Building comfort performance assessment using a monitoring tool

Topic B12: Productivity and economics

BUILDING COMFORT PERFORMANCE ASSESSMENT USING A MONITORING TOOL

Peer van KEMENADE[1], Marcel GLC LOOMANS[1,*], Siem OPSCHOOR[2] and Jan LM HENSEN[1]

[1]Department of the Built Environment, Eindhoven University of Technology, Eindhoven, The Netherlands
[2]DWA, Bodegraven

[*]*Corresponding email: M.G.L.C.Loomans@tue.nl*

SUMMAR

Often a discrepancy exists between the theoretical and actual (perceived) comfort level in buildings. Monitoring tools, like Monavisa, are used to assess the building system performance. In this study, it is investigated whether and to what extent the data collected by a monitoring tool can also be used to assess the building comfort level. To this end additional measurements are done in three case study buildings, next to the data the installed monitoring tool collects from the building system. Furthermore, the occupants of these buildings filled in questionnaires about their comfort perception. Analysis and comparison of the measurement and questionnaire results with comfort standards and monitoring tool data showed that the building sensor, depending on its position in a room, can miss influences like solar radiation which are experienced by (part of) the building occupants. Assessment of this data may lead to an inaccurate comfort assessment for an entire room. Furthermore, it appeared that questionnaires are essential in giving value to the comfort assessment produced by a monitoring tool. This because a monitoring tool assesses the comfort parameters based on (theoretical) comfort standards, which may not apply to a practical situation and the actual indoor environment perception of the building occupants.

Keywords: In-use performance assessment, Building monitoring, Comfort perception, Comfort measurement, Comfort standards

INTRODUCTION

A comfortable indoor environment is an important parameter in the productivity, happiness and satisfaction of building occupants [1][2]. While comfort standards provide guidelines for what should be a comfortable indoor climate, often a discrepancy exists between the theory provided in these guidelines and the actual comfort perception of building occupants [3][4][5].

Meanwhile, monitoring tools are an emerging niche in the assessment of building system performance, assessing data collected by the building management system (BMS). The Monavisa monitoring tool, developed by DWA, is an example of such a tool [6]. Besides monitoring the building systems, Monavisa can provide an assessment of the indoor environment of the building, e.g. comfort, based on monitored performance indicators like temperature and CO_2-concentration. An example of the (visual) assessment that can be provided is shown in Figure 1. It can assess the data at different aggregation levels.

This study evaluated the comfort assessment by Monavisa, and provides a method and suggestions for future improvements and possibilities in building comfort performance assessment using a monitoring tool. It answers three research questions:

- How representative is the data monitored by Monavisa for the conditions in an entire room?
- To what extent does the comfort assessment by Monavisa correspond with the level of comfort perceived by building occupants?
- What possibilities does a monitoring tool like Monavisa offer in achieving a comfortable indoor environment for all occupants?

Figure 1. Monavisa interface and different levels of detail at which Monavisa shows information. From top to bottom: general overview for each category [Comfort, Energy, Building systems, Data availability]; overview for daily, weekly and monthly performance for each monitored room; detailed overview and assessment for each time interval and notifications for each monitored room [monavisa.dwa.nl].

METHODS

The research applied addressed three parts. First the validity of the data used and generated by Monavisa is analyzed. Secondly, this data is compared to the comfort ranges and limits set by standards like ISO, in which the ranges and limits which Monavisa uses for its assessment also are regarded. This produces outcomes on the (dis)satisfaction with the indoor environment. Finally, these results are compared to the actual perception of the indoor environment by the occupants, and the agreement with the prediction and assessment by comfort standards and Monavisa.

In order to evaluate the comfort assessment by Monavisa, additional measurements in three case study buildings, which are monitored by the tool, are performed. The case study buildings are located in the Netherlands. Building A is an office building with offices for about six occupants each. Building B is an educational institution where the offices for the staff also offer place for about six occupants. Building C is a fairly recently renovated office building with several large open plan offices. Occupants in this building generally do not have a fixed workspace. For each building three rooms, are selected where the measurement equipment was placed. Room selection was based on room layout and the preparedness of the occupants to cooperate in the surveys. The measurement lay-out aligns with the work of Wagner et al.[7] and Choi et al.[8]. In this paper only a number of results are shown.

