Due to the ventilation system in schools

Students' perceived thermal comfort

Good air quality in classrooms supports children's learning ability. Poor IAQ in schools influences the performance and attendance of students, primarily through health effects from indoor pollutants [1]. Besides the air quality in schools the thermal environment in schools is becoming a growing concern [2,3,4].
Already in 1996 a nationwide, on-line web-based survey was held in the United States by Sonne et.al [5]. Most responses were directly on-line, with a few obtained by phone. There were 239 total respondents (0.25 % response rate). There was at least one response from each of 46 states. Temperature was by far the greatest comfort complaint in regular classrooms, with 50.5 % of respondents indicating "many" or "chronic" problems. At 22.5 % of respondents, temperature was by far the greatest cause of chronic complaints, followed by IAQ, humidity and odours see figure 1.

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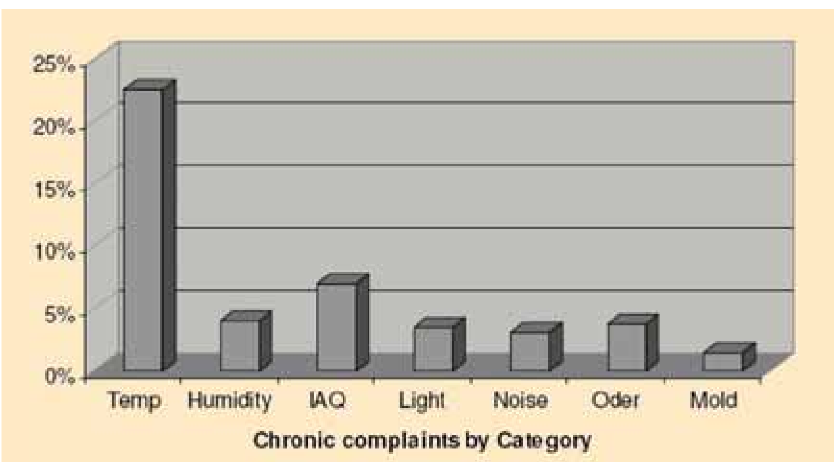
There is good evidence from literature that moderate changes in room temperature, even within the comfort zone, effect student's abilities to perform mental tasks requiring concentration, such as addition, multiplication, and sentence comprehension. Overall, warm temperatures tend to reduce performance, 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. Jago and Tanner made a short historical overview in 1999 [6].



Chronic Complaints by Category [5].
- Figure 1 -

Already in 1931 the New York State Commission on Ventilation (1931) conducted major investigations into the physiological and psychological reactions to various atmospheric conditions by school children in classroom settings [7]. 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. Thus they recommended that schools maintain room temperatures between 20 °C and 21,1 °C with sufficient air movement to eliminate objectionable

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odours and to avoid excessive drafts. Based on a survey given to teachers, McDonald in 1960 [8] concluded that classroom conditions improved by air conditioning included reduced annoyances, improved visual display and flexibility, and comfortable conditions. Teachers' attitudes and work patterns were significantly improved due to less fatigue. Likewise, student performance, attitude, and behaviour improved in proper air conditioned climates making it easier to concentrate and making them feel less drowsy and fatigued. Nolan in 1960 [9] reported that higher temperatures have a negative relationship with academic learning. Peccolo in 1962 [10] noted that ideal thermal classroom environments had an effect on the mental efficiency of students especially in situations where students were performing clerical tasks calling for quick recognition and response. Thus, he supported maintenance of an ideal temperature range for higher achievement. Stuart and Curtis in 1964 [11] reported greater gains in academic achievement of students in climate controlled schools as opposed to those students in non-climate controlled schools. In relation to this finding, Mc. Cardle in 1966 [12] discovered that students in an ideal thermal environment made significantly fewer errors on tasks and required less time to complete the tasks than students in regularly controlled thermal environments.

Seppänen, Fisk and Faulkner [13] mention the research by Pepler and Warner [14] and Johanson [15]. Pepler and Warner in1968 [14] performed experiments with 36 female and 36 male students in a climate chamber. They found an inversed U-shape relationship between time to complete a task and temperature, with the longest time to complete assignments work at 26.7 °C. However, the error rate was lowest at 26.7 °C.

