PRACTICAL INVESTIGATION OF INDOOR ENVIRONMENTAL PARAMETERS MEASUREMENTS IN AN OFFICE-RETAIL BUILDING

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Keywords: indoor air quality (IAQ), indoor environmental parameters, monitoring, office retail building with constant air volume (CAV)

SUMMARY

The aim of this paper is to evaluate practical measurements of indoor environmental parameters in an office-retail building in Falkenberg, Sweden. The purpose of this study is to evaluate the monitoring data obtained from a building and to assess indoor environmental parameters, long-term comfort, and building classification of this building. The outcome of this paper lies in comparison of real conditions to the suggested conditions in national building standards. The evaluation is used to assess the potential for improvement of indoor conditions in this building.

INTRODUCTION

In Sweden, mostly due to the financial reasons the majority of commercial buildings still have a constant air volume (CAV) system compared to demand controlled ventilation (DCV) system, although the latter system allows a better control of indoor environmental quality and energy usage. The hypothesis in this paper lies in investigation of indoor climate conditions of an office-retail building (Figure 1) with CAV based on real measurements and in applying the results to improve the conditions in this office-retail building. This paper aims to show that monitoring and proper data evaluation are important parts of achieving of a good performing and optimised building.

METHODOLOGIES

Building Description, HVAC System, and Monitoring System

Built in 2009 this two storey building with a total floor area of 2 203 m^2 is used as offices (for the owner and rented to a third party), a retail with a packing area and a warehouse (Figure 1). The building envelope is made from steel and concrete, all insulated in order to reduce the thermal loss (total U-values in $W/(m^2.K)$: wall 0,315; floor 0,146; roof 0,193 and doors/openings 1,2). This building could be considered as a multi-functional building with an air and water based ventilation system. In this system there are two methods of ventilation and heating/cooling: air diffusers with constant airflow and climate beams with constant volume on the air side and variable on the water side. This system can be considered as a constant air volume system (CAV).

The building has HVAC system which is can be split in three sub-systems and each sub-system has one air handling unit with a rotary heat exchanger respectively (TA/FA1, TA/FA2 and TA/FA3). TA/FA1 serves a warehouse, TA/FA2 serves three building areas: office, retail and packing area: and TA/FA3 servers the area with offices rented to a third party (Table 1). Both office areas are heated and cooled by climate beams served separately by two air handling units (TA/FA2 and TA/FA3). In the common areas of both office areas (corridors and such) are installed air diffusers with constant airflow. The retail area is heated by air diffusers with constant airflow and cooled by a mix of central air and fan coils. The packing area is air-heated via air diffusers and cooled with an active beam above the work desk. Furthermore in this packing area (see additional design airflow of 300 l/s * in Table 1), a split system and extra heaters were installed when the purpose of this area changed from storage to a packing area and to compensate heat peaks during summer. The warehouse is heated to 16°C only by the air diffusers especially designed for large spaces.

Figure 1. Office building, located in Sweden.

Table 1. Building area served by TA/FA2 with total airflow of 1 800 l/s (+300 l/s *) and area descriptions including monitoring parameters (T = temperature, RH = relative humidity).

<table>
<tr><th></th><th>Area, floor area [m^2] and monitoring probe</th><th>Design airflow [l/s]</th><th>Monitoring parameters</th></tr>
<tr><td rowspan="5">IED</td><td rowspan="3">Office, 481 m^2 (2110, 2109, 2108)</td><td rowspan="3">752</td><td>• climate beam 1: T and RH for primary air, secondary air, incoming air (after coil)
• climate beam 2: T and RH for pressure and valve operation
• work desk 1: T and RH</td></tr>
<tr><td>• climate beam 3: T and RH for primary air, secondary air, incoming air (after coil)</td></tr>
<tr><td>• climate beam 4: T and RH for primary air, secondary air, incoming air (after coil)</td></tr>
<tr><td>Retail, 439 m^2 (101)</td><td>900</td><td>• behind a cashier: T and RH at 1,1 m</td></tr>
<tr><td>Packing, 514 m^2 (111)</td><td>175+300*</td><td>• climate beam 5: T and RH for primary air, secondary air, incoming air (after coil)
• work desk 2: T and RH at 1,1 m and T at 0,1 and 1,8 m</td></tr>
<tr><td>AHUD</td><td>Unspecified</td><td>-</td><td>• T for exhaust air from office area, supply before main coils, supply after main coils (office duct), supply after post heat coil (retail duct)</td></tr>
</table>

