designed and constructed almost like any other building type with very little attention to the indoor environment. As Mendell and Heath (2005) published, this situation can easily lead to an improper school building environment and a poor indoor quality. Many studies are investigating the thermal perception of pupils and the indoor climatic conditions in classrooms. Liang, Lin, and Hwang (2012) and also Sfakianaki et al. (2011) proved that building envelope design has a high impact on indoor thermal conditions in naturally ventilated spaces. Moreover through Santamouris et al. (2008) studies it is established that there is a statistically significant relation between window opening and the indoor–outdoor temperature difference.

Thermal comfort is one of the most important parameters of the indoor quality and is defined through ISO Standard 7730 (1994, 2005) and ASHRAE Standard 55 (2010) as the state of mind that expresses satisfaction with the thermal environment in which it is located. These standards present the appropriate conditions for obtaining thermal comfort conditions under thermal equilibrium between the human body and the environment. Thermal comfort is affected by heat, conduction, radiation and heat losses by evaporation. Six factors are influencing the thermal comfort of humans, four of which are environmental (physical parameters) and two personal factors. The environmental factors are the air temperature, the mean radiant temperature, the air velocity and the air humidity. Personal factors are the metabolic rate of the human and the insulation through clothing. All these processes are based on the combustion, i.e. energy production based on food processing. The human body has a very effective system of regulating the temperature, which is constant at about 37 °C. However the environment in which people are living has in most cases lower temperatures and during summer higher ones. Catalina and Iordache (2012) mentioned that all these aspects of the indoor environment interact and may have consequences on the overall indoor comfort and building energy consumption. In order to characterize thermal conditions of an indoor space, Fanger (1970) developed a model which is based on the PMV and PPD indicators. Predicted mean vote (PMV) is the average comfort vote, using a seven-point thermal sensation scale from cold (−3) to hot (+3) as it is referred on the ASHRAE 55 Standard (2004, 2010). The PMV zero is the ideal value, representing thermal neutrality. This model was originally developed by collecting data from a large number of surveys on people subjected to different conditions within a climate chamber. Predicted percentage of dissatisfied people PPD is related to the PMV as is defined as an indicator that establishes a quantitative prediction of the thermally dissatisfied people. The model is also based on the simplification that PPD is symmetric around a neutral PMV (Papadopoulos, Oxizidis, & Papandritsas, 2008). The PPD indicator is associated with the PMV using Eq. (1) or a diagram which will presented in the following results

$$\mathrm{PPD} = 100 - 95\exp(-0.335\,\mathrm{PMV4} - 0.217\,\mathrm{PMV2}) \quad (1)$$

People have different metabolic rates that can fluctuate due to activity level and environmental conditions. The ASHRAE Standard 55 (2010) defines metabolic rate as the level of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface. Metabolic rate is expressed in met units, which are defined as 1 met = 58.2 W/m^2, which is equal to the energy produced per unit surface area of an average person seated at rest. The surface area of an average person is 1.8 m^2. ASHRAE Standard 55 provides a table of met rates for a variety of activities. Some common values are 0.7 met for sleeping, 1.0 met for a seated and quiet position, 1.2–1.4 met for light activities standing, 2.0 met or more for activities that involve movement, walking, lifting heavy loads or operating machinery. For intermittent activity, the Standard states that is permissible to use a time-weighted average metabolic rate if individuals are performing activities that vary over a period of one hour or less.

Concerning the clothing, the layers of insulating clothing can either help keep a person warm or, at the same time, in case of high physical activity, prevent heat loss or possibly lead to overheating. The amount of thermal insulation worn by a person has a substantial impact on thermal comfort, because it influences the heat loss and consequently the thermal balance. Layers of insulating clothing prevent heat loss and can either help keep a person warm or lead to overheating. Generally, the thicker the garment is, the greater insulating ability it has. Depending on the type of material the clothing is made out of, air movement and relative humidity can decrease the insulating ability of the material.

Clothing insulation is expressed in Clo units where 1 Clo corresponds to an *R*-value of 0.88 F ft^2 h/Btu. The ASHRAE Standard 55 (2004, 2010) contains tables with more information about clothing levels for common ensembles or single garments.

The current literature presents the indoor environmental quality assessment based on field surveys and questionnaires' campaigns applied in existing buildings (Cheong et al., 2003; Mumovic et al., 2009). Thermal comfort of schools is significant since it is correlates with the energy efficiency of the building; the wicked energy efficiency of a school building due to the lack of insulation or the absence of windows' airtightness always affects the indoor thermal comfort of users. One of the greatest challenges of modern design is to create thermally comfortable environments in the buildings through studying in detail all the factors that contribute to it. The goal is to achieve indoor thermal comfort with the least possible energy expenditure.

2. Methodology

In order to examine the thermal comfort in school buildings, a typical secondary school is selected. Neapolis Gymnasium is selected as a representative school and therefore its results may provide useful information for the majority of schools in Cyprus. This typical school consists from most common constructural, heating and cooling characteristics. Neapolis Gymnasium is considered as a typical and representative school as this is derived from previous studies (Katafygiotou & Serghides, 2013). Preliminary data are collected regarding the architectural, mechanical and operational