Johansson in 1975 [15] exposed 18 boys and 18 girls with light clothing in a climate chamber to effective temperatures of 24, 27 and 30 °C, corresponding normally-clothed subjects with the same degree of thermal strain at 23, 30 and 36 °C. Several tests were used to evaluate the effect of thermal environment on performance. Most tasks were impaired for higher two temperatures. Performance in tests of learning, addition and multiplication tests were 10 –14 % worse at the effective temperatures of 27, 29 °C than in 24 °C. Perceptual tasks measuring cue-utilization and attention had an inverted U-shape relationship with temperature with the best performance In 27 °C.

Smith and Bradley [16] refer in their article about the influences of thermal conditions on teacher's work and student performance to Lofstedt et.al [17] and a article by Kevan and Howes [18] which reports the results of two studies relevant to this issue; the first demonstrated that students' test performances were better in air-conditioned than in non-air-conditioned classrooms; and the second found that the classroom temperature preferred by the majority of Oregon (USA) teachers was approximately 21 °C.

In their overview review of school environments and performance Mendell and Heath [1] refer to the experimental studies of Schoer and Shaffran from 1973 [19]. They assessed performance of students in a pair of classrooms set up as a laboratory, with one classroom cooled and the other not. The study found a general advantage for performance tests in the cooled environment, with a consistent tendency for more complex performance tests.

Lackney in 1999 refers his article [20] to Harner (1974) and McGuffy (1982). Harner [21] when reviewing optimal temperature levels for student's performance found that reading and mathematical skills were adversely affected by temperatures above 23.3 °C, reading speed and comprehension were most affected by temperature. A significant reduction in reading speed and comprehension occurred between 23.0 °C and 27.0 °C. Also mathematical operations such as multiplication, addition and factoring decreased significantly by air temperatures above 25 °C. The overview of McGuffy from 1982 [22] shows that in general, historical empirical studies going back 50 years have indicated that temperatures above 26.7 °C, tend to produce physiological effect that decrease work efficiency and output. Thermal conditions below optimal levels affect dexterity, while higher than optimal temperatures decrease general alertness and increase physiological stress. According to Schneider in 2002 [23], McGuffey [22] was one of the first to synthesize existing work linking heating and air conditioning to learning conditions. Schneider mentions the research by King and Marans from 1979 [24] 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 [25] a summary is given of the effects of temperature for student performance, based on studies by Levin from 1995 [26] and Wyon et al. from 1979 [27]. Temperature effect where also studied by Wyon in a two call-centres. This confirmed the previous findings that moderately raised air temperatures have a negative effect on office work performance.

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 recent study is by Wargocki and Wyon [28] who designed experiments to determine 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 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 from 2007 [29]. 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.
As stated by Wargocki and Wyon in 2006 [30] unsuitably high temperatures are quite common in classrooms not only in summer but sometimes also in autumn or winter, even those in cold countries. 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. Many schools have only natural ventilation, due to wind and outside cold windows must often remain closed to prevent draft. Traditionally the windows are designed to provide as much daylight as possible, with large glazed areas facing the sun. So the thermal winter conditions in schools are a problem. This is the reason why new system designs for heating of schools are investigated to improve the present situation about thermal comfort in school buildings.
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 Hydronic Radiant Heating Systems (HRH Systems).

Basis of HRH systems is the idea of a floor heating system with tubes imbedded in the core of a concrete ceiling. 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.
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 fulfil 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 increase indoor air quality. 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.
In 3 different schools with HRH measurements were done and the results and conclusion will be presented. The results of the schools will be compared to traditional schools and also be compared with an office building with HRH.

School	A1	B1	C1	D1	E1
Heating	Panel heating	Convector heating	Panel heating	Panel heating	Panel heating
Ventilation	Natural supply, mechanical exhaust	Natural supply, mechanical exhaust	Natural supply, mechanical exhaust	Natural supply, mechanical exhaust	Natural supply, mechanical exhaust

Information about schools of series 1 (Joosten 2004) [31].
- Table 1 -

School	A2	B2	C2	D2	E2	F2
Heating	Convector heating	Convector heating	Panel heating	Floor heating	All air	All air
Ventilation	Natural supply, mechanical exhaust	Natural supply, mechanical exhaust	Balanced mechanical ventilation with heat recovery	Balanced mechanical ventilation	Balanced mechanical ventilation	Balanced mechanical ventilation with heat recovery

Information about the school of series 2 (van Bruchem 2005) [32].
- Table 2 -

School	A2	B3	C3
Heating	HRH	HRH	HRH
Ventilation	Natural supply, mechanical exhaust	Natural supply, mechanical exhaust	Balanced mechanical ventilation

Information about the schools with HRH (Scholten 2006)[33].
- Table 3 -

METHODOLOGY

Many different heating and ventilation systems are used in schools, with in the Netherlands as traditional and 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 these traditional natural supply with mechanical exhaust-only ventilation systems and in 5 Dutch schools measurements were conducted in the heating season for a period of around 7 days, this study was followed by 6 schools with different ventilation systems and 3 schools with hydronic radiant heating and hybrid ventilation.

