SUSTAINABLE SCHOOL BUILDINGS: SOME OF THE LATEST DUTCH EXAMPLES OF NEARLY ZERO EMISSIONS BUILDINGS

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ABSTRACT

In the Netherlands with respect to sustainable educational building there is a continuous development going on from sustainable building, to Passive House schools, to nearly Zero Emission Buildings to even Energy positive buildings. The Dutch government started a special funding program to stimulate the innovation of high performance schools. Some of these schools were built as extreme sustainability friendly schools while also much attention was given to comfort and health aspects. Three of these new schools were investigated: two passive house schools and the first net ZEB designed school are analyzed, measured and their results were compared with 13 other recent but more traditional designed schools, as well as with schools from earlier research. The results showed that concerning Indoor Air Quality and thermal comfort the new environmental schools did not perform very well. This is a disappointing result which indicates that is necessary to pay enough attention to the basic functionalities of a school (health and comfortable indoor environment) instead of focusing too much on sustainability.

INTRODUCTION

Indoor Air Quality and thermal climate in schools are problematic in many countries [Smedje et al.1997, Heath and Mendell 2002, Daisey et al.2003, Shendell et al 2004, Mendell and Heath 2005, Mi et al.2006, Kurnitski 2007, Clements-Croome et al.2008]. For Indoor Air Quality there is more and more attention, but often there is little or no focus on the thermal climate in schools [Landrigan 1997, Daisey et.al 2003]. As the energy use of school buildings became a critical factor in the design as the sustainability demands are getting tighter. However although energy is very important we should not forget the comfort needs, necessary attention level and health of the vulnerable children as they spent a large part of their time in school. Therefore it is very important that the thermal comfort and Indoor Air Quality of a school are good.

Ventilation

Indoor Air Quality in schools is primarily evaluated by CO_2-concentrations. ASHRAE Standard 62-1999 recommends an indoor CO_2-concentration of less than 700 ppm above the outdoor concentration, which means around 1200 ppm, to satisfy comfort criteria with respect to human bio effluents. Dutch schools have to meet the Dutch Building Code, which recommends a level of 1000 ppm CO_2-concentration with a maximum of 1200 ppm. The air change rates are mostly fixed values which do not take into account the effect of the external air pollution [Hani et al 2011]. The European indoor climate standard EN15251: 2007 provides different allowed CO_2 levels depending on the external air CO_2 concentration. However also in this standard the air change rates are still constant. Table 1 presents the CO_2 values according to the EN15251. The latest Dutch design guide, ISSO publication no. 89 [ISSO 2008] should lead the path to better IAQ in schools, see Table 2.

Table 1. CO_2 levels according to the EN15251

Category	Respective CO_2 level exceeding external air concentration in ppm for energy calculations
I	350
II	500
III	800
IV	> 800

Table 2. Different classes for IAQ regarding CO2-content

Class	A [Very good]	B [Good]	C [Acceptable]	D [Insufficient]
CO_2 content [ppm]	%of total school hours < 800	% of total school hours 800 - 1000	% of total school hours 1000 - 1200	% of total school hours > 1200

However if we look at the results of earlier Dutch studies on school ventilation [Zeiler and Boxem 2007], see table 3, it shows that there is no adequate Indoor Air Quality on quite a number of schools. If we look at other international research on ventilation in schools we that the situation is not much different. Mercier et al. found in their research on hybrid ventilation in Nordic schools that the measured carbon dioxide levels in classrooms ranged from 1150 – 1550 ppm, which was over the recommended limit [Mercier et al. 2011]. In Germany the situation is not much better [Hellwig 2010].

Table 3. Dutch studies: CO_2 levels in schools [Zeiler and Boxem 2007].

