Field study on the performance of hybrid ventilation with HRHC in schools

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ABSTRACT

Optimal indoor air quality, thermal comfort and energy conservation in schools is of great importance. A new development in indoor climate control in schools is hydronic radiant heating and cooling (HRHC). This system uses building mass to heat and cool the building. Water filled pipes are embedded in the core of the concrete slab. Water near comfort temperature is used. Slow accumulation of concrete results in small adaptation possibilities in order to meet the needs of users. Research has shown that the storage capacity of the concrete is in principal more than enough to maintain comfortable room temperature. While there are many examples of HRHC in commercial office buildings available, very little has been reported about school applications. The objective of the research is examining thermal comfort where obtained with HRAC. Measurements were done in three schools.

1. INTRODUCTION

Normally the heating in schools is done by panel heating. An alternative is to provide the heating through a combination of radiation and convection inside the building. This strategy uses warm surfaces in a conditioned space to heat the air and the space enclosures. The systems based on this strategy are often called Radiative Heating Systems. If the heating of the surfaces is produced using water as transport medium, the resulting systems are called Hydronic Radiant Heating Systems (HRH Systems). Different names are given to the system; Thermally activated building systems or parts or components (TABS), concrete core conditioning (Koschenz, 1999), thermo active core systems (TACS). In Dutch, the name betonkernactivering or bouwdeelactivering is used primarily. In the Netherlands, different recommendations are made for designing indoor climate. By providing heating to the space surfaces rather than directly to the air, HRH Systems allow the separation of the tasks of ventilation and thermal space conditioning. While the primary air distribution is used to fulfill the ventilation requirements for a high level of indoor air quality, the secondary water distribution system provides thermal conditioning to the building. The separation of tasks should not only improve comfort conditions, but should also increases indoor air quality.
HRH Systems use the large surfaces available for heat exchange, usually almost a whole ceiling and sometimes whole vertical walls. Due to the large working heating surfaces the temperature of the heating water has to be only slightly higher than the room temperature. This small temperature difference allows the use of heat pumps with very high coefficient of performance (COP) values, to further reduce the energy requirements.
Basis of HRH systems is the idea of a floor heating system with tubes imbedded in the core of a concrete ceiling, see figure 1. The thermal storage capacity of the ceiling limits the control of this system. Due to the large thermal storage capacity responds of the system to temperature changes is rather slow. This leads to the requirement of relatively low surface temperatures to avoid uncomfortable conditions in the case of fast reduced heating loads. The heating power of the system is therefore limited.

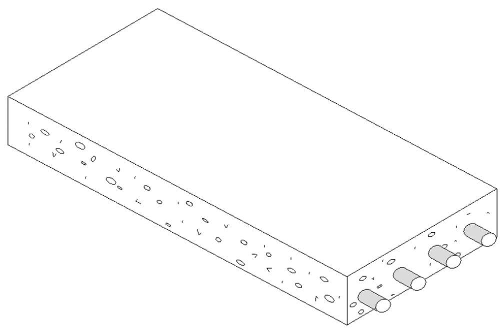

Figure 1: Concrete Core Conditioning

The installation of a floor heating system can also be used to cool the school. Hydronic radiant heating and cooling systems operate with temperatures close to design room air temperatures. When mated with a ground-source heat pump, these systems provide excellent energy efficiency. High heating supply water temperature and low cooling supply water temperature reduce the energy efficiency. While there are many examples of hydronic radiant heating and cooling installations in commercial office buildings available, very little has been reported about school applications.
One of the most dominant features of a school is of course its classrooms with its high occupancy density. This high occupancy density results in a large internal heat sources(up to 3 kW) and necessary extensive ventilation. Natural or controlled ventilation, needed for removing internally generated contaminants, without active heating, is not sufficient for the provision of required thermal comfort conditions. This paper will focus on

the thermal comfort of HRCH in classrooms. Studies of thermal comfort in school buildings are scare (Becker e.al. 2007) and especially about the school with HRCH.

