THE THERMAL COMFORT AND IAQ OF RECENT DUTCH ENERGY EFFICIENT OFFICE BUILDINGS WITH THERMAL ACTIVATE BUILDING SYSTEMS

Wim Zeiler, Koen Smelt and Gert Boxem

TU Eindhoven
Den Dolech 2
Eindhoven, Netherlands
w.zeiler@bwk.tue.nl

ABSTRACT

The need for more energy efficient Heating Ventilation and Air Conditioning systems led to a search for new systems for heating, cooling and ventilation of buildings. Strong reduction of energy consumption within the built environment is necessary because of the growing effects of depletion of fossil fuel and global warming. This lead to a almost standard concept of energy efficient office buildings in the Netherlands. That concept exists of heat pumps and LTES aquifers combined with thermally activated building systems (TABS). Though there are many studies about TABS behaviour they are mainly based on simulations and only a very few actual field studies have been performed on the ventilation performance, draft and the perceived comfort of the ventilation in combination with TABS. Therefore measurements were done and questionnaires held to determine the perceived comfort and IAQ in three recently completed office buildings with the energy efficient TABS concept. The results showed that in one office the percentage of predicted satisfied persons would be more than 40% and the others respectively around 20% and around10%. The results of the held questionnaires also showed that the three buildings score on average 4 on a scale from 1 to 7 for the aspects of perceived indoor comfort, so the occupants were slightly more dissatisfied with the performance of the TABS.

KEYWORDS

Thermal comfort, Indoor Air Quality, Termal Activated Buildings Systems

1 INTRODUCTION

During the last years global warming, the deterioration of the environment and the limited amount of fossil energy have focussed the attention to the development of more energy efficient systems for heating and cooling (De Carli et al 2003). Main principle of modern building design is, besides a healthy and comfortable indoor climate, a low energy consumption and durability. Thermally Activated Building Systems (TABS) have emerged as energy efficient ways for cooling and heating of buildings (Gwerder et al 2008, Olessen 2012). Different names are given to the system; thermally activated building systems or parts or components (Weber 2005), concrete core conditioning (Koschenz, 1999), thermo active core systems (TACS). In Dutch, the name betonkernactivering or bouwdeelactivering is used primarily. TABS uses the capacity of the massive floor or wall to cool or heat the building. Plastic pipes are positioned between the reinforcement and concrete is poured over. Depending on temperature difference between supply and room, the concrete is absorbing the heat in the room or heating the room. The temperature span is near comfort temperature, approximately between 18 and 25 ^oC. Precaution has to be taken in cooling mode, since condensation on the surface has to be prevented. For ventilation Hybrid ventilation is a energy efficient solution (Delsante and Vik 2000). Hybrid ventilation has access to two ventilation modes (natural ventilation and mechanical ventilation) in one system and as such exploits benefits of both modes (Heiselberg 2002). Advanced hybrid ventilation technology fulfils the high requirements on indoor environmental performance and the increasing need for energy savings by optimizing the balancing between indoor air quality, thermal comfort, energy use and environmental impact (Heiselberg 2002). Natural ventilation is difficult to control in winter therefore often hybrid ventilation is chosen as a solution for ventilation with mechanical supply in winter. For the generation of heat or cold heat pumps are preferred because they can use low temperature energy sources from the environment. To create a good energy efficiency performance for a heat pump it is necessary to have a small difference in temperature level of the energy source and the needed heat or cold. This is best done by using low temperature heating and high temperature cooling systems. For such systems large surface areas are required to exchange enough energy to the room of a building. TABS are a good solution because their large surface area's to exchange heat or cold allows to transform the generated small temperature differences being generated by the heat or cold generation. Therefore, Hybrid ventilation and TABS in combination with a heat pump is often used in present buildings. This system uses the 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. Much research has been done in simulations of TABS still for us the questions remains if simulations are enough especially with systems like TABS. One of the possible drawbacks with this system is that the use of small temperature differences results in low thermal driving forces to compensate for locally appearing unexpected cold air flow through cavities cause by building defects such as "cold bridges", insufficient insulation on specific details or unexpected behaviour of occupants. Such aspects do not occur in simulations but only in real life situations. As such a field test gives much clearer picture of the practical resulting comfort of such systems compared to simulation tests which are often used to look into the expected behaviour of such innovative systems.