Study	No. schools	CO_2 levels ppm	
		Average	Range
1984	11	1000	500-1500
1990	6	1290	950-1950
1995	6	1320	700-2700
1997	96	990	425-2800
2004	5	1220	480-2400
2004	11	1580	450-4700
2005	6	1355	550-3000

Thermal comfort

For Indoor Air Quality there is more and more attention, but often there is little or no focus on the thermal climate in schools [Landrigan 1997, Daisey et al. 2003]. 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. Jago and Tanner [1999] made a short historical overview and found that 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. Some of their findings showed that temperatures above 23,9 ºC produced such harmful effects as increased respiration, decreased amount of physical work, and conditions favourable to disease.

A more recent study is by Wargocki and Wyon [2007a] 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 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 [2007b]. 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 [2007a] are larger than reported effects on the performance of office work by adults [Wyon and Wargocki 2006a-c]. They conclude that this indicates that children may be more susceptible than adults to environmental conditions.

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. There for it important not only to look at the energy consumption and Indoor Air Quality, but also at the thermal comfort performance of schools.

METHODOLOGY

Three very recent built sustainable designed schools were analyzed and the results compared with other more traditional schools as well as a series of modern schools. To investigate the results of the sustainable schools measurements were done concerning thermal comfort and indoor air quality. During a week different measurements in schools were undertaken to be able to define the quality of indoor air quality and thermal comfort.

The Veldhuizerschool

The Veldhuizerschool in Ede is the first passive school in the Netherlands. The construction of the school was finished in July 2011. Build according to the passive house principle means extreme airtightness, highly insulated with a Rc = 10 m²K/W, triple glazing and on top the school has a green sedum roof .

Figure 1 The Veldhuizer school and classroom

The conditioning is done by individual room ventilation systems with heat exchangers. The pupils, as well as all the electrical equipment [e.g. computers, monitors, etc], contribute to the heating of the school. The air distribution is by textile ducts, see Fig. 2. Only during start-up of the lessons heating energy is needed, the rest of the day the students generate enough heat to warm the classroom. This results in an energy consumption which is almost 75% less than traditional school buildings.

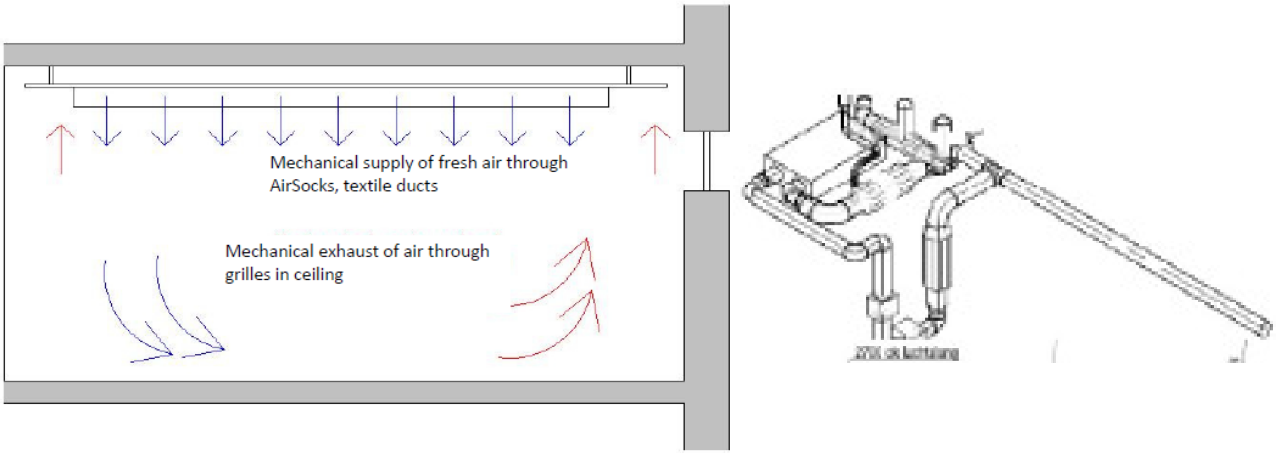

Figure 2 Indoor principle of Veldhuizerschool, Ede

Christiaan Huygens College: an energy plus school

Christiaan Huygens College is the first CO2-neutral and energy plus school in the Netherlands, see Fig. 3. The new building uses a compact construction in order to limit the surface area of the façade, thus reducing excess heat in summer and heat loss in winter as much as possible. At the same time, well-insulated windows allow natural daylight to flood the building without causing overheating. Thanks in part to the Energy Roof, a combination of PV and thermal collectors integrated into its roof cover, the school building generates more energy than the school needs for its own use. The indoor climate is regulated with a floor heating / cooling system with a ground source heat pump. A balanced ventilation system, see Fig. 4 is used to provide sufficient fresh air in the classrooms and this can be used for additional cooling during the summer.