Schools

From January 29th till March 31st 2004 measurements were conducted in 5 selected schools in alphabetical order from school A1 to E1, see table 1 by Joosten [31]. From January 13th till February 22nd 2005 the second series of long-term measurements were conducted in 6 new selected schools, see table 2 by van Bruchem [32]. From January 10th till March 3rd 2006 measurements were done in 3 different school buildings with HRH, see table 3 by Scholten [33].

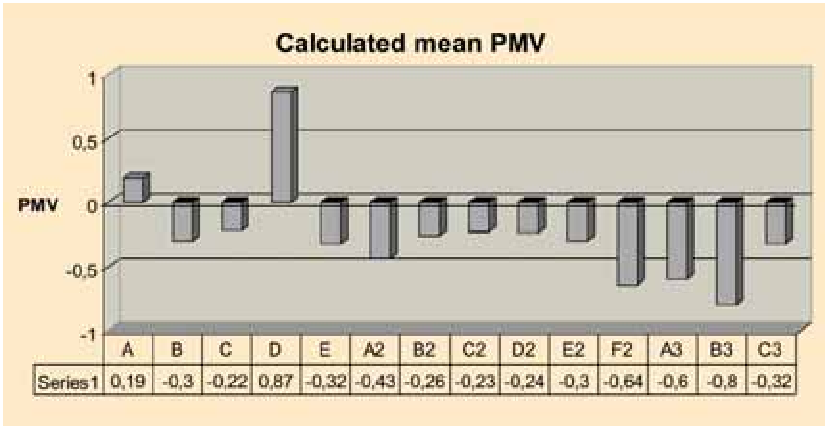
Measurements

In order to obtain objective information about the performance of the different heating systems in the schools with respect to thermal comfort measurements were conducted during minimal 1 week in the heating season. One classroom in each school building was selected for these measurements. A device was developed to measure thermal comfort parameters at 1.1m above floor level, the seating position of the teachers for the perceived comfort. The measurements in the classroom include measurements of air temperature, radiant temperature, relative humidity and air velocity and were logged every 6 minutes. Equipment specifications used for those long-term measurements are shown in table 4.

Questionnaires

In all schools, questionnaires were given to the teachers to get an impression of the satisfaction of the users, with regard to indoor air quality and thermal comfort. Generally, the facility manager of the school helped by distributing the questionnaire and gave information about the ventilation and heating system. The questionnaires had questions about environmental perception, personal well-being and application of the system for the winter situation comprised: perceived thermal comfort, perception of indoor air quality, use of ventilation system and perception of cleanliness [31]. For clarity's sake, different scales are used in the Occupants' questionnaire for different aspect of the thermal comfort. Perceived comfort is measured in the questionnaire for the winter situation and summer situation. Thermal comfort was expressed in three questions: overall thermal comfort (1=comfortable, 7= very uncomfortable), warmth/coldness (1=too warm, 7=is too cold) and stability of temperature (1=stable, 7= strong variation during the day).

The questions are based on a unipolar scale and should be interpreted as: 1= comfortable/ good … 7 = very uncomfortable/ insufficient.
For some questions, a bipolar scale should be used for interpretation. In those question is asked for example: 1 = too warm ….7 = too cold. The optimum of 4 is replaced by 1, the same optimum as questions with a unipolar scale. The score of a bipolar scale are transformed to a score on a unipolar



Overall results PMV of all the schools measured

- Figure 2 –

Parameter	Sensor Type	Output	Range	Accuracy
T radiant	Globe thermometer / pt100		100 ohm = 0 °C	Neglected
T air	Rense HT-733-M-06	0 - 10 V	-20….80 °C	± 0.3 °C
Realtive humidity	Rense HT-733-M-06	0 - 10 V	0….100 %	± 2 %
Air velocity	Schmidt flow sensor SS20.01	0 - 10 V	0….20 m/s	± 2 %
Logger	Data logger Grant 1402		-20 - 20 V	± 0.029 % + 10 mV

Measurement equipment.