2 MEASUREMENTS IN 3 OFFICES

Human thermal comfort is affected by a number of parameters, namely according to Franger's comfort equation, and the respective standard EN ISO 7730 (ISO 2005). Underlying the resulting predicted mean vote (PMV) or the predicted percentage dissatisfied (PPD) was calculated based on the six parameters: air temperature, radiant temperature, relative air velocity, humidity, clothing and activity. In three offices measurements were done according to NEN-EN-ISO 7726 (ISO 1998) to determine the personal thermal comfort of occupants in relation to the six above mentioned parameters. Measurements were done in one office space in each of the three selected recently completed office buildings in the Netherlands. Table 1 provides an overview of the used measurement equipment.

Table 1: Used 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.

Besides the PPD extra attention was given to the occurrence of draft. Roughly, it is advised to keep the average air speed lower than 0.15 m/s. However, there is also a relation between the air speed and turbulence intensity. Fanger determined the relation between draught and persons dissatisfied:

$$DR = (34 - T_a) \cdot (\bar{v} - 0.05)^{0.62} \cdot (37 \cdot \bar{v} \cdot Tu + 3.14) \quad (1)$$

$$Tu = \frac{\sigma}{v} * 100 \quad (2)$$

Where:

DR=	Draught rate	(%)
v=	average air speed	(m/s)
Tu=	relative turbulence intensity	(-)
σ=	standard deviation of fluctuations in air speed	(-)

In offices as a standard 15% DR is recommended.

Building A

Users	170
Completed	2011
Floor space	14.000 m²
Ventilation	Hybride
Heating/cooling	TABS

This is an environmental research building, see Fig. 1, inspired by the Cradle to Cradle (C2C) principles the design and construction of the building was taken one step further than most sustainable buildings built to date in the Netherlands. The designers Claus and Kaan Architects were instructed to keep as close to this philosophy as possible and had to meet a number of stringent material specifications. For example the hull is made of durable concrete without any artificial additives and no sealant, solvents or such like were used in the process. Using materials such as wood, glass, steel, flax, ground limestone and granular debris creates a streamlined building with an open and natural appearance. Efforts towards energy efficiency cover two areas: reducing consumption and sustainable production, both of which lead to a reduction in CO_2 emissions. Hybrid ventilation system was installed with natural supply and mechanical exhaust. Heating is delivered through concrete core activation.

Figure 1. Building A with the setup of the measurement equipment

Building B

Users	150
Completed	2009
Floor space	6.500 m²
Ventilation	Mechanical
Heating/cooling	Thermal Activated building Systems

This is a municipality building of a middle seized town in the Netherlands, see Fig. 2. It has an electrical heat pump with an Aquifer Thermal Storage system and Thermal Activated Building System integrated in the floor for heating and cooling.

Figure 2. Building B with the setup of the measurement equipment

Building C

Users	600
Completed	2000
Floor space	3.700 m²
Ventilation	Mechanisch
Heating/cooling	Thermal Activated Building Systems

This building is an office of one of the biggest building services contracting companies in the Netherlands, see Fig. 3. It also as an electrical heat pump with Aquifer Thermal Energy Storage and Thermal Activated building Systems for heating and cooling.

Figure 3. Building c with the setup of the measurement equipment

Users opinion is of great importance. 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. The users were asked to rate different aspects of the comfort. Distinction was made between summer and winter. The questionnaire used is based on the validated list which has been developed in the Health Optimisation Protocol for Energy-efficient Buildings research (Hoope 2001)