Figure 3. Christian Huygens College Eindhoven: the first energy plus school, Large central atrium within the school and Class room

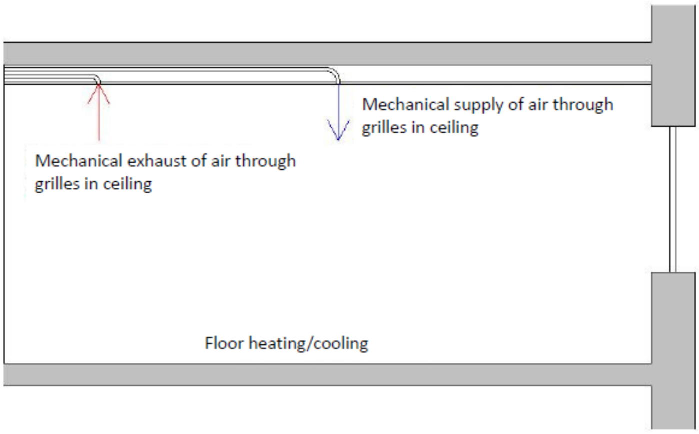

Figure 4. Indoor principle of Christiaan Huygenscollege, Eindhoven

OdyZee school: a NZEB passive house school

In 2009 the Dutch government started the so called UKP NESK program to stimulate innovation for energy neutral buildings. UKP means unique chances projects and NESK means 'Towards energy neutral schools and offices' [Naar Energieneutrale Scholen en Kantoren]. This program of the Dutch government gave funding to projects which show exceptional innovation in the area of energy conservation, sustainability or organization within the building industry. These are the most interesting projects in the field of NZEB in the Netherlands. The OdyZee school is the first school within the UKP NESK program that was finished, see Fig. 5. The energy concept of the school is based on applying the Passive house-concept, with an average insulation with a Rc-value of 10 m2W/K and triple glazing. The school has a ground source heat pump, low temperature floor heating system, balanced mechanical ventilation with 85%heat recovery and a solar boiler. IAQ is control on a maximum CO2-level of 800 ppm. The Energy Performance Coefficient value is 0.54, which will be reduced to zero after installing 500 m2 PV panels.

Figure 5 OdyZee school built conform the Passive house concept and Class room of the OdyZee school

The building of the OdyZee school is executed as a passive school. This means that the façades have a high thermal insulation combined with extreme air tightness. The school is equipped with a balanced ventilation system which should ensure a healthy indoor air quality, see Fig. 6. The building is designed to become class A ventilation.

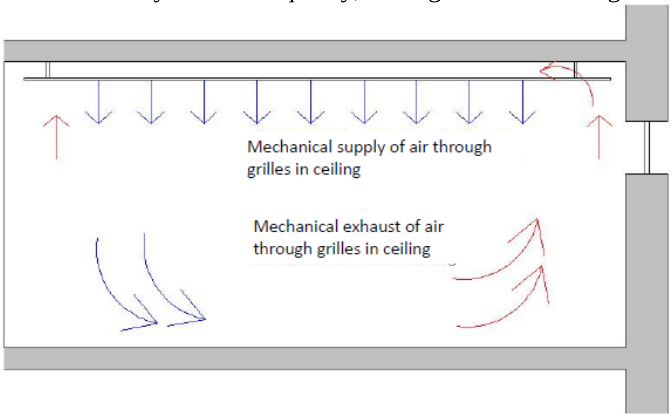

Figure 6 Indoor principle of SO/VSO OdyZee, Goes

MEASUREMENTS

One classroom in each school building was selected for measurements in the heating season during one week. The Equipment specifications are shown in table 5 and which include measurements of air temperature, radiant temperature, relative humidity, air velocity and CO_2 concentration. The different sensors were placed a tripod put in the middle of the classroom, see Fig. 5

