Assessing the energy use and IAQ of various HVAC systems during the early design stage

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ABSTRACT

The early design stage of a building is decisive for describing the concept of the HVAC system. Designers and practitioners can adjust and optimize the design during this stage as it provides them with enough resilience to adapt new changes. In practice, a well-defined optimization process is essentially required in order to achieve the project's goals within a reasonable time span. These goals vary from one project to another, and sometimes they require a comprehensive study to identify the factual and stochastic parameters and their impact on the design. This paper presents a workflow process to design three Heating, Ventilation, and Air-Conditioning (HVAC) systems for a modern Swedish office building focusing on operational energy use and Indoor Air Quality (IAQ) indices. The workflow follows a bottom-up approach starting from analysing the building's requirements, then defining multiple concepts for the HVAC system, and eventually, quantifying the systems' performance by the means of comparative study. The three HVAC concepts included in this study are; airborne constant air volume (ON/OFF), airborne Variable Controlled Ventilation (VAV), and hydronic system integrating Active Chilled Beams (ACB). The first two systems rely solely on air as heating and cooling medium, while the ACB system requires water circuit and primary fresh air to provide the necessary induction. All three systems are designed to maintain a certain limit of operative temperature that varies depending on season and occupancy schedule. Furthermore, the design criteria states that all systems must achieve a good indoor climate with low sound levels and air speeds in the occupied zone. The study shows that all three systems have an operational energy use under the limits prescribed by the Swedish building regulations. However, a significant reduction in the size of air ducts and operational energy use can be achieved when implementing an ACB system when compared against ON/OFF and VAV systems. This reduction in energy use comes in the expense of relatively higher operative temperatures during the occupied summer periods, as lesser amount of air is supplied to the zone. This increase in temperatures is correlated with higher performance loss in office tasks performed by the building occupants. An optimization of the ACB system is suggested in order to compensate the performance loss by lowering the thermostat control point of the ACB's. This scenario would increase the cooling energy use compared to the base case, but, at the same time, ensures an overall reduction in comparison with ON/OFF and VAV systems.

KEYWORDS

energy use, IAQ, optimization process, task performance

1 INTRODUCTION

The decisions made during the early design stage are highly important to ensure a smooth process that achieves the desired goals during the lifetime of a project. Bragança et al (Bragança, Vieira, & Andrade, 2014) discussed the influence of a well-planned project that includes sustainable criteria on the reduction of both negative impacts and project cost increase. This study aims to provide a well-defined process that includes all parties involved in building projects. The process emphasizes on the importance of understanding the needs from each person involved in the project. This would serve the purpose of reaching to collective-optimal decisions, while avoiding uncertainties regarding the design criteria. The study also highlights the possibility to include different proposals during the early design stage, and how a final decision could be made based on qualitative and quantifiable measures.

2 METHODOLOGY

The reference building used in this study is shown in Figure 1. The modern Swedish office building is divided into six thermal zones where each has an occupancy pattern based on the suggestion of (Halvarson, 2012). These occupancy patterns are utilized in the operation of the HVAC system, where the control strategy of the mechanical system relies on both temperature and occupancy sensors.

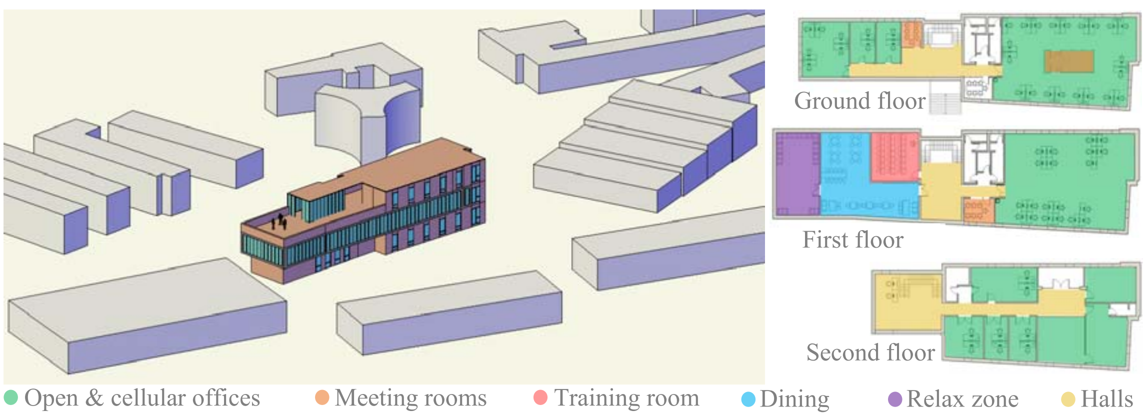

Figure 1: Conceptual view of the office building together with the thermal zones separation.