Measured performance indicators are temperature (5-45^{o}C; ±0.4^{o}C), CO_2-concentration (50+2% reading ppm) and relative humidity (0-100%; ±2%). These parameters are used as key performance indicators (KPIs) by Monavisa for assessment of the indoor environment. Monavisa obtains its information from the BMS. Additionally, an indoor comfort measurement stand was applied for assessment of the local PMV and PPD (air velocity [0.05-1m/s; ±(0.02+1% reading m/s)], air temperature [0-50^{o}C; ±0.1^{o}C] and globe temperature [0-50^{o}C; ±0.1^{o}C]). In this calculation values for metabolism and clothing resistance are estimated. The measurement equipment is placed near the workspaces of the occupants, while the building sensors are positioned at the wall or in the ceiling. Measurements were done during the months May, June and July 2013.

As guideline for a (theoretically) comfortable temperature range, the ISO 7730 standard[9] is used in this study. According to class B as defined in the informative Annex of this standard, in summer a temperature of 24 ± 2 °C should be comfortable for most occupants. The comfortable temperature range for the case study buildings used in Monavisa however was set at 21 ± 2 °C, which was based on the personal insight of the responsible engineer. The building system therefore aims to keep the temperature within this range.

Next to the measurements, post-occupancy evaluation (POE) questionnaires among the building occupants are held in order to determine how the indoor environment is perceived and how these outcomes compare to the measured values. A custom questionnaire was created for this research, based on currently available questionnaires like those from the CBE[10] and HOPE[11]. The questions mainly focused on perception of the thermal indoor environment and indoor air quality. In two buildings, weekly questionnaires were held during six weeks, next to one general questionnaire regarding the conditions during the year. The results of these weekly questionnaires are compared to the daily assessment of the indoor climate by Monavisa (green (comfortable), yellow (almost uncomfortable), or red (uncomfortable)), in order to check the validity of the Monavisa assessment based on the calculated theoretical comfort range. In one building questionnaires were provided at the start and at the end of the measurement period.

RESULTS & DISCUSSION

When comparing the temperature measurement results, it appears that at several positions the temperatures measured with the equipment placed at the workspace are higher than the temperatures measured by the building system. An example of that is given in Figure 2 (top-left) where the measured temperature at the workplace is compared to the measured temperature at the room sensor for the building management system. Regarding the positions of the concerning workspace and the building sensor, the temperature difference in this case can be contributed to the influence of solar radiation. The results show that, depending on the position of the building sensor, the effect of solar radiation on the thermal sensation of occupants can easily be missed, and therefore lead to an incorrect (thermal) comfort assessment. Nevertheless, good agreement sometimes was found as well (Figure 2 [top-right]).

Comparison of CO_2-measurements (Figure 2 [bottom]) shows an example of a constant difference between the values measured by the placed equipment and the building sensor. This most probably can be contributed to offsets in the building sensor and/or measurement equipment, which may cause an incorrect assessment of the indoor environment (air quality).

The obtained measurement results indicate that the conditions in a room could be monitored more representatively by using multiple sensors for data collection (depending on the room and building layout). Offsets in measurement equipment may be accounted for to some extent.