2. METHODOLOGY

The most important research on thermal comfort is done by P. Fanger (Fanger, 1970). The Predicted Mean Vote model (PMV) is the basis of the most important indoor climate standards in Europe (NEN-EN-ISO 7730, 1996) and America (ASHRAE Standard 55, 1992). This model assumes the thermo physiological properties of the human, such as sweat production and heat resistance of the skin. Measurements are done on order to determine what average people consider comfortable. This rate (PMV) is translated into a percentage of people dissatisfied (PPD). The relation is given below (figure 2).

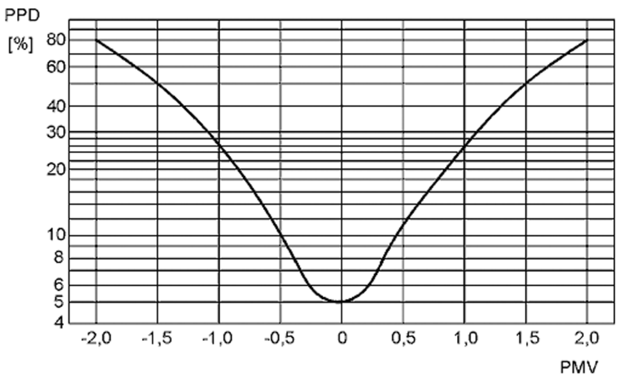

Figure 2: The percentage of people dissatisfied (PPD) as function of the predicted average thermal sensation PMV.

This graph shows that with excellent conditions, a maximum of 95% is satisfied with the indoor climate. The strength of this model is that it gives a clear guideline of what on average is considered comfortable. Dutch guidelines determine a PMV between -0.5 and +0.5. This is shown in the figure below. The clo-value is a standard for the level of insulation of the clothing. A clo-value of 1.0 is considered standard office clothing for men, see figure 3.

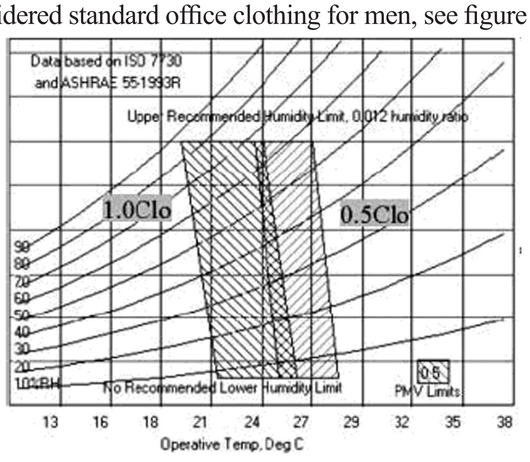

Figure 3: Range of acceptable indoor climate according to Fanger, based on 10% dissatisfied (PMV ±0.5). (Scholten 2006)

3. EXPERIMENTS

In 3 different school buildings with TABS measurements were done and questionnaires held. The characteristics of the different projects are given in figure 4 - 6. During one week all the relevant parameters to calculate the PMV values were determined. In the same period the questionares were held.

Figure 4: School A (Scholten, 2006)

Figure 5: School B (Scholten, 2006)

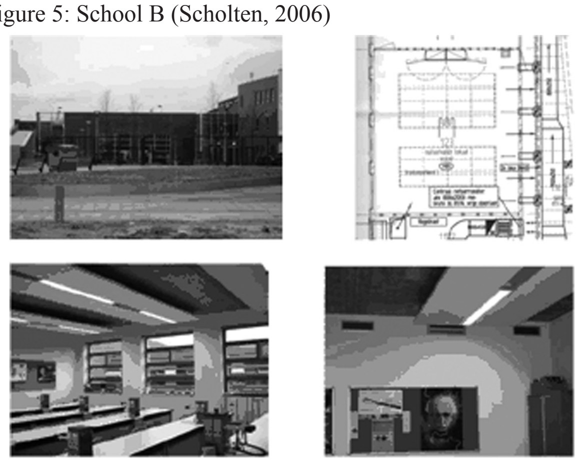

Figure 6: School C (Scholten, 2006)

4. RESULTS

4.1 PMV

PMV(predicted mean value) is calculated during office hours, using metabolic rates of 65 W/m² and clothing value of 1. The frequency of occurrence of PMV value's is given in the figures below for the 3 projects.