3 RESULTS

3.1 Measurements

Building A

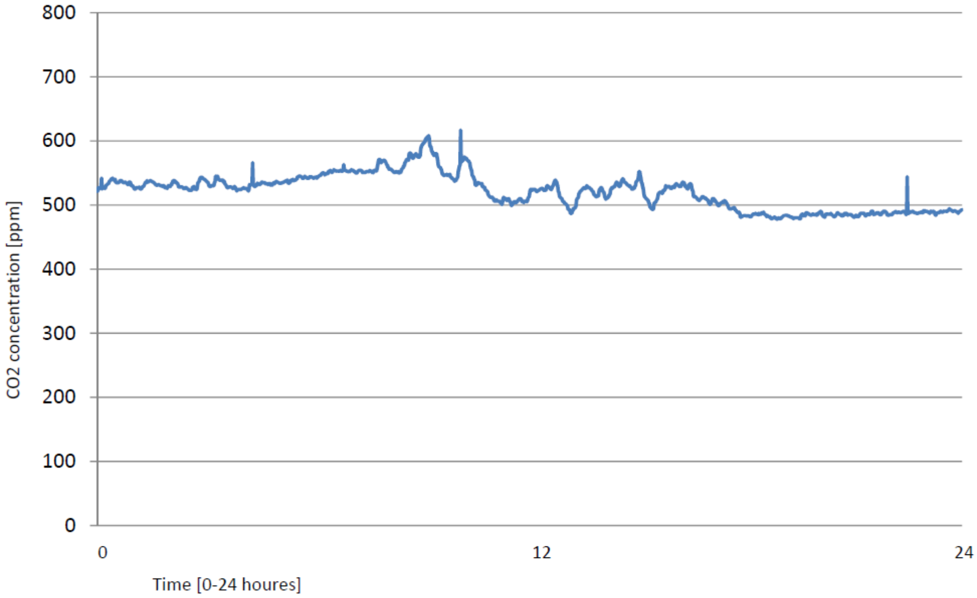

Figure 4. CO_2 concentration during one working day in office A

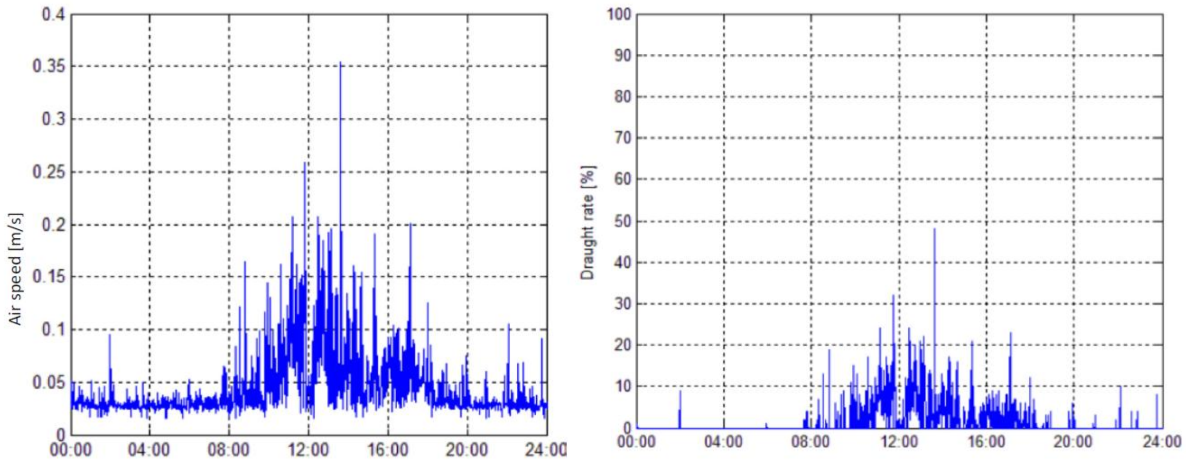

Figure 5. Air speed and draught rate in office A

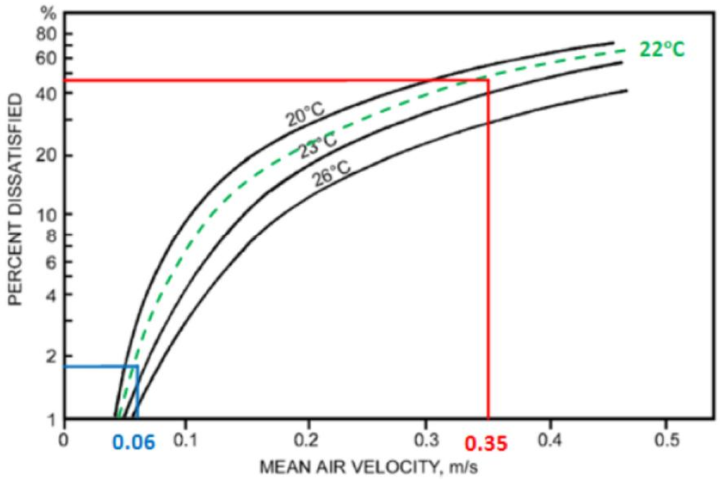

Figure 6. Percentage dissatisfied based on air temperature and minimum and maximum mean air velocity in office A