A process to define clear objectives during the early design stage is suggested by the authors of this study, see Figure 2. The process ensures an agile workflow that involves all parties included the early design stage. Starting from the needs prescribed by the building owner, moving to the architect who designs the building envelope and interior circulation, up to the HVAC engineer responsible for designing and steering the mechanical systems. The suggested process provides more flexibility to adapt new changes that occur at any time during the early design stage. In this study, the first step in the process focuses on the architectural model where the building envelope has an average U-value that complies with the latest regulations of the Swedish building code BBR (Boverkets byggregler, 2018). Once the thermal zones have been designated, each zone is appointed to an occupancy pattern to define sources of internal heat gains. The second step is to integrate the occupancy patterns with the logic of the temperature control strategy. For example, for an office zone that is occupied at 11:00 hours, the zone is maintained at an operative temperature not exceeding 26 °C and 22 °C in summer and winter periods, respectively. On the other hand, when the office is not occupied, the mechanical system is regulated by a setback operative temperature of 28 °C and 18 °C in summer and winter periods, respectively. The advantage of the setback temperatures is to avoid high thermal powers when the zone is occupied after vacant periods, as seen on the first occupancy day after weekends and holidays. Subsequently, the three suggested HVAC concepts are defined in terms of operating schedules, required air volumes for fresh air according to Standard BS EN 15251:2007 (British Standards Institute, 2007), and required air and water volume flow rates to achieve the desired zone temperatures. The ON/OFF system has two operating modes, the first of which is to supply the maximum air volume when the building is occupied, the second mode supplies only the hygienic flow when the building is unoccupied. The VAV and ACB varies the air and water volume flow rates, respectively, according to the occupancy pattern. Later, the three systems are designed and simulated in order to assess the performance of each system in terms of energy use and IAQ. Energy modelling and indoor climate simulations are carried out using TEKNOsim software (Lindab AB, 2018). CADvent (Lindab AB, 2018) is used to design and draft the HVAC system. lindQST (Lindab AB, 2018) is a web application for product selection and indoor climate simulations of rooms integrated with products. The task performance in office environment is calculated according to the equation provided by Seppänen et al (Seppänen, Fisk, & Lei, 2006) as shown in Equation 1.