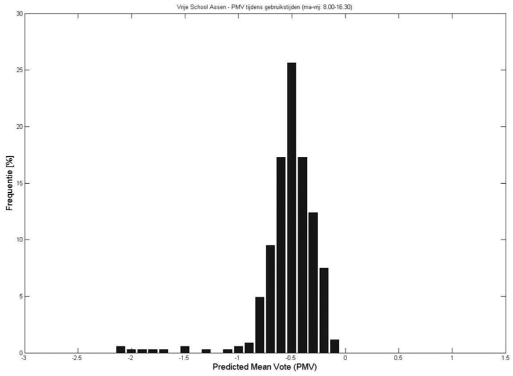

Figure 7: PMV in School A(Scholten, 2006)

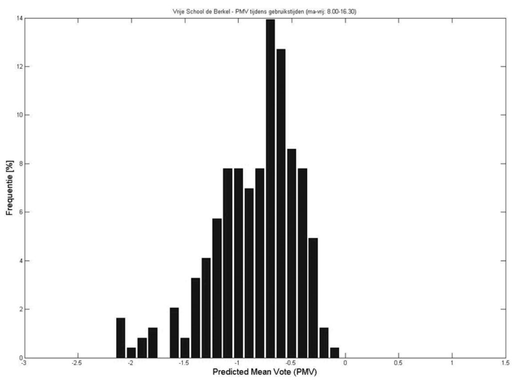

Figure 8: PMV in School B (Scholten, 2006)

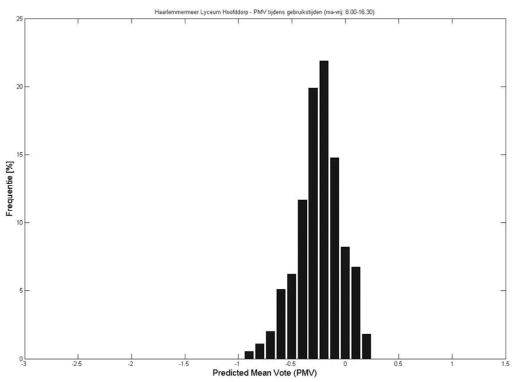

Figure 9 : PMV in School C (Scholten 2006)

Thermal comfort is expressed in The Predicted Mean Vote (PMV), which is calculated according to ISO-7730(Scholten, 2006).

Figure 7 shows that 90% of the time, the PMV between -1.0 and 0 is achieved in school A. It is shown in figure 8 that school B on the other hand predicts a lot more unsatisfied users, with 90% of the time, the PMV between -1.5 and -0.5. In school C 90% of the time the PMV is between -0.5 and 0, figure 9. In school B more than 30% of time, the PMV is less than -1.0.

4.2 Questionnaire

Users opinion is the central point of this research. First of all, perception of indoor climate is important for determining whether users are comfortable. Secondly it is important how the interaction with the system is experienced. Since measurements could only be done for a short period of time, the opinion of the user of summer conditions is also important. Users of both rooms are done have filled in a questionnaire. Unfortunately, it was not possible to survey all users. The questionnaire used is based on the validated list which has been developed in the HOPE research (Health Optimisation Protocol for Energy-efficient Buildings) (HOPE, 2001). For clarity's sake, different scales are used in the questionnaire. These scales have been translated to one universal scale. The score of a bipolair scale are transformed to a score on a unipolair scale (Joosten, 2004). This seven point scale translates good results into point 1, and bad results in point 7.