Monitoring of indoor climate conditions (Indoor Environmental Data = IED) is accomplished by data loggers (temperature and relative humidity) placed in different places in the building: in several rooms in owner´s offices and a retail with packing area. Due to a request from facility management personnel extra loggers were placed in the packing area in order to evaluate air stratification. The time step for logging of data is every 6 minutes and the monitored data are collected by a computer managed via a remote connection. The TA/FA2 (Air Handling Unit Data = AHUD) is monitored by an internal control system which collects information about temperature, humidity, fans power, and airflows and pressures, and other parameters with a time step of 30 minutes. The outdoor climate data are supplied by meteorological station Torup A by SMHI (2014).

The monitoring period for IED was February 2011 – October 2013 and for AHUD it was March 2011 - March 2012. In this paper only results from monitoring from respective building areas (as defined in Table 1) are evaluated.

RESULTS AND DISCUSSION

Evaluation of Complexity of Monitoring Data

In this paper parameters from IED measurements collected in 2012 from office rooms 2110, 2109 and 2108 are the most complete (100%), yet for the office rooms 111 and 101 there are some months where recorded data were partial (99,0% and 98,6%) due to malfunctioning on the probes. The data for AHUD (temperature and airflow) were considered as the most complete data in year 2012 (96,0% complexity of data).

Complexity of IED and AHUD including Findings

The evaluation of IED shows that all temperature graphs are similar and have expected profiles, apart from missing data gaps. It can be assumed that the collected data are credible.

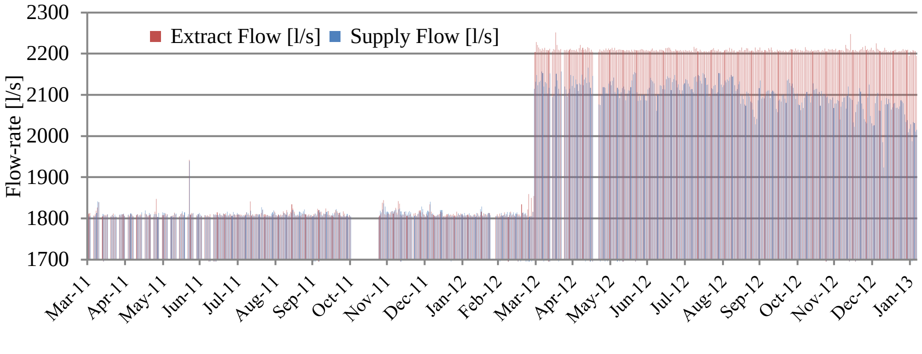

Figure 2. Extract and supply airflow values for TA/FA2 (missing data and increase of airflow).

The indoor temperature measurement in AHUD shows that there are no missing data and the profile of indoor temperature is coherent with outdoor temperature. As for airflow values, Figure 2 shows the complexity of data (missing data in 2011 and in 2012 as white gaps) and in addition there is an increase of airflow from the end of March 2012 when the usage of packing area has changed. Before the increase of airflow the building was pressure-balanced, and after airflow increase the building is evidently in under-pressure state with the possible leakage of external air through the building envelope, which influence performance of HVAC system.

In AHU TA/FA2 there is a bypass option which is usually beneficial to use during night time and the absence of people (Saturdays afternoon, Sundays and holidays). Using a bypass the internal air would be recirculated in a building which would reduce required energy; and due to the bypass of rotary heat exchanger, also electrical fan power would be reduced as the fans have less pressure drop to compensate for. Because of specific fan power (SFP) is measured as a sum of specific power for both fans, the night mode regulation should allow to turn off the exhaust fan and lower down SFP significantly because of the fact that the pressure drops in the heat exchanger are bypassed. In Figure 3 it can be seen how this is not happening during the bypass function, perhaps due to a wrong regulation.