Table 4 Measurement periods

School	Location	Measurement period
A	Ede	07-03-2012 till 14-03-2012
B	Goes	26-03-2012 till 02-04-2012
C	Eindhoven	03-04-2012 till 12-04-2012

Figure 7 Measurement pole setup

Table 5.Measurement equipment

Type of measurement	Equipment	Brand	TU/e ID	Range
Temperature	Sensor	EE80	2335	0° - 40°C
Radiant temperature	Black sphere PT100	-	612	-100° - 300°C
Relative humidity	Sensor	EE80	2335	0 - 100%
Air velocity	Omni speedometer	Sensor HT428	708	0.05 - 5 m/s
CO_2 -concentration	Sensor	EE80	2335	0 - 5000 ppm
Log data	Data logger 2F8	Grant 2020 series	1816	n.v.t.
Process data	Laptop	Dell Latitude C840	1629	n.v.t.

RESULTS

Ventilation

Since the IAQ inside the schools is one of the main subjects in this research, it is interesting to look at the differences in IAQ between the three investigated schools. The graph given below [Fig 8] is a representation of the CO_2 concentration in all three schools during one school day from 08:00 in the morning till 17:00 in the afternoon.

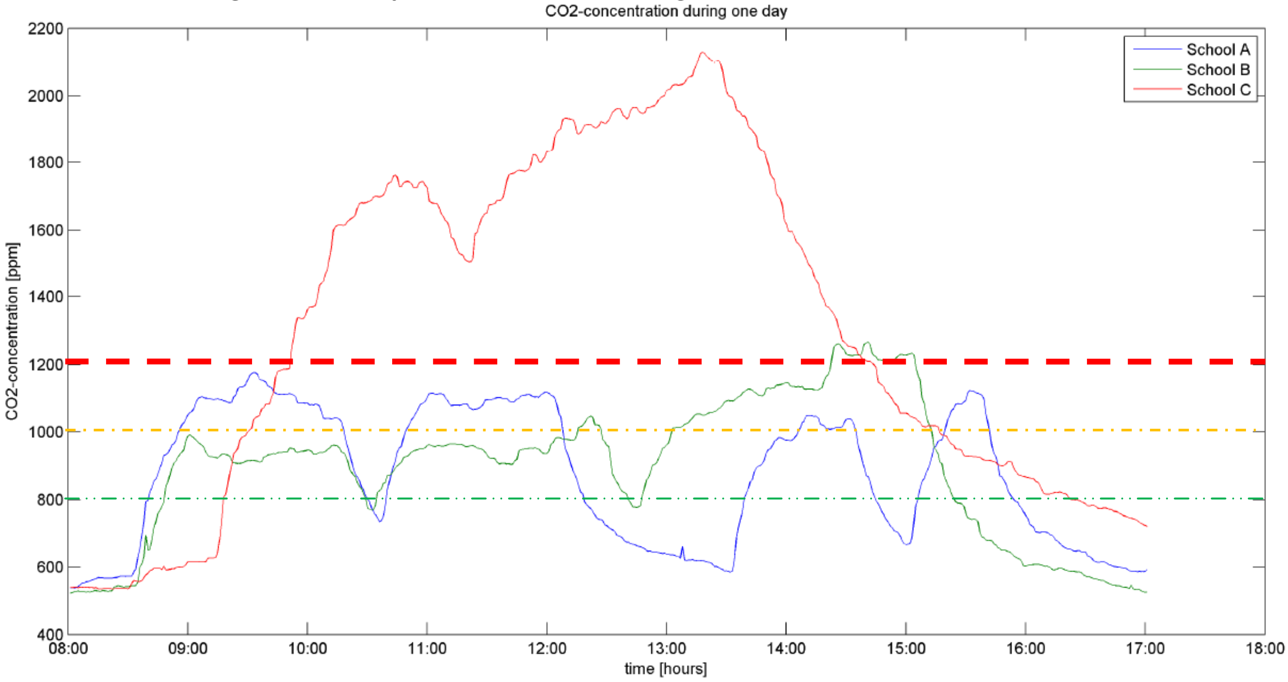

Figure 8 CO2 concentrations during one school day

When looking at these results, it becomes visible that the IAQ of school A and B for the largest part of the school day, is between 800 and 1200ppm, which means that the IAQ of these schools most of the time corresponds to class B/C. Looking at school C, a large peak with a CO2 concentration over 2000ppm is visible, around midday, see Table 6. This means that for a large part of the day the IAQ of school C corresponds to class D, which is undesirable. The table below depicts the distribution of school hours for each school in the different IAQ classes.

Table 6 Actual IAQ class of each school

Class	A [Very good]	B [Good]	C [Acceptable]	D [Insufficient]