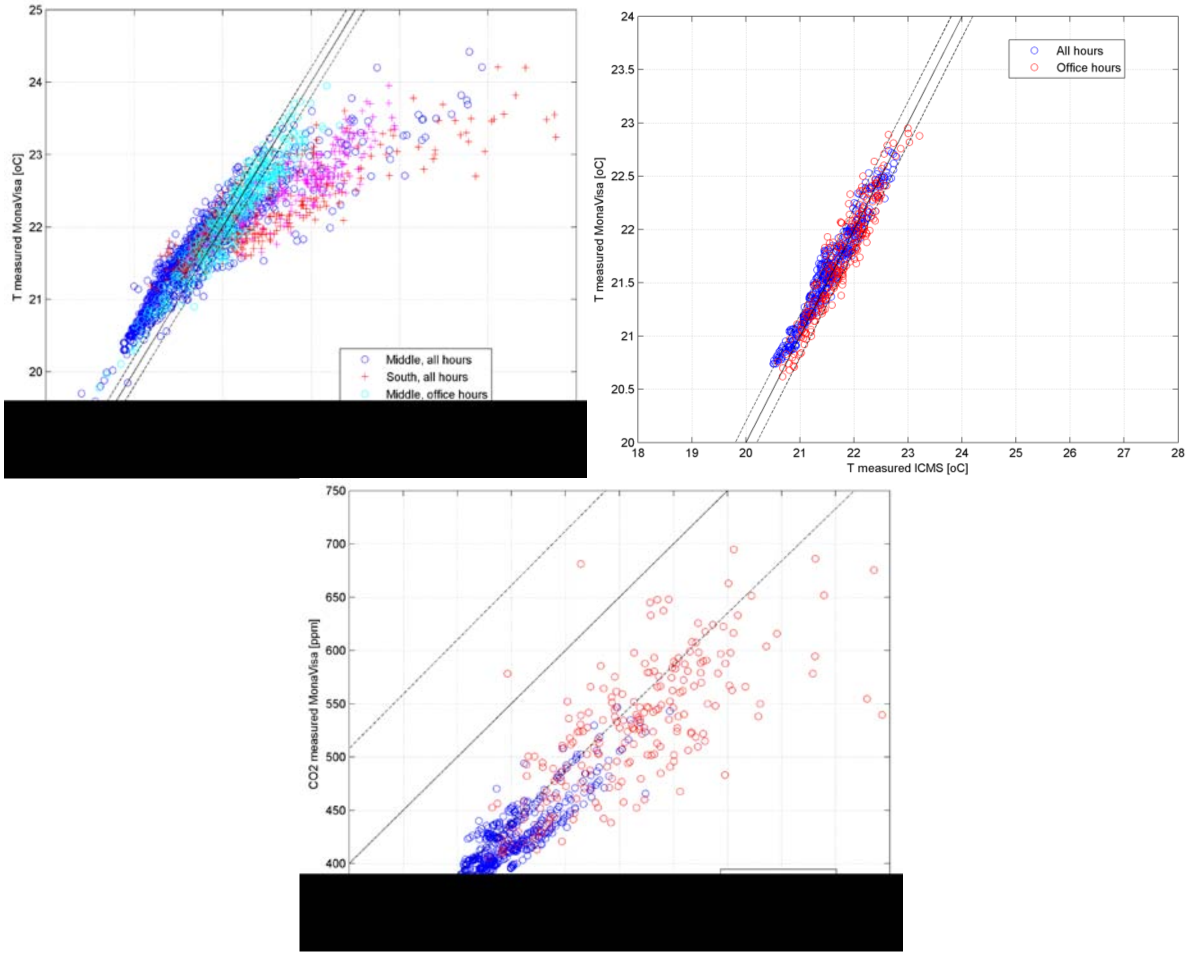

Figure 2. Top-left/-right: Measured temperature with the placed equipment (horizontal axis) plotted with the temperature measured by the building system (vertical axis). Bottom: Measured CO2-concentration with the placed equipment (horizontal axis) plotted with the CO2-concentration measured by the building system (vertical axis). The black lines indicate the equipment measurement error.

Measured temperatures in one of the case study buildings were generally around 21 °C (i.e. the set point set in the BMS), and therefore below the by ISO 7730 (informatively) proposed comfortable summer temperature range of 22 – 26 ºC. At these temperatures and assuming the PMV-value as derived from the measurements (figure 3, left), it can be expected that occupants would tend to rate the thermal indoor climate as ‘slightly cold’. Note, however, the sensitivity of the PMV towards the assumed clothing resistance and metabolism.

Assessing the questionnaires from this building it appeared that occupants voted more towards ‘slightly warm’/ ‘warm’ than ‘slightly cold’ / ‘cold’ (Figure 3, right). This shows that for this building the proposed comfort temperatures based on the standards would not have resulted in an improved perception of the thermal environment. The temperature range set for this case, based on personal experience, worked well and would assume that optimization of the set-point is better obtained through POE than through following the standard informative guideline for this building. Additionally, this may have interesting consequences for the operation of the building HVAC system and its energy use.