- Table 4 -

too hot		<- neutral ->				too cold
1	2	3	4	5	6	7
			becomes			
7	5	3	1	3	5	7

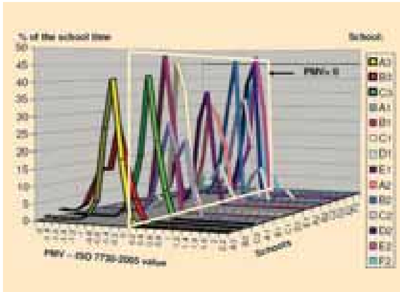
Transformation of outcome questionnaires to 7 point scale.

- Table 5 -

School	A1	B1	C1	D1	E1	A2	B2	C2	D2	E2	F2	A3	B3	C3
Returned questionnaires	6	4	6	8	7	9	8	7	11	9	6	5	8	9

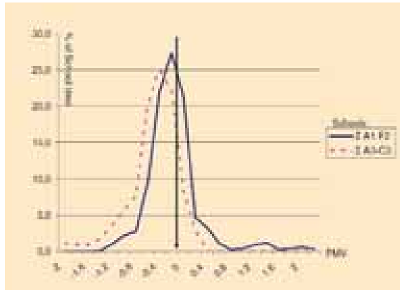
Overview completed questionnaires by the teachers of the different schools.

- Table 6 –



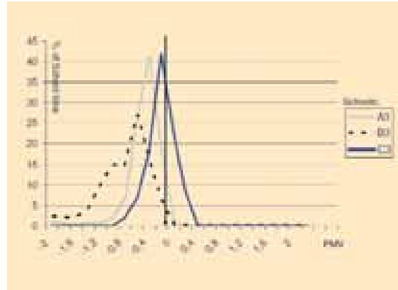
Spread of PMV values of different schools.

- Figure 3 –



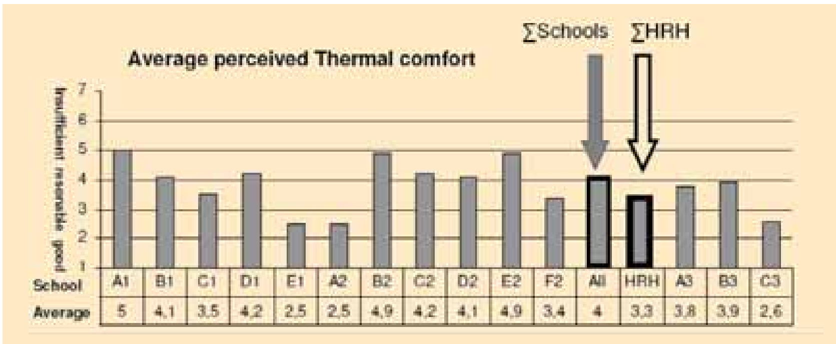
Comparison spread of PMV values of 'normal'schools (A1-F2) and schools with HRH (A3-C3).

- Figure 4 -



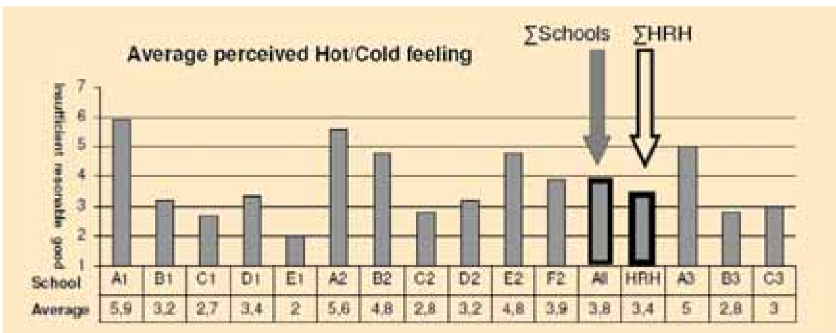
Comparison spread of PMV values of different schools with HRH (A3, B3, C3).