CO_2 content [ppm]	% school hours < 800	% school hours 800 - 1000	% school hours 1000 - 1200	% school hours > 1200
School A	32%	22%	46%	< 1%
School B	15%	47%	32%	6%
School C	28%	12%	10%	49%

Temperature

What we found from our measurements is that the average temperature during classes is ranging from on average 20.7 °C(A, Fig. 9) , 21.6 °C (C, Fig. 11) up to 23.2 °C (B, Fig. 10). This is clearly much too warm given the fact that this was during a winter period. If we look at the control strategy we find different solutions depending on the kind of heating system applied. The two schools with floor heating show a slow decreasing characteristic whereas the heating up is almost as fast as that of the all air system of school A. School A is controlled on a minimum temperature of 19.5 °C, which is conform the guidelines, whereas school B and C never reached their minimum control room temperature to activate the heating system. The process control responds of school A is fluctuating within almost 0.5 °C, which is an excellent result. By reducing the temperature setting at the start of the classes the temperature shift of plus 2 °C might be reduced even further. The temperature control of achool B and C are less good and show an overshoot of almost 3 °C on a already too high night temperature of 21.3 °C respectively 20.3 °C. This clearly shows that slow responding heating systems like floor heating are not a suitable solution for schools with their fast changing internal loads at the beginning of classes due to the high density of pupils in the classroom and the resulting high internal heat load. In school the average temperature during classes is with 23.2 °C just too high and outside classes the rooms should be ventilated more with fresh outside air.