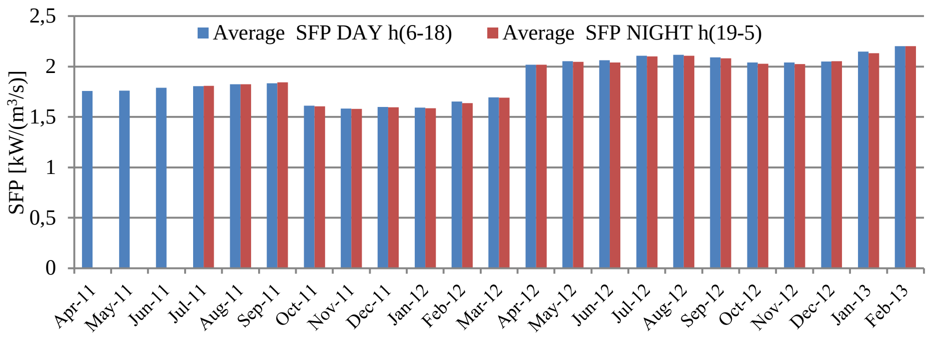

Figure 3. Monthly average of specific fan power (SPF, kW/(m^3/s)) in day/night modes.

Evaluation of Indoor Environmental Parameters in a Building

From the recorded data information can be extracted on indoor environmental parameters of temperature and relative humidity in the occupied areas of the building and to evaluate if the mechanical ventilation is performing as required by standard values suggested by ISO 7730 (2005). In this work it was chosen to focus on weekly comparisons of outdoor temperature and indoor temperature (measured at height of 1,1 m as the best representation of operative temperature). Besides it was chosen to focus also on air stratification in the packing area due to complaints of cool discomfort during winter time.

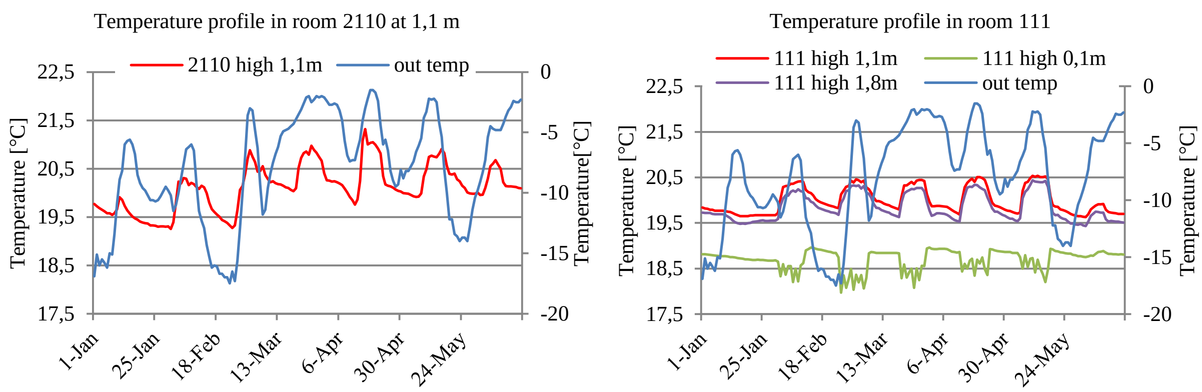

Figure 4. Indoor and outdoor temperature weekly profiles at office room 2110 and packing area 111 (temperature stratification).

In Figure 4 the profile of indoor temperature is fluctuating accordingly to the outdoor temperature except for weekends, where a drop of indoor temperature of 2°C is allowed. In packing area 111 there is also fluctuation of temperature and it can be seen that temperature at 1,1 m is higher than the temperature recorded at 1,8 m. This is unexpected, but might be explained with proximity of computers that could false the records. In this rather detailed measurement it is shown that also the temperature at 0,1 m is low (around 18,5°C), which might be in accordance with the complaints received from the facility management personnel. It should be noted that it is a working area, so rather lower temperature could be allowed due to the higher *met* (activity level). It should be taken into account that the analysis in Figure 4 considers just one measurement location and it might not be a true representation of the whole area, in fact the complains might be referred to the area close to the warehouse with a temperature lower than the packing area. Because of that this point would need further investigation.

