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Effects of thermal activated building systems in schools on thermal comfort in winter

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ABSTRACT

There is a growing attention for the Indoor Air Quality problems in schools, but there is far less attention for the thermal comfort aspects within schools. A literature review is done to clear the effects of thermal quality in schools on the learning performance of the students: it clearly shows that thermal environment is like IAQ of great influence to the students' performance. As many studies focus on the ventilation aspects we focus more on the thermal comfort of the schools through measurements and questioners held in 14 schools equipped with different types of ventilation and heating systems.

A new approach to design adequate thermal comfort solutions for school buildings was developed during the last years: Thermo Active Building Systems, which uses thermo activated concrete. In three new schools with Thermo Active Building Systems thermal comfort was determined through measurements and questionnaires and compared with that of 11 schools more traditional heating systems

1. Introduction

1.1. Effects of classroom temperature on students' performance

Indoor Air Quality and thermal climate in schools are problematic in many countries [3,5,9,17,21,22,27,28]. For Indoor Air Quality there is more and more attention, but often there is little or no focus on the thermal climate in schools [5,18]. There is good evidence from literature that moderate changes in room temperature, even within the comfort zone, effect student's abilities to perform mental tasks requiring concentration, such as addition, multiplication, and sentence comprehension. Overall, warm temperatures tend to reduce performance, while colder temperatures reduce manual dexterity and speed. Many studies have revealed that the thermal environment in the classroom will affect the ability of students to grasp instruction.

1.2. Historical overview studies on thermal comfort in classrooms and its effects

Jago and Tanner [13] made a short historical overview and found that already in 1931 the New York State Commision on Ventilation [23] conducted major investigations into the physiological and psychological reactions to various atmospheric conditions by school children in classroom settings. Some of their findings showed that temperatures above 23,9 °C produced such harmful effects as increased respiration, decreased amount of physical work, and conditions favourable to disease.

According to Schneider [25], McGuffey [20] was one of the first to synthesize existing work linking heating and air conditioning to learning conditions. Schneider [25] also mentions the research by King and Marans [15] who found that as temperature and humidity increase, students report greater discomfort, and their achievement and task-performance deteriorate as attention spans decrease. Cooler classrooms created increased feelings of comfort, activity and productivity.

In [6] a summary is given of the effects of temperature for student performance, based on studies by Levin [19], Wyon et al. [35] and Wargocki et al. [31].

The results of the 'historic' studies summarized above suggest that increased classroom temperatures can have negative effects on the performance of schoolwork by children.

A more recent study is by Wargocki and Wyon [33] who determined whether avoiding elevated temperatures in classrooms can improve the performance of schoolwork by children, and if so, by how much. They concluded that reducing moderately high classroom air temperatures in late summer from the region of 25 °C to 20 °C by providing sufficient cooling, improved the performance of students on two numerical tasks and two language-based tasks resembling schoolwork. Improvement mainly occurred in terms of

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the speed with which these tasks were performed, with almost no effects on errors. A fairly good agreement in terms of the effects on performance was obtained between two independent experiments, in which children's thermal sensation decreased from slightly too warm to neutral, carried out one year apart. In addition, their experiments investigated the effects of increased outdoor air supply rate on the performance of schoolwork by children as a continuation of two other experiments in the same series, reported in a separate paper by Wargocki and Wyon [34]. Their results both confirm and supplement the findings of thermal effects on children's schoolwork performance that were obtained in the above mentioned studies about thermal effects on school performance in the moderate temperature range.

The observed effects of increased ventilation rate and reduced temperature on the performance of schoolwork by children by Wargocki and Wyon [33] are larger than reported effects on the performance of office work by adults [36,37]. They conclude that this indicates that children may be more susceptible than adults to environmental conditions. The observed difference between adults and children though might also occur because adults are expected to overcome the negative effects of indoor environmental conditions to meet deadlines [32].

1.3. The need for new heating systems for schools

In 1996 a nationwide, on-line web-based survey was held to inform about the indoor climate related aspects of schools in the United States by Sonne et al. [29]. There were 239 total respondents (0.25% response rate). More than fifty percent (50.5%) of the respondents indicated "many" or "chronic" problems. At 22.5% of respondents, temperature was by far the greatest cause of chronic complaints, followed by IAQ, humidity and odors see Fig. 1.