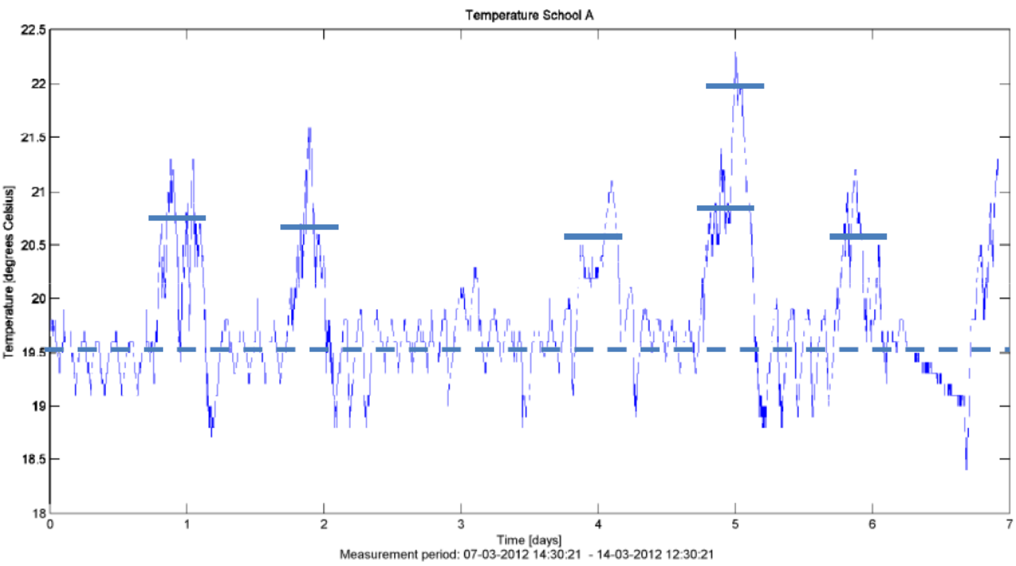

Figure 9 Indoor temperature during complete measurement period school A

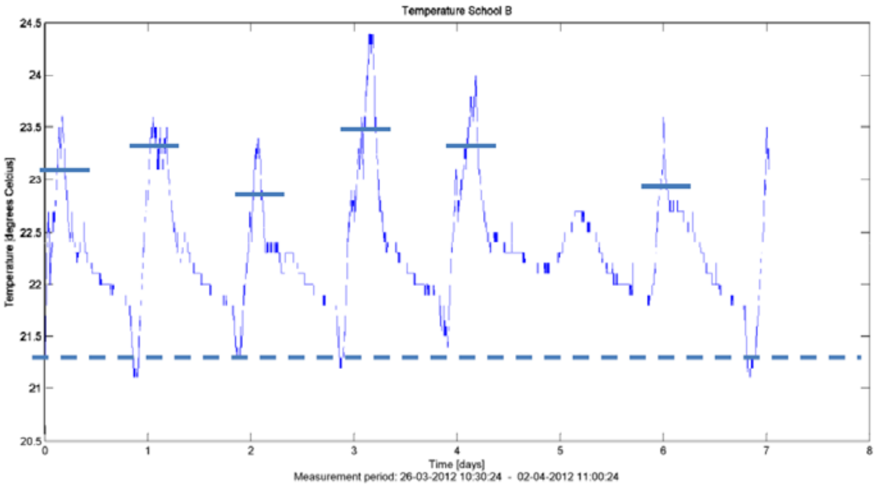

Figure 10 Indoor temperature during complete measurement period school B

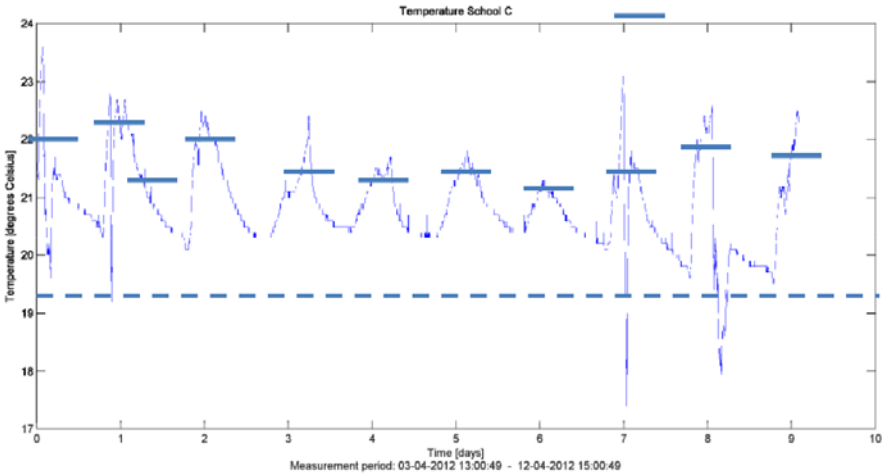

Figure 11 Indoor temperature during complete measurement period school C

DISCUSSION

In earlier research by van Dijken (2004) 11 schools were investigated on their Indoor Air Quality. This study gave the percentage of school time in which the CO_2 concentrations are above 1200 ppm, which determines the percentage of time in which the Indoor Air Quality inclass D (insufficient IAQ). In a recent report by the Dutch society of architects, BNA, ten recently completed more traditional designed and built schools were examined on the aspects of IAQ and thermal comfort [Grosveld 2011]. This gave us another opportunity to compare our results of the three highly sustainable designed schools [A,B and C] with results of more traditionally designed schools.   Important is to conclude if the new schools reach an sufficient level of Indoor Air Quality confirm the Dutch ISSO 89 guideline. Fig. 12 represents the percentage of time time that the CO_2 concentration is higher than 1200 ppm, so when the Indoor Air Quality is not good enough. It shows clearly that there has been made progress if we look at the percentage of class hours which do not have an adequate level of CO_2 concentration: average study by van Dijken 67%, average by BNA 14.7 % and average of sustainable schools 19%. There are still important lessons to be learned. Maybe the new REHVA guidebook on Indoor Environment and Energy Efficiency in Schools [d'Ámbrosio Alfano et al. 2010] can provide some help. It gives an overview on the main aspects of and critics on school buildings envelope and system design, aiming to obtain comfortable and energy sustainable indoor environments for schools [Lanniello and d'Ambrosio Alfano 2010].