Long-term Comfort

The focus is on analysis of long-term comfort conditions based on the calculations of the environmental comfort indexes Percentage of People Dissatisfied (PPD) and Predicted Mean Vote (PMV), in other words the monthly accumulated hours in which people are feeling discomfort. The calculating procedure of PPD and PMV follows the standard ISO 7730 (2005) including calculation of other related parameters (*met* as activity level in Table A.1 in ISO 7730 (2005), *clo* as clothing level based on De Carli et al (2006)). Another required parameter is a sum of weighted time factors (WT_{warm} and WT_{cool}) as defined by Olesen (2000). In this work, WT_{warm} and WT_{cool} were evaluated for the different building´s areas and these factors were related to mean monthly temperature recorded in the respective areas.

Some authors assess that an appropriate value of weighted time factor (WT_{warm} or WT_{cool}) may be a total of 100-150 hours per year. In existing standards there is still no limit value for this parameter, but using this procedure it is necessary to consider the building use and the geographical location to understand where to go for the optimization of comfort conditions without increasing energy need of a building too much as explained by De Carli (2006).

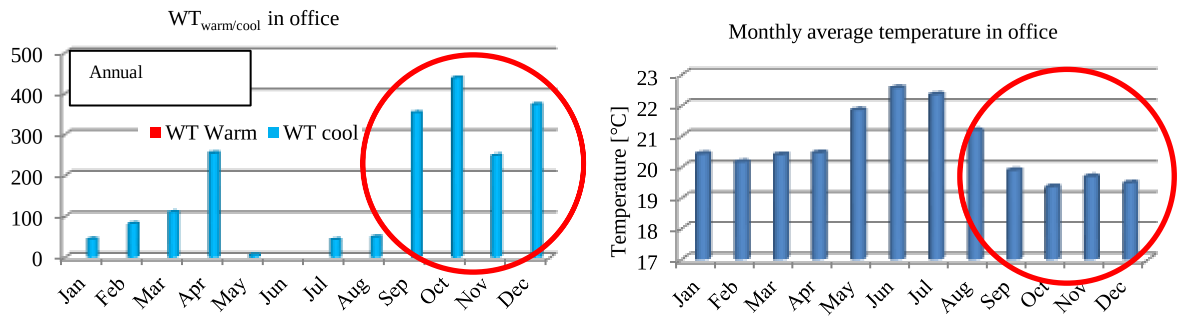

Figure 5. Monthly and annual weighted time factor (WT) and monthly average temperature in office.

Figure 5 shows significant cool thermal discomfort (WT_{cool} = 2 007 hours; WT_{warm} = 0 hours) in office rooms, where the correlation between increase of cool discomfort and decrease of temperature is marked. The results for the retail and packing areas in Figure 6 show the same relation with the recorded temperature but reversed WT, i.e. retail (WT_{cool} = 0 hours; WT_{warm} = 780 hours) and packing (WT_{cool} = 0 hours; WT_{warm} = 1 017 hours). The indoor temperature profiles for these two areas are almost the same as the ones recorded in the office.

To summarize, the analyses show various types of discomfort in the investigated building areas. Yet, it must be stressed out that analyses are done with standardized parameters, not considering the real thermal feeling of people inside the building. In addition, it is interesting to notice that in an area with high personalization of temperature (offices) the only discomfort condition is the cool one; otherwise in the centralized controlled areas (retail and packing) only warm discomfort is noticed, coherent with the post-installation of a split unit in packing and two fan coils in the retail areas. That allows assumption that a cooler temperature is desired inside this building.

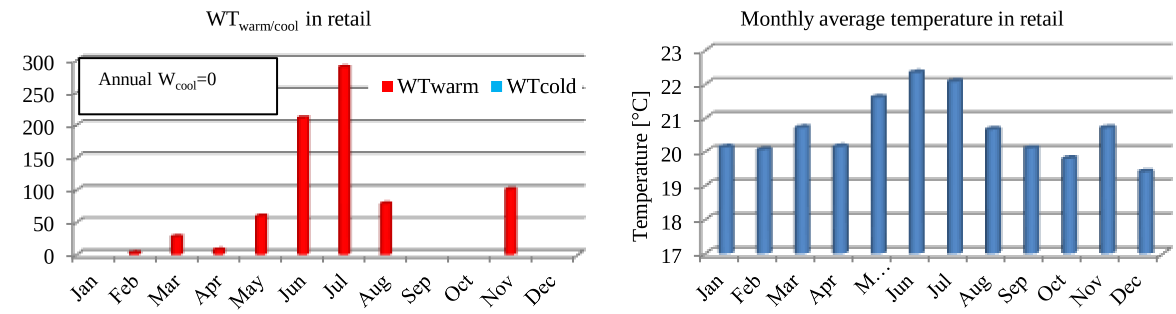

Figure 6. Monthly and annual weighted time factor (WT) and monthly average temperature in retail.