As stated by (Wargocki and Wyon [32]) unsuitably high temperatures are quite common in classrooms not only in summer but sometimes also in autumn or winter, even those in northern 'cold' areas. The most common reason for such high temperatures is that classroom ventilation rates are too low to remove the excess heat load caused by sunshine entering the windows. Traditionally the windows are designed to provide as much daylight as possible, with large glazed areas facing the sun. Many schools have only natural ventilation, due to wind and outside cold windows often must remain closed to prevent draft. So surprisingly in winter thermal conditions in schools can be a problem. This is why new system designs for heating of schools are investigated whether they improve the present thermal comfort situation in school buildings.

Normally heating in schools is by convection through panel heating. An alternative is to provide heating through a combination of radiation and convection. This strategy uses warm surfaces to heat the air and the space enclosed. Systems based on this strategy are often called Radiant Heating Systems. If heating of the surfaces is done by using water as heat exchange medium, they are called Hydronic Radiant Heating Systems (HRH Systems) or Thermo Active Building Systems (TABS) [16].

By providing heating to the space surfaces rather than directly to the air, TABS allow separation of ventilation and thermal space conditioning. While the primary air distribution is used to fulfill ventilation requirements for a high level of indoor air quality, the secondary water distribution system provides thermal conditioning to the building. Basis of TABS systems is the idea of a floor heating system with tubes imbedded in the core of a concrete ceiling. See Fig. 2.

While there are many examples of TABS installations in commercial office buildings [30], there have been reported very few examples of applications in schools. This paper will focus on the thermal comfort resulting from the application of TABS in classrooms.

2. Methodology

The objects of study were primary schools in the Netherlands. The thermal indoor environmental quality of schools with TABS is compared to that of more traditional schools. Many different heating and ventilation systems are used in schools, with as mostly used traditional solution panel heating with natural supply with mechanical exhaust of air. The goal of our first study was to evaluate the performance of exhaust-only ventilation systems. In 5 Dutch schools measurements were conducted in the heating season for a period of around 7 days. These measurements included: IAQ (CO_2), thermal comfort, airflow and outdoor conditions. A logbook and questionnaires obtained information about use of ventilation facilities and satisfaction of users [14]. In a following study, 6 schools with different ventilation systems were studied, to search for concepts, which had fewer problems [2]. The aim of the study was to investigate the thermal environmental quality in school classrooms in general and compare this with the thermal environment quality in school classrooms with TABS by means of both an objective (by measurements of specific parameters) and a more subjective approach (by questionnaires). Human thermal comfort is affected by a number of parameters, namely according to Franger's comfort equation, and the respective standard EN ISO 7730 [11]. Underlying the resulting predicted mean vote (PMV) or the predicted percentage dissatisfied (PPD) as indices for thermal comfort quality a comfortable ranges of the six model parameters, air temperature, radiant temperature, relative air velocity, humidity, clothing and activity, are calculated. Several measurements according to NEN-EN-ISO 7726 [12] were done in an office to determine the personal thermal comfort of occupants in relation to the six above mentioned parameters. Also twice a questionnaire was held to get a picture of the perceived thermal comfort of the occupants.

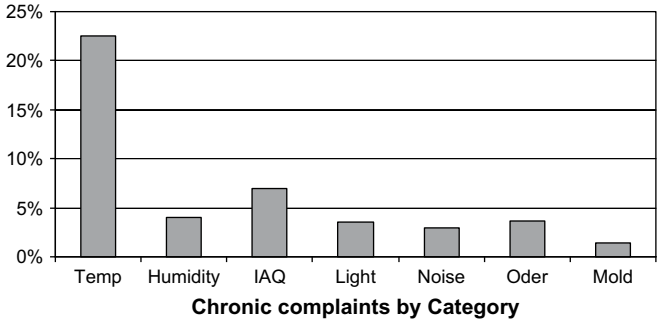

Fig. 1. Chronic complaints by category [29].

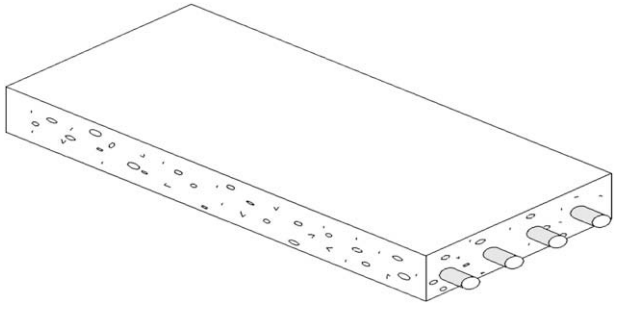

Fig. 2. Concrete core conditioning.