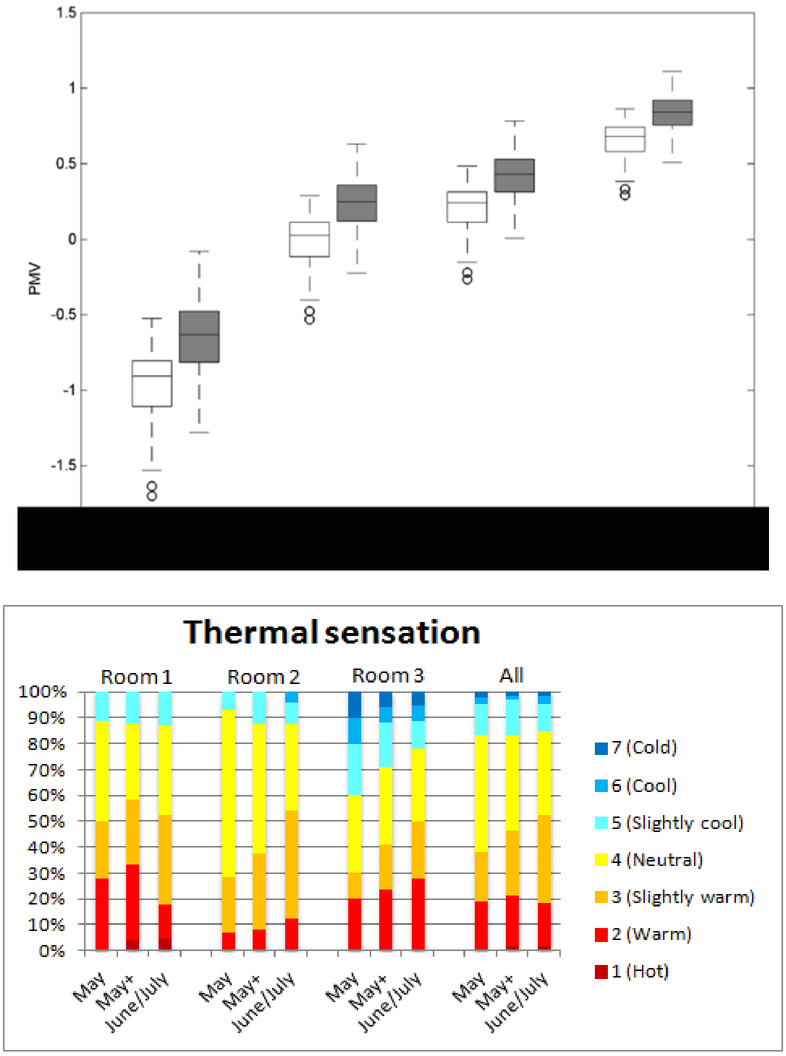

Figure 3. Top: PMV values calculated for four different combinations of met- and clo-values. Regarding the circumstances during the measurement period, the combination ‘1.2 met, 0.6 clo’ was most likely to occur, which corresponded to a PMV value of -1 to -0.5 (‘slightly cold’). Bottom: questionnaire results for thermal sensation votes in the same room.

Next to the implementation of comfort guidelines, the formulation of the comfort requirements is important when they are part of performance requirements set out in a building specification or rental agreement. Comfort guidelines generally define a maximum number of occupants ‘dissatisfied’ or a minimum number of occupants for whom the indoor environment has to be ‘acceptable’.

The requirements in place for one of the case study buildings could be interpreted as ‘80% of occupants satisfied’. Although in some research ‘satisfied’ and ‘dissatisfied’ are considered to be complementary, in this study a distinction is made between ‘satisfied’, ‘not dissatisfied’ and ‘dissatisfied’, in which the distinction is made for the ‘neutral’ vote (see also Figure 4 [left]). This neutral vote is regarded as being neither satisfied nor dissatisfied.

The graph in Figure 4 [right] shows the difference an expression of ’80% of occupants satisfied’ can make compared to an expression of ‘80% of occupants not dissatisfied’ (which could be defined similarly as ‘20% of the occupants dissatisfied’ or ‘acceptable for 80% of the occupants’). For overall indoor environmental quality (IEQ) the 80% requirement is met when formulated as ‘occupants being not dissatisfied’, while it is not met for ‘occupants satisfied’. Figure 4 also shows that it can be important to define to which performance indicator the formulated requirements relate. The 80%-requirement is met for overall IEQ, but not for thermal comfort (temperature) and indoor air quality individually.

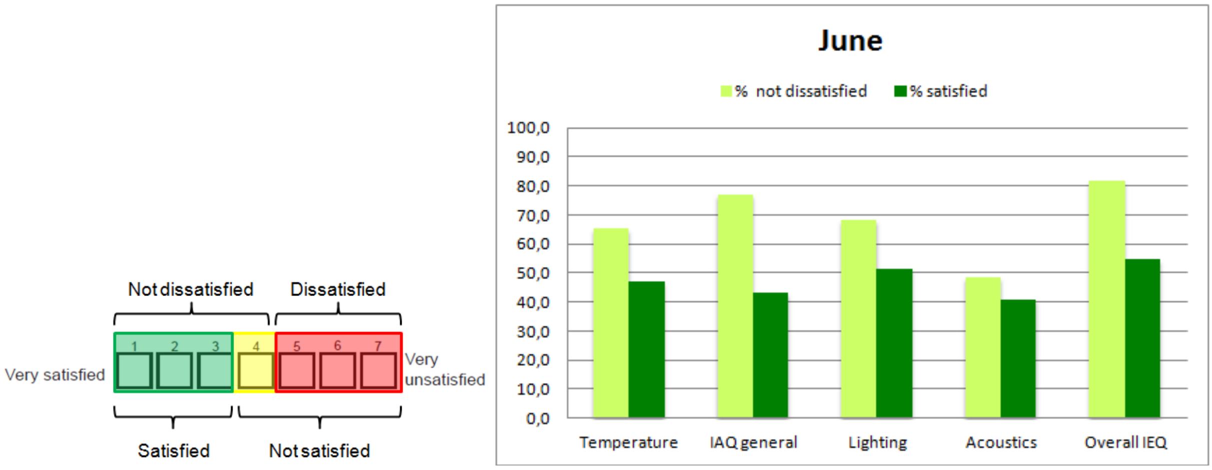

Figure 4. Questionnaire results for one of the case study buildings on occupant satisfaction with aspects of the indoor environment and overall indoor environmental quality (IEQ), divided between occupants who voted to be ‘not dissatisfied’ (vote 1 – 4) and occupants who voted to be ‘satisfied’ (vote 1 – 3).