- Figure 5 -



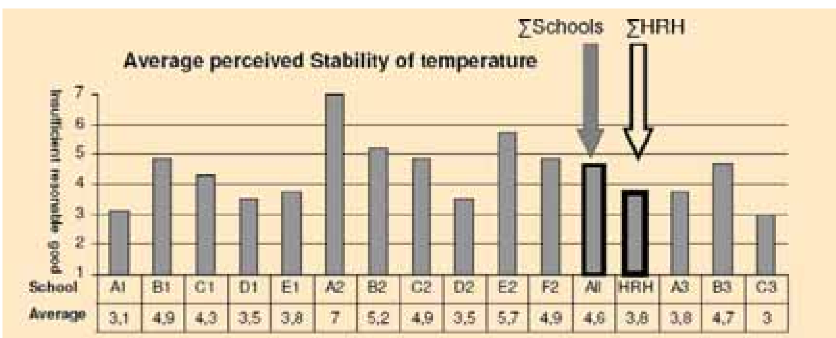
Perceived average thermal comfort.

- Figure 6 -



Perceived average hot/cold feeling.

- Figure 7 -



Perceived average temperature stability.

- Figure 8 -

scale [31]. This seven point scale translates good results into point 1, and bad results in point 7, see table 5.

RESULTS

Measurements

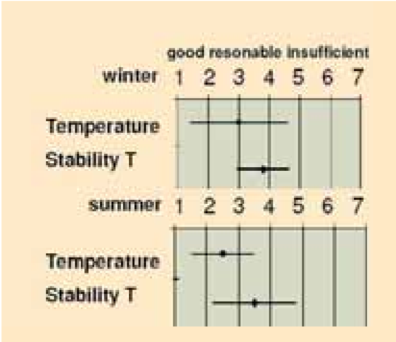
Present insight on thermal comfort is based the Predicted Mean Vote model (PMV) by Fanger in 1970 [34] which is the basis of the indoor climate standards in Europe (ISO 7730) [35] and America (ASHRAE Standard 55) [36]. PMV (predicted mean value) is calculated during class hours, using metabolic rates of 65 W/m² and clothing value of 1. The PMV values ere determined as a time average in the same position. In figure 2 an overview is given of the calculated average PMV of the different schools based on the measurements that were done within the schools.

More important than the average value is the spread of the PMV values of schools, see figure 3 with on the y-axis the % school time and on x-axis the PMV value. The focus is on the 3 projects with HRH and their spread of frequency of occurrence of PMV value's so in front of figure 3 there are the schools with HRH: A3, B3 and C3.

Questionnaires

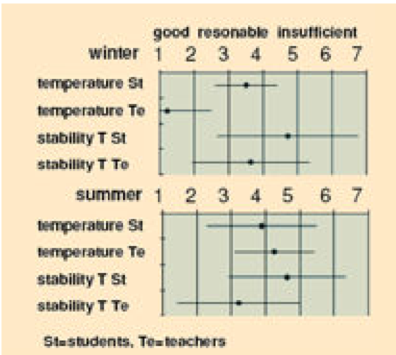
At the schools only the teachers were ask to fill in the questionnaires, table 6 gives the complete overview of the completed questionnaires from the different schools.

The results of the questionnaires related to the aspects of thermal comfort are given in figure 6, 7 and 8. The results of all schools are represented in the diagram as also the average rating of the 'traditional' schools and the schools with HRH. The rating of the average of the 'traditional' schools is indicated by all, and the average of the HRH schools with HRH, see also the arrows in the diagrams. The ratings given by the teachers of the schools are represented. This clearly shows that the perceived thermal comfort in its different aspects is not too good. This is related to the outcome of the



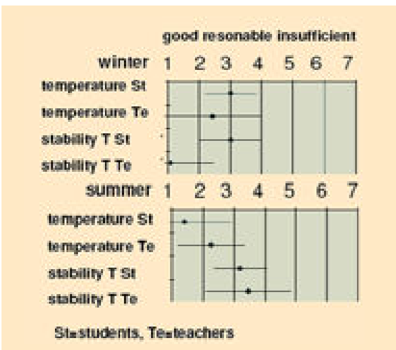
School A (only teachers) winter and summer (Scholten 2006) [33].

- Figure 9 -



School B in winter situation and summer situation (Scholten 2006) [33].

- Figure 10 -



School C in winter situation and summer situation (Scholten 2006) [33].

- Figure 11 -

research by Sonne [5], clearly the temperature is an aspect that needs improvement.

Closer look at the perceived thermal comfort of schools with HRH systems

From the aspects of perceived thermal comfort, feeling hot or cold and the perceived temperature stability, there is only a slight advantage for the HRH systems. Still this is a good argument to look deeper into the schools with HRH. In contrast to the questionnaires for the first and second series, for the third series schools with HRH, not only about the winter situation questions were asked but also about the summer situation. The distinction is made between summer and winter in order to get a full view about the perceived thermal comfort by HRH systems. Results of the questionnaires are given in figures 9, 10 and 11. Respectively temperature, stability of temperature and air speed are rated.