Building B

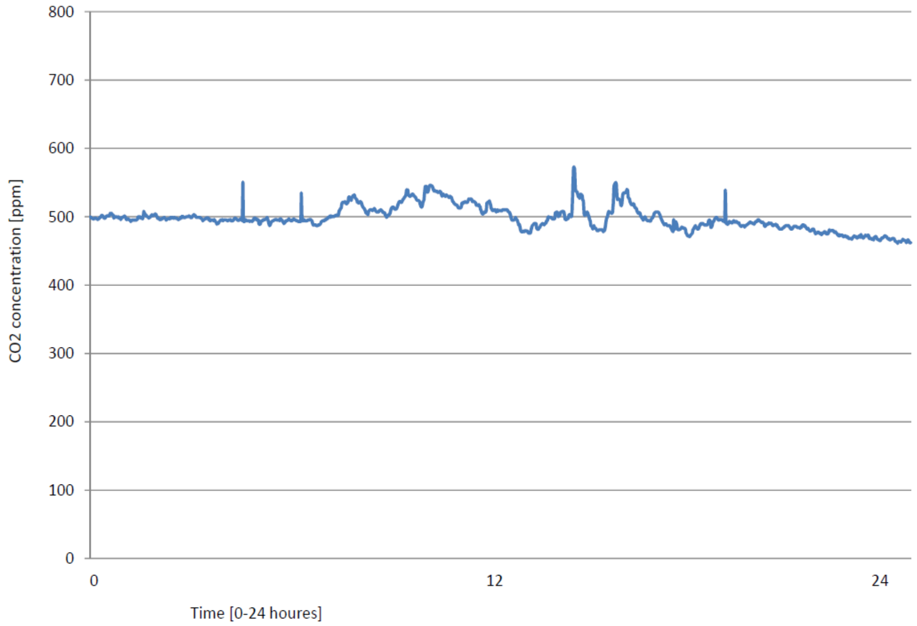

Figure 7. CO_2 concentration during one working day in building B

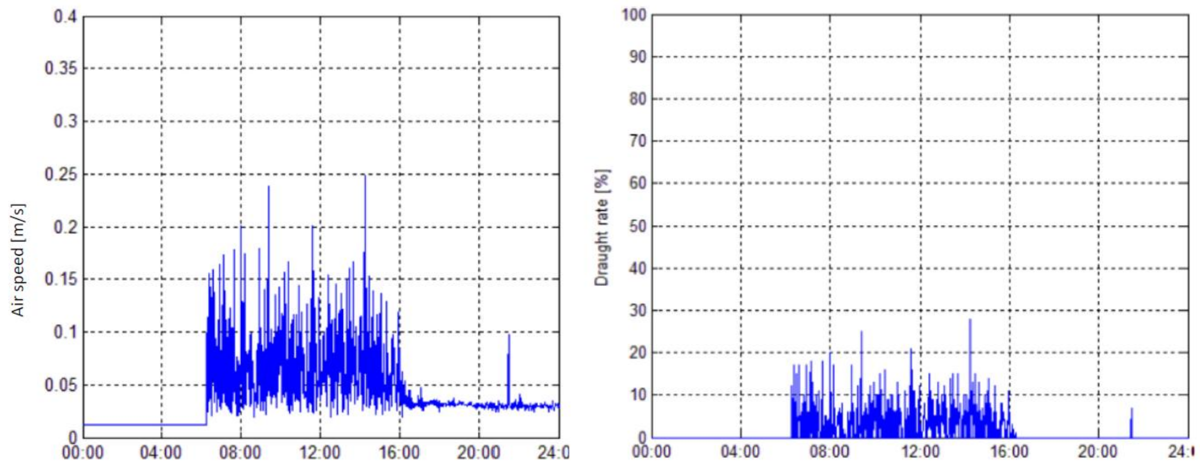