CONCLUSIONS

When assessing the indoor environment using a monitoring tool, it is important to check whether the monitored data is representative for the conditions at the workspaces of occupants. The measurement results for the case study buildings show that when influences like solar radiation are not registered by the building system, this can lead to an incorrect assessment of the (perceived) indoor environment.

Questionnaires are important in giving value to the comfort assessment by a monitoring tool such as Monavisa, since a discrepancy between the predicted (guidelines) comfort level and the perceived comfort level at a specific temperature is not unlikely. A yearly questionnaire on the indoor environmental quality, optionally complemented by ‘right-now’ surveys, adds to the value of comfort assessment with a monitoring tool.

The direct applicability of the comfort standards in their current form for comfort assessment with a monitoring tool in an in-use situation is questionable. It is important to approach the indoor environment from the point of view of the occupants, rather than a theoretical point of view[12]. As theoretical values are often based on the average of a large group or on the ‘average person’, they normally will not apply to the individual occupant.

A monitoring tool like Monavisa, combined with POE questionnaires, may offer the possibility to reach a high percentage of satisfied occupants; at least higher than the 'acceptable for 80% of the occupants' standard which is currently handled by most comfort guidelines, as a monitoring tool can respond to information available from the building and its occupants. Based on this interaction, a monitoring tool combined with questionnaires may provide the opportunity of creating a 'comfort profile' for each monitored room, based on the preferences of occupants. On the other hand, the actually measured parameters provide the constraints for such a support. E.g. irregular noise disturbance or emission of odorous gases may affect the perception of the indoor environment, but when not measured these cannot be linked to potential causes for dissatisfaction. When using a monitoring tool for the assessment of the indoor environment, it is always important to realize what aspects of the indoor environment can (and cannot) be evaluated with the available data, and value the assessment in that context.

REFERENCES

[1] Cabanac M., 1986: 'Pleasure and joy, and their role in human life', in Clements-Croome, D. (ed.), *Creating the Productive Workplace*, 2nd edn, Taylor & Francis, London, p. 3 – 13.

[2] Clements-Croome D., 2006: *Creating the Productive Workplace*, 2nd edn, Taylor & Francis, London.

[3] Humphreys M.A. and Nicol J.F., 2002: *The validity of ISO-PMV for predicting comfort votes in every-day thermal environments*. Energy and Buildings, no. 34, p. 667 – 684.

[4] Humphreys M.A. and Hancock M., 2007: *Do people like to feel 'neutral'? Exploring the variation of the desired thermal sensation on the ASHRAE scale*. Energy and Buildings, no. 39, p. 867 – 874.

[5] Hoof J. van, 2008: *Forty years of Fanger's model of thermal comfort: comfort for all?* Indoor Air, no. 18, p. 182 – 201.

[6] Opschoor S., 2013: Vergelijken van werkelijke prestatie met prestatie-eisen. TVVL Magazine, no. 11, p. 34 – 35.

[7] Choi J.-H., Loftness, V. and Aziz A., 2012: *Post-occupancy evaluation of 20 office buildings as basis for future IEQ standards and guidelines*. Energy and Buildings, no. 46, p. 167 – 175.

[8] Wagner A., Gossauer E., Moosmann C., Gropp Th. and Leonhart R., 2007: *Thermal comfort and workplace occupant satisfaction — Results of field studies in German low energy office buildings*. Energy and Buildings, no. 39, p. 758 – 769.

[9] International Organization for Standardization (ISO), 2005: Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. ISO 7730:2005, International Organization for Standardization, Geneva.

[10] CBE (2012), Center for the Built Environment, last viewed 28 January 2014 <http://www.cbe.berkeley.edu>

[11] HOPE (2005), Health Optimisation Protocol for Energy-efficient Buildings, last viewed 28 January 2014 <http://hope.epfl.ch/index.htm>

[12] Moezzi M. and Goins J., 2011. *Text mining for occupant perspectives on the physical workplace*. Building Research & Information, no. 39, p. 169 — 182