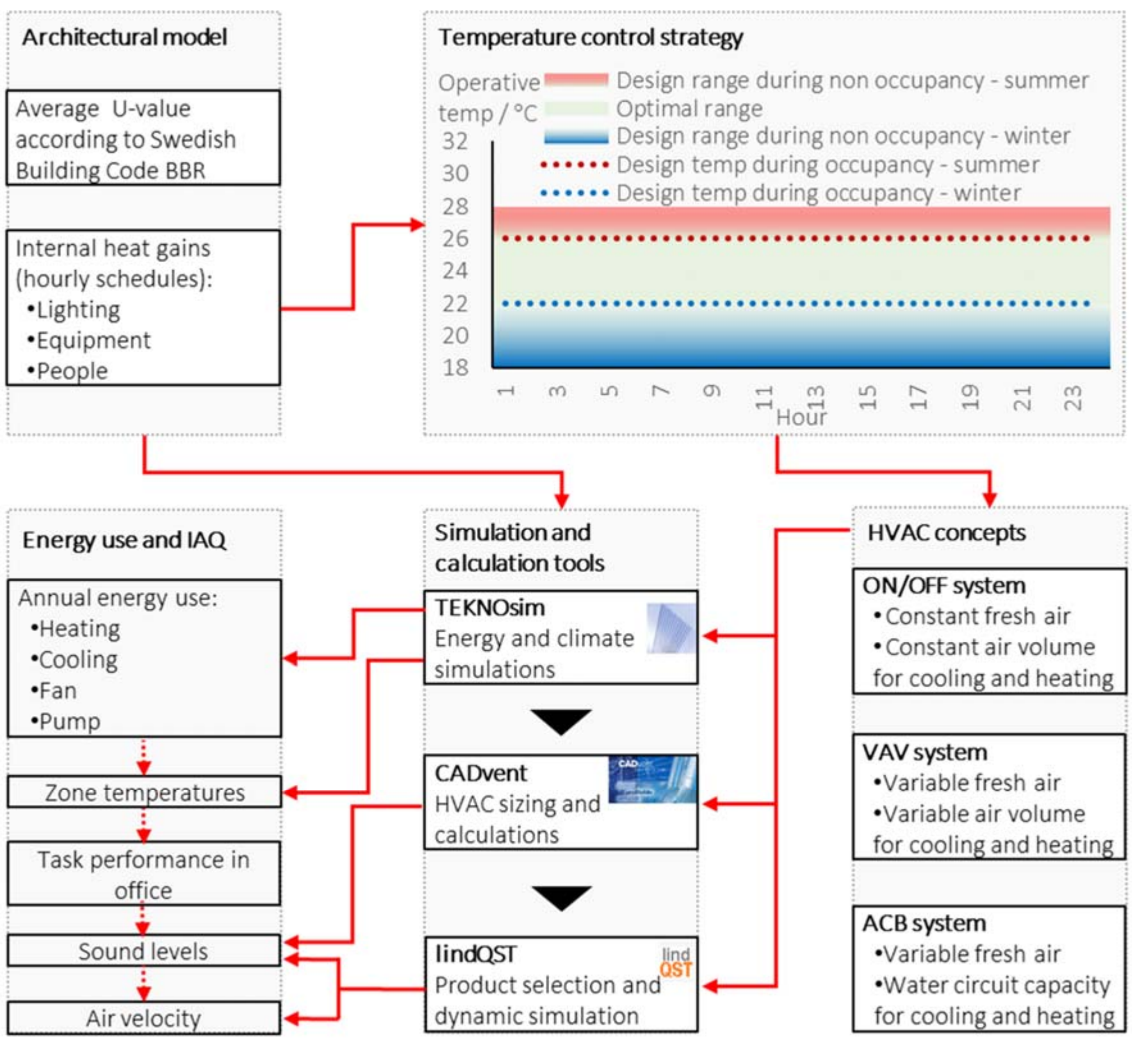

Figure 2: An overall process for optimizing the building design during the early design stage.

Finally, the output of each software is generated and the results are analysed, where the maximum allowed sound level should not exceed 30 dB(A), and the air velocity in the occupied zone should be below 0.2 m/s.

$$P = 0.1647524 \cdot T - 0.0058274 \cdot T^2 + 0.0000623 \cdot T^3 - 0.4685328 \tag{1}$$

Where:
P is productivity relative to maximum value
T is room operative temperature in °C

3 RESULTS

The design of the three HVAC systems is shown in Figure 3. It can be seen that the first two system, ON/OFF and VAV systems, require larger ductwork in order to deliver the necessary air volumes for heating and cooling. This demands a bigger space in the suspended ceiling to ensure a non-exposed ductwork. Furthermore, these two systems have a bigger size for air handling unit. Hence, bigger size of cooling and heating coils is required to treat the air to the desired supply conditions. On the other hand, the ACB system has the smallest duct and air handling unit size, where all of the ducts are circular. The circular ducts yields to lower pressure drop in the system, and consequently lower specific fan power. In addition, the ACB system becomes much more beneficial in large multi-story buildings, where it can have more stories for the same building height when compared against ON/OFF and VAV systems.