Building Classification

The main design values from the building standard EN 15251 (2007) are used when designing a building, i.e. recommended indoor temperatures for heating/cooling for energy calculations in various types of buildings (Table A.3 in EN 15251 (2007)) and designed criteria for the humidity in occupied spaces if humidification/dehumidification systems are installed (Table B.3 in EN 15251 (2007)). These design values can be used also retrospectively for evaluation of a current monitored building. In this paper, considering the available data, the choice is to focus on energy and relative humidity classifications.

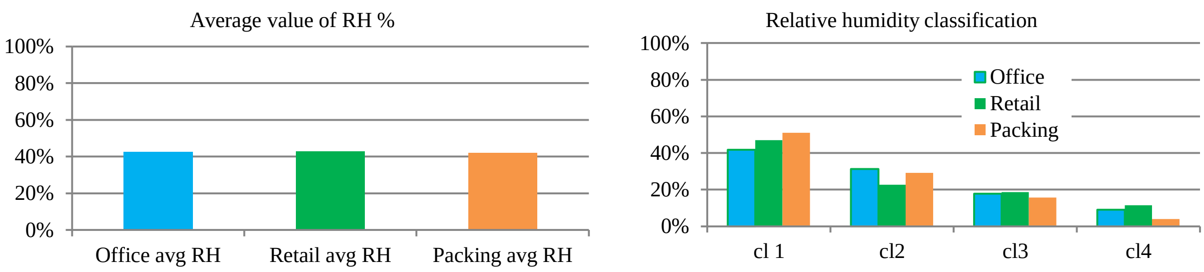

Figure 7. Relative humidity classification based on EN 15251 (average and detailed).

For evaluation of relative humidity (RH) classification during occupied period are used measurements at height of 1,1 m for an office room 2110, retail 101 and packing area 111 (Figure 7). The graphs show that the average relative humidity is approximately 42% for office, retail and packing areas. The detailed result show that almost half of the results are falling in between 43-52% for all monitored building´s areas. All these results show the compliance with the *class 1* with RH varying between 30-50%.

The same procedure is done for energy classification for winter and summer periods in accordance with the building standard EN 15251 (2007). The overview of energy classification (Figure 8) shows that in winter period the office falls in *class 1* and retail with packing area falls in *class 2*. *Class 2* in retail and packing areas seem to be acceptable although for more than third of the time the temperature falls between 17,5-20,5°C in winter period (Figure 9). This could be solved by more accurate regulation in retail and packing areas.

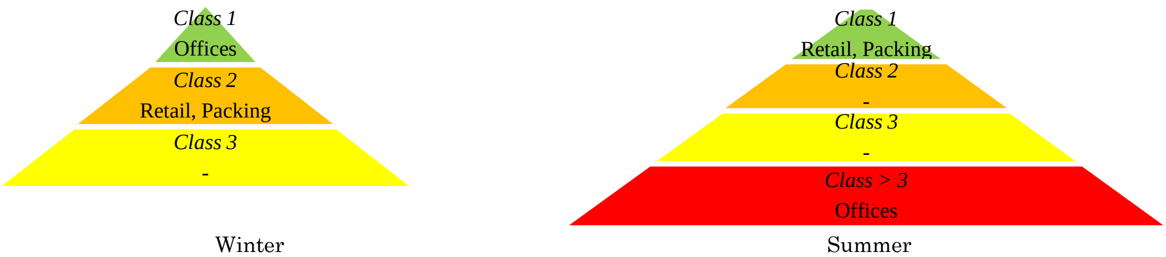

Figure 8. Overview of energy classification for office, retail and packing areas (for winter and summer periods).