It is interesting to see that there is a rather large difference between the rating from the questionnaires by the different respondents, e.g. The range for temperature stability by the teachers for school B in winter is between 2,7 and 6,8, a difference of 4,1! Differences in rating as outcome of the questionnaires of more than 2 or 3 are quite common. This makes it necessary to have sufficient respondents to have reliable outcomes. In this study the number of respondents is restricted to the teachers of students of specific classrooms and therefore statistically not significant.

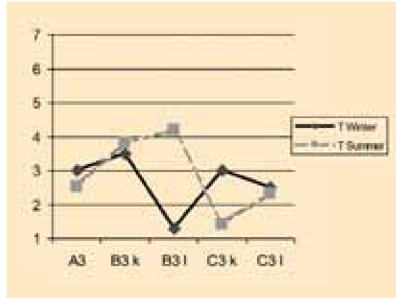
Figure 12 shows that the perceived temperature comfort in winter is better than the comfort in summer, but is on average good to moderate.

Figure 13 shows that the perceived temperature stability comfort is rated reasonable. There seems to be not much difference between the summer and winter situation.

When comparing the rates from the questionnaires given by students and teachers, there is a mixed result between school B3 and C3, so that there is not a clear conclusion possible, see figure 14 and 15.

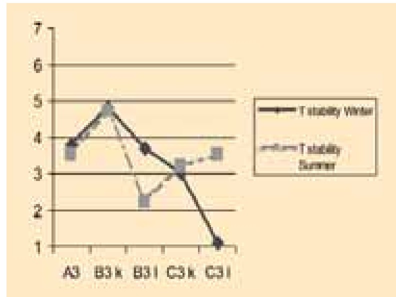
CONCLUSIONS

This research gives a literature overview of the importance of a good thermal indoor environment for the performance of students. It is clear from recent research and research in the past that temperatures in classrooms are important factors in the learning process and improving them should be given much priority. In the Netherlands some new schools were equipped with innovative heating and ventilation systems: Hydronic Radiant Heating combined with natural air supply and mechanical exhaust. In 3 schools these systems were examined



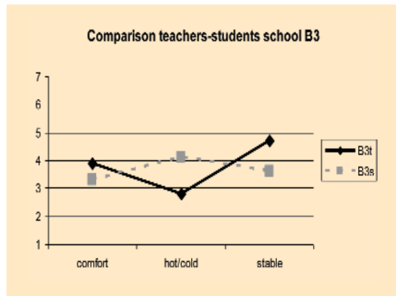
Perceived temperature comfort in winter and summer schools with HRH.

- Figure 12 -



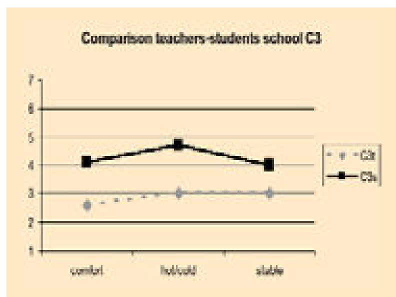
Perceived Temperature stability comfort schools with HRH.

- Figure 13 -



Rating by teacher and students compared by school B3.

- Figure 14 -



Rating by teacher and students compared by school C3.

- Figure 15 -

and the results of the measurements compared with the results of two series measurements in schools with more traditional heating and ventilation systems.

To sum up all the results overviews are presented of all the calculated mean PMV based on the measurements

during the winter period of all the projects and the results of questionnaires about the perceived thermal comfort in the winter situation. Concluded is that the comfort of the schools with HRH is not much better than the other schools, there is only a slightly improvement. That the schools with HRH do not have a much better mean PMV and perceived thermal comfort was something not expected on forehand, a major improvement to the thermal indoor comfort was expected.
The following conclusions can be drawn from the measurements and questionnaires:

- Measurements and questionnaires provide an insight in the effects of HRH on the climate itself and the individual perception.
- HRH itself can assure an acceptable indoor temperature. The users are a little more satisfied during winter compared to more traditional system solutions. Questionnaire shows that the building users are slightly less satisfied in summer compared to winter.
- 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
- The comfort of schools with HRH is not necessary much better than schools with other more traditional heating systems.

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