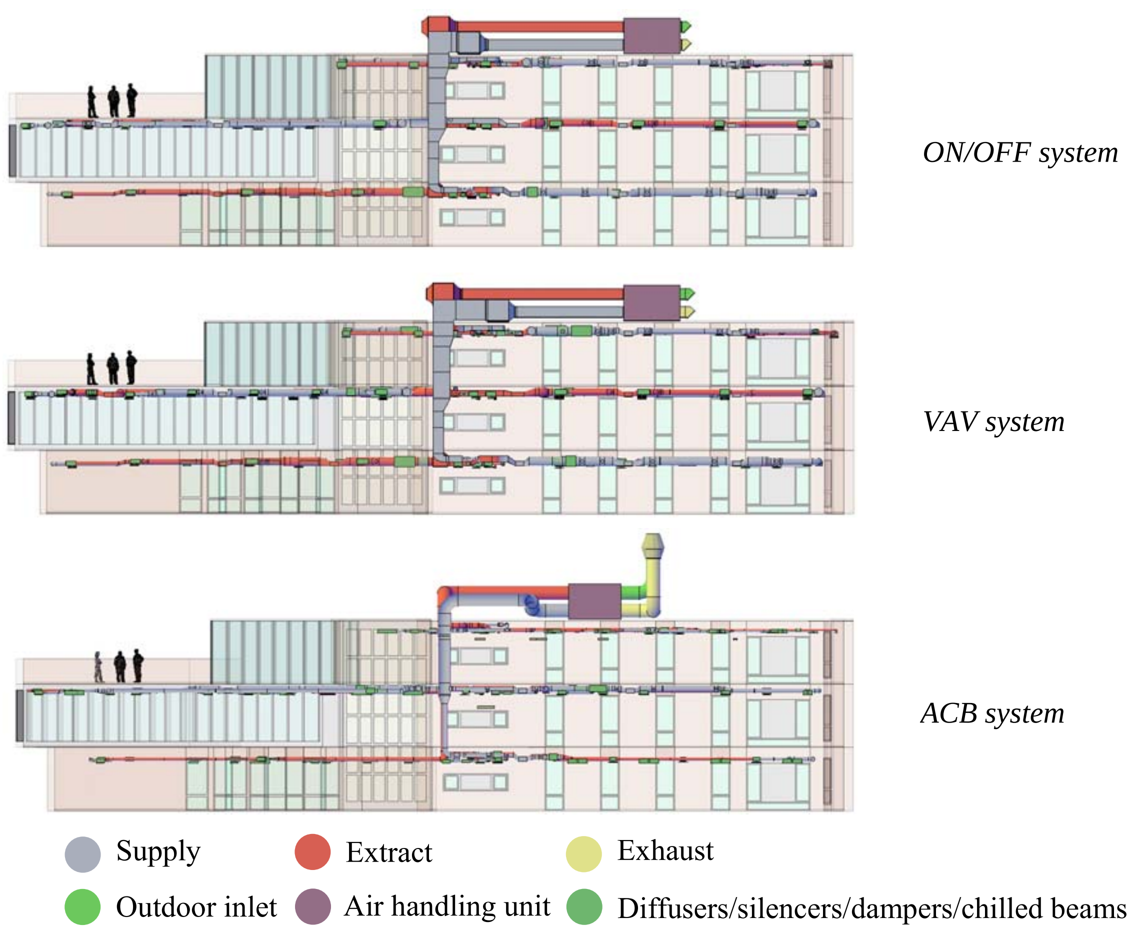

Figure 3: Cross section of the three HVAC systems superimposed on the building.

The hourly operative temperatures in offices during occupancy periods have been exported from TEKNOsim software and converted into a relative performance using Equation 1. Figure 4 shows the relative performance for a given system on the Y-axis, and the relative performance of ACB system on the X-axis. The ACB system is believed to have the best task performance when compared to the other two systems. This is why the task performance of the ACB system is used as a reference case. The values in Figure 4 are sorted in an ascending order, where the maximum performance of 1.0 occurs at a temperature of 21.75 °C. The ON/OFF system, represented in circles, has a best-fit regression line with a value of 0.9563 in comparison to the performance of ACB system. This means that the ACB system provides a better IAQ with temperatures that correlate to higher performance from the occupants. On the other hand, the VAV system, represented in triangles, shows a lower value for the best-fit regression line with a magnitude of 0.8948. The lower performance in VAV system corresponds to the fact that the system varies the supplied air volume according to the occupancy pattern. This leads to more temperature fluctuation in offices, as the system requires more response time to reach the desired indoor temperatures. The blue circle in Figure 4 represents the