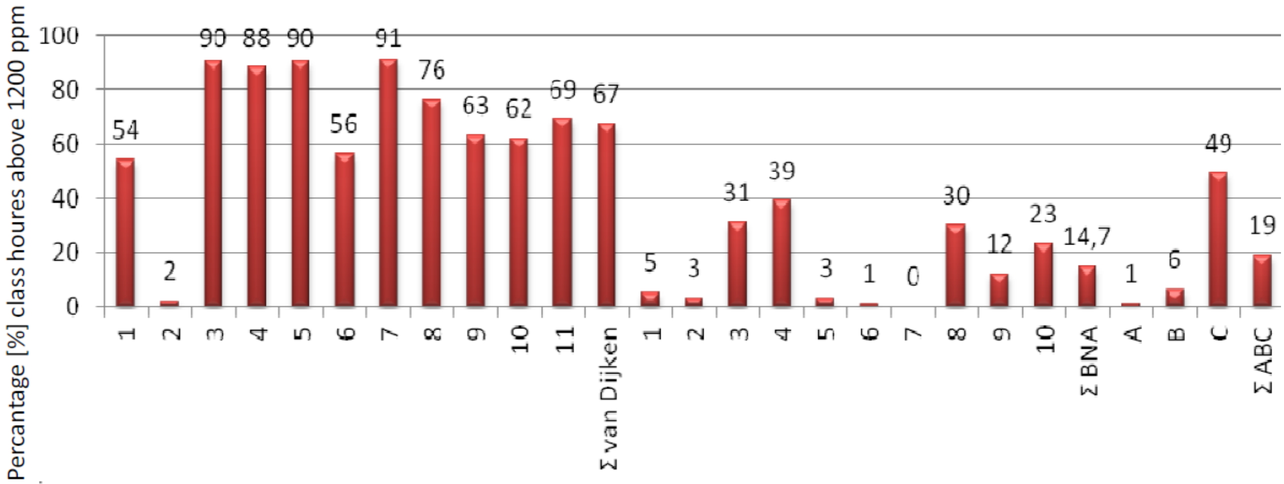

Figure 12 Comparison of percentage that the CO2 concentration is above 1200 ppm.

CONCLUSIONS

We presented the latest developments on sustainable school design in the Netherlands. We looked at what are reasonable IAQ levels for classrooms and presented the Dutch standard for IAQ in classrooms. This enabled us to compare the measurement results of three recent completed sustainable schools with the IAQ standard. The IAQ of the three sustainable schools is not much better than schools based on more traditional design approaches in relation to the Indoor Air Quality. This research gives an introduction on the importance of a good thermal indoor environment in schools 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 thermal comfort should be given more attention. In 3 of the latest sustainable schools the Indoor Air Quality and thermal comfort were examined and results compared with results of two series measurements in more traditionally designed schools. The sustainable schools did not outperform the more traditional designed recent completed schools of the BNA study. We can conclude however, that there is made an impressive improvement in comparison with older schools, like those in the study by van Dijken. Clearly there is more knowledge and insight on how to improve IAQ, however focusing on sustainability lead to slightly less good IAQ. This indicates that a school design team should not only focus on sustainability but first of all should pay attention to reach an adequate Indoor Air Quality and good thermal comfort for the school.

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