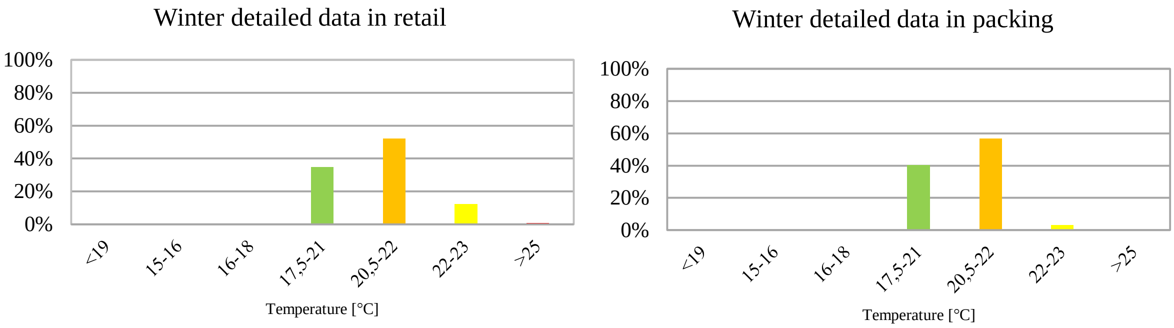

Figure 9. Detailed energy classification for retail and packing areas in winter period (total and split in temperature ranges).

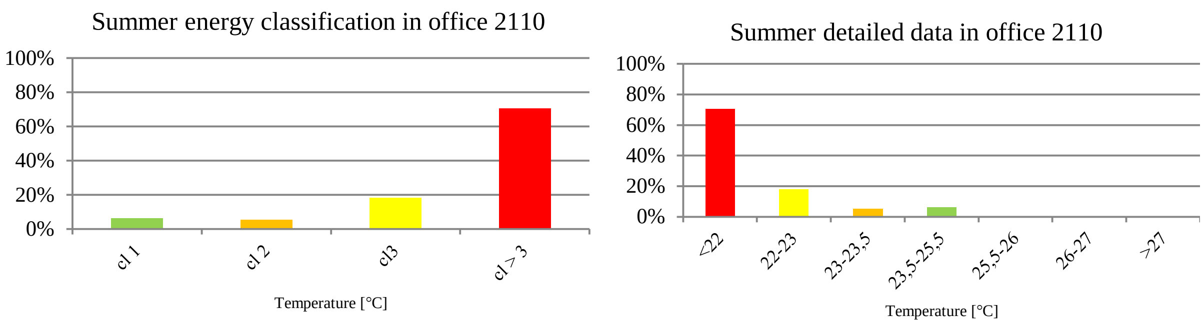

Figure 10. Detailed analysis of energy classification in office area in summer period (total and split in temperature ranges).

Considering office area (Figure 10) it can be noted how the summer temperatures are lower than the maximum contemplated in the building standard EN 15251 (2007). In Figure 10 temperature in summer is 2/3 of time below 22°C and this means that it falls even outside *class 3*. Further consideration should be done linking these analyses with the long-term comfort evaluation in order to further assess energy consumption related to long-term indoor environmental parameters.

RESULTS AND DISCUSSION

The results from analyses of monitoring data of IED and AHUD show that there is a problem with extract and supply airflows which seems to create higher than normally expected under-pressure and it influences efficiency of HVAC system in a building. Also the night mode regulation does not seem to be effective, i.e. lowering of SPF during unoccupied period.

The evaluation of IED shows that the stratification of indoor temperature in packing area is uneven. In addition, in the area with high personalization of the temperature (office rooms) the only discomfort condition is the cool one, otherwise in the centralized controlled areas (retail and packing) only warm discomfort is noticed, coherent with the post installation of a split unit in the packing and two fan coils in the retail areas.

The relative humidity levels in investigated areas are within the range of recommended values for *class 1*. The energy classification in winter is *class 1* for offices and *class 2* for retail with packing area. The office area has rather low summer temperature. In retail and packing areas there is a possibility for improvement via a better regulation.

CONCLUSIONS

The common feature for all three areas (office, retail and packing), in most of the cases, are all over-heated or over-cooled. More careful regulation of HVAC system would reduce energy consumption and also increase the energy class of the whole building, as well as delivering a better indoor environment.

FURTHER WORK

The further work will focus on comparison of constant air volume (CAV) and demand controlled ventilation (DCV) systems in order to show the performance levels in the different situations. This work is based on master thesis project by Errico (2014) in cooperation of Swegon AB and University of Padua.

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