Figure 8. Air speed and draught rate in office B

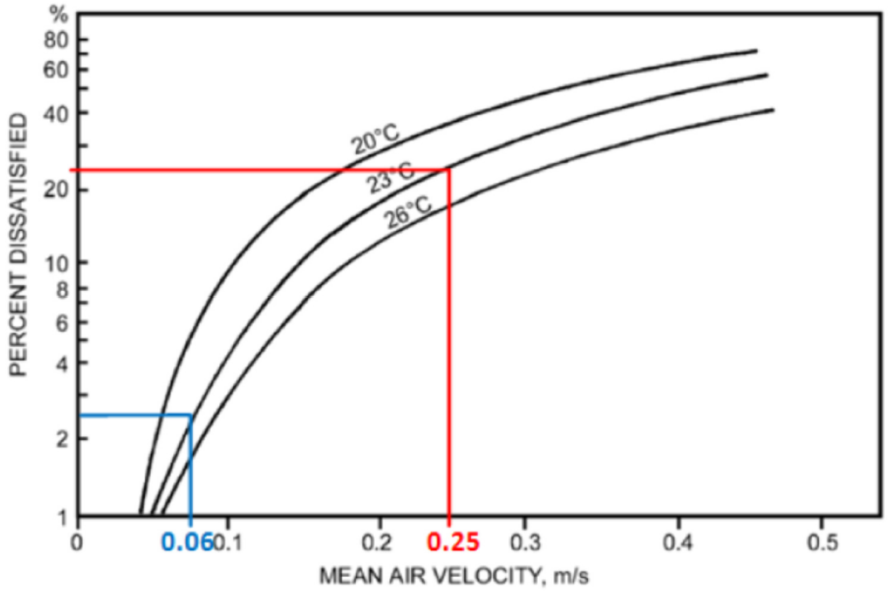

Figure 9. Percentage dissatisfied based on air temperature and minimum and maximum mean air velocity in office B