The users have been asked to rate different aspects of the comfort. Distinction is made between summer and winter. In order to get a full view, some questions have been asked about the user's health. Results of the questionnaire are given in figures 9 - 11. Respectively temperature, stability of temperature, air speed, humidity, freshness and smell of the air and sound is rated.

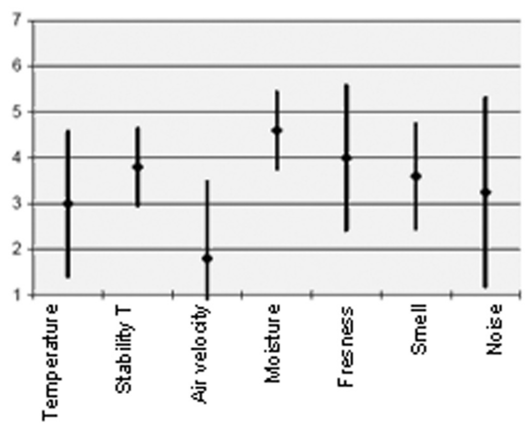

Figure 10 A: School A winter (only teacher) (Scholten, 2006)

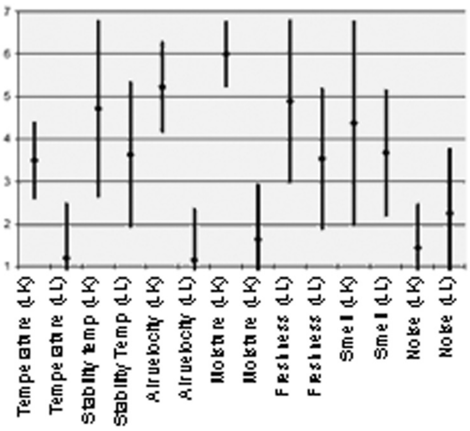

Figure 11 A: School B winter situation (Scholten, 2006)

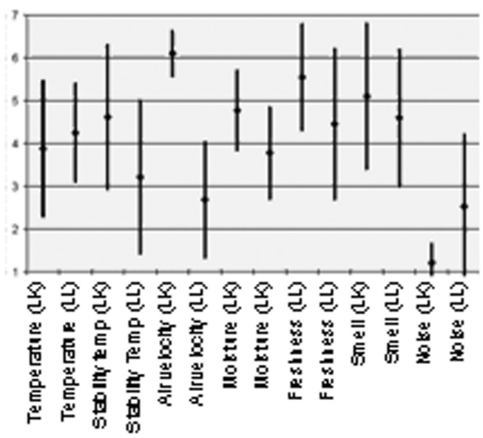

Figure 11 B: School B summer situation (Scholten, 2006)

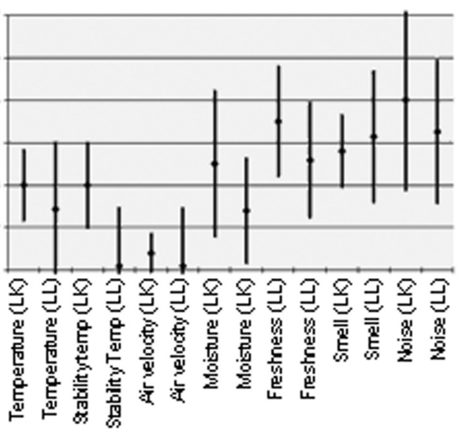

Figure 12 A: School C winter situation (Scholten, 2006)

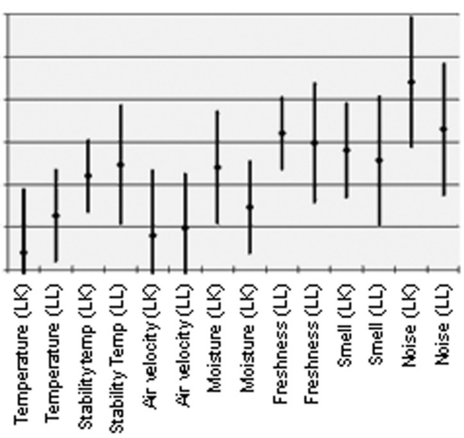

Figure 12 B: School C summer situation (Scholten, 2006)

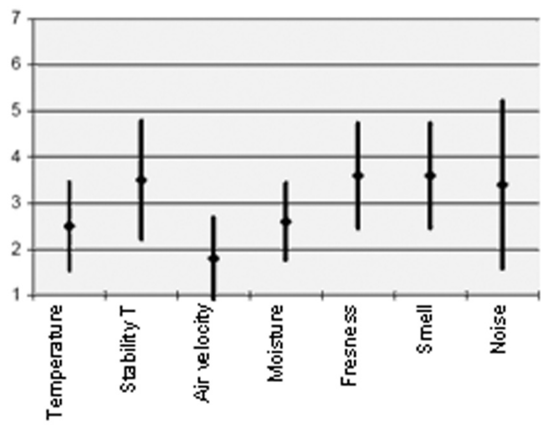

Figure 10 B: School A summer (only teachers) (Scholten, 2006)

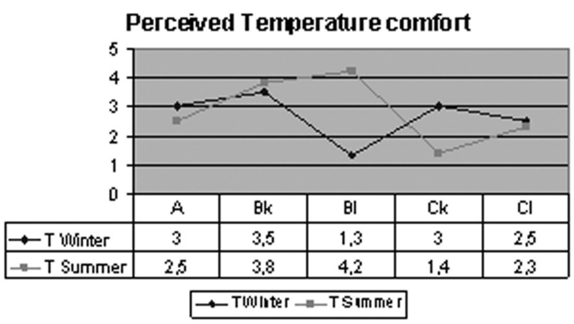

Figure 13: Perceived Temperature comfort

Perceived Temperature comfort in winter is mostly perceived better than the comfort in summer, see figure 13, but is on average good to reasonable. Range is from average 1,4 upto 6,5, clearly the perceived comfort of the office building is insufficient.

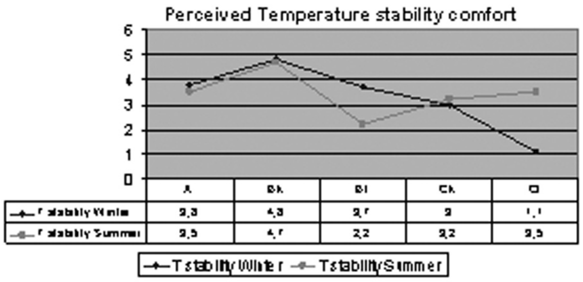

Figure 13: Perceived Temperature stability comfort

Perceived temperature stability comfort is rated reasonable, see figure 13. There seems to be not much difference between the summer and winter situation.

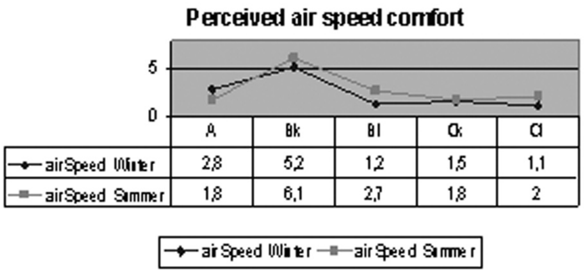

Figure 14: Perceived air speed comfort

The perceived air speed comfort is slightly better in winter than in summer, see figure 14. With one exception, the teachers of school B, all other situations are perceived as good.

DISCUSSION

Three important conclusions can be drawn from the measurements and questionairs:

Measurements and calculations provide an insight in the effects of TABS on the climate itself and the individual perception.

TABS itself can assure an acceptable indoor temperature. The users are satisfied during winter. Questionnaire shows that the building users are slightly less satisfied in summer.

Bench marking of the specific parameters concerning thermal comfort gives a clear picture whether or not a project is within the normal range of performance

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