Building C

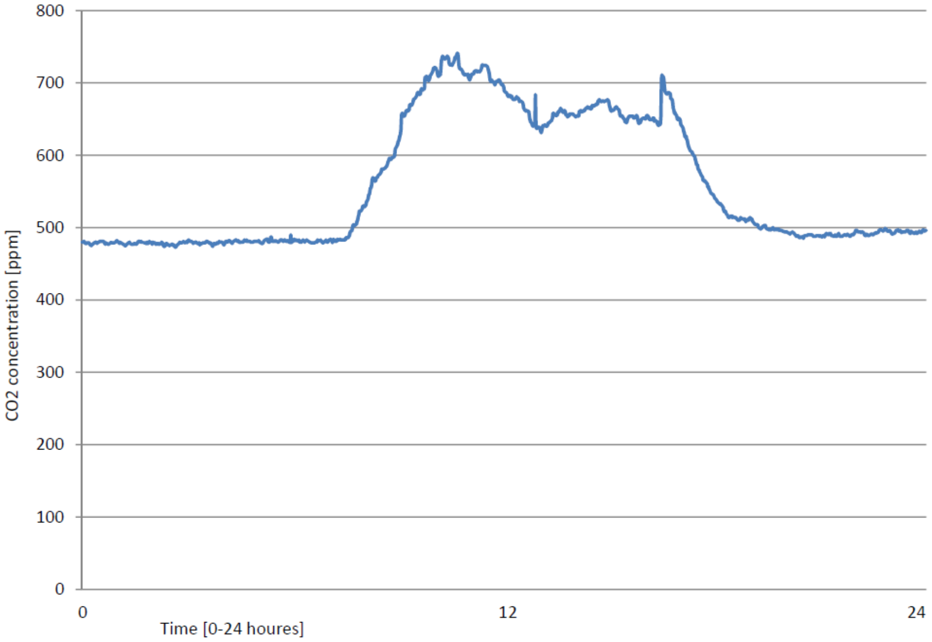

Figure 10. CO_2 concentration during one working day in building C

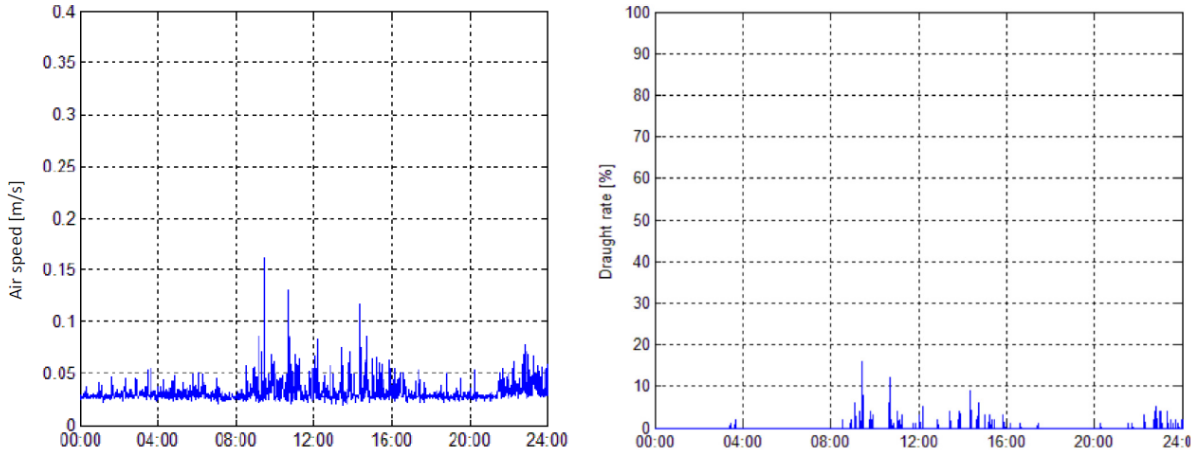

Figure 11. Air speed and draught rate in office C

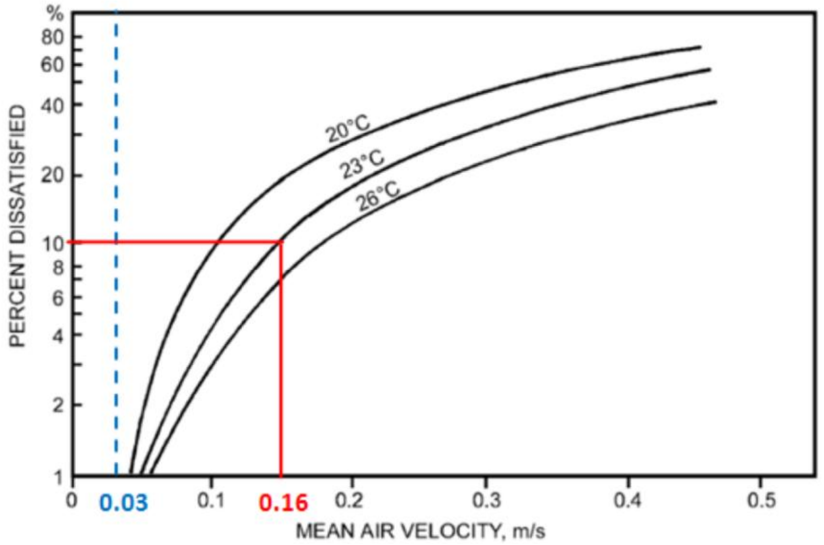

Figure 12. Percentage dissatisfied based on air temperature and minimum and maximum mean air velocity in office C

3.2 Questionnaires

The response for the buildings was nearly the same: 15(A), B(14) and C (14) and represent around 70% of the people in the direct area of the measurements.

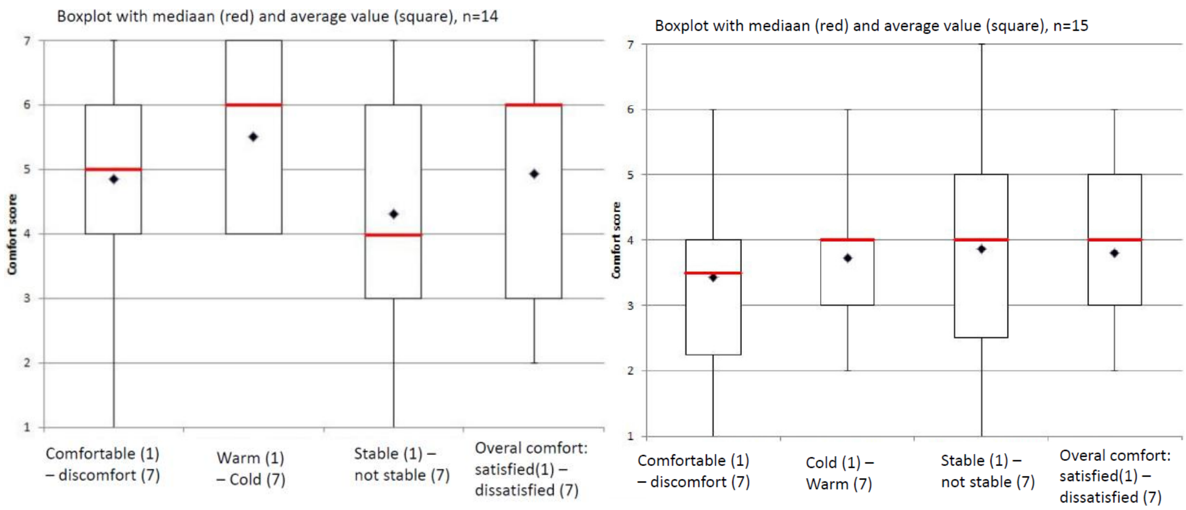

Figure 13. Office building A results winter and summer questionnaires

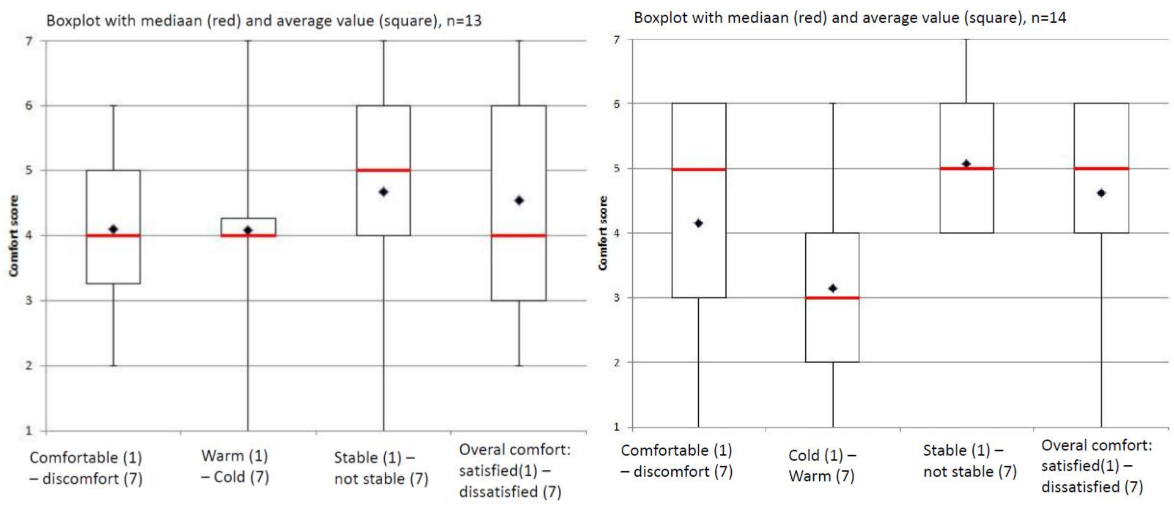

Figure 14. Office building B results winter and summer questionnaires

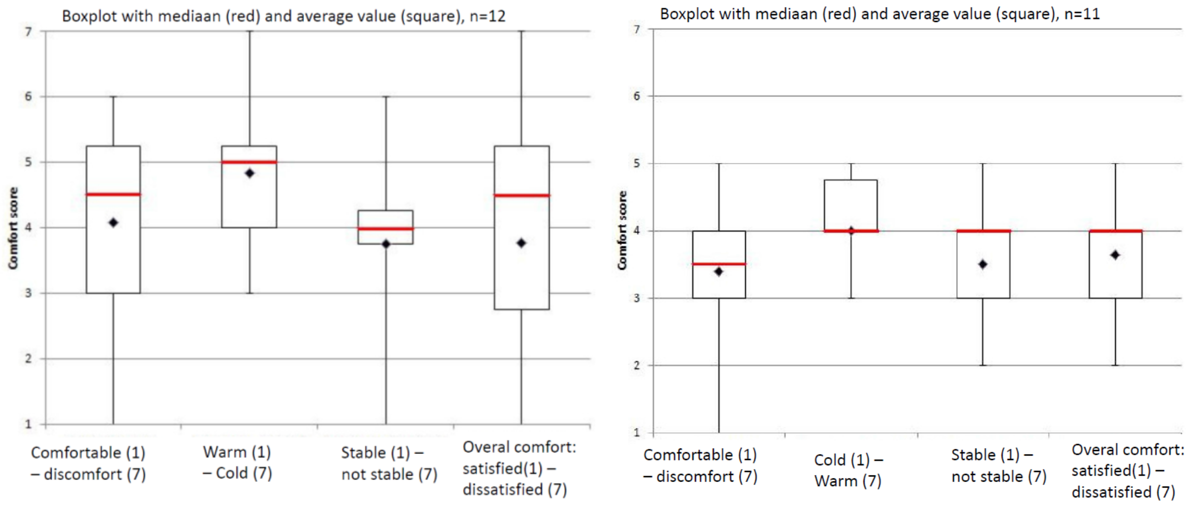

Figure 15. Office building C results winter and summer questionnaires

4 CONCLUSIONS

Air Quality
A relatively good indicator for the level of ventilation and indoor air quality is the CO2-concentration. The results presented in Fig. 4, 7and show that there are very low CO2 concentration levels within the measured office buildings. Definitely the mechanical ventilation does its work rather well.

Air speed
The figures 5, 8 and 11 give the measured air speed in an office. Guidelines give a maximum air speed of 0.15 m/s (Fanger 1970). The figures show that only in one case, office C, the air speed is always within these boundaries.

Draft
From Fig. 5, 8 and 11 it can be concluded that building C has an exceptional low draft rate, were as in building A and B the draft rate is around on aravege 10%.

PPD
PPD (predicted percentage dissatisfied (ISO 2005)), is calculated using metabolic rate of 65 W/m2 and clothing value of 1. From Fig. 6, 9 and 12 it is concluded that especially in building A there is unacceptable high draft rate where also building B shows a high draft rate.

Questionnaires
The results of the questionnaire for respectively temperature, stability of temperature, air speed, humidity, freshness and smell of the air showed on average not a very high rated satisfaction (on average around 4 on a scale from 1 (good) to 7 (bad).
Figure 13 to 15 show that the temperature is not quite acceptable during the winter (average scores resp 5.5, 4 and 4.8 on a scale from 1 to 7). The air speed stability, with an average score of 4 is also considered moderate comfortable.

Measurements and questionnaires provided an insight in the effects of TABS on the thermal climate itself and the individual perception. The following conclusions can be drawn from the measurements: TABS can assure an acceptable indoor temperature. Precaution has to be taken with the Hybrid Ventilation integration in the building façade. Since for TABS supply temperatures close to comfort temperature are used, there is little room for mistakes. Cold air from thermal bridges and natural supply ventilation cannot be counterbalanced by TABS. In the examined building, users keep ventilation grilles shut in order to prevent cold supply air from causing discomfort. However, this results in a climate where no planned ventilation takes place. The result of the measurements showed that extra care should be taken to the quality of detail finishing of the outer walls and facades. Often their quality is not as good as expected with major draw backs to the comfort of occupants.

Simulations are often used to study the influence of different aspects related to the use of TABS (Koschenz 1999). These simulations use per example the TRNSYS building simulation program (TRNSYS 2005), in which the Resisantance-Capacitance (RC) modelling approach (Weber and Johannesson 2005) for TABS has been gradually developed (Olesen et al 2006, Lehman et al 2007, Gwerder et al 2008, Ma et al 2013). However this field study, as well as an earlier field study (van Schijndel 2006) showed that in practice TABS encounter many in simulation unforeseen aspects which are sometimes critical for its functioning. Also in the study by Rijksen et al (2010) they found deviations between measurements and simulations due to to malfunctioning of some TABS. This because, especially with TABS the margin for the driving heating or cooling capacities are limited. Therefore the installed capacities should be not too much optimized based on simulation results but a safety factor should be applied to install some more capacity to be able to deal with practical imperfections.

The measurements and questionnaires provided an insight in the effects of TABS on the thermal indoor climate and individual perceived perception. The following conclusions can be drawn from the measurements: TABS itself can assure an acceptable indoor environment what temperature and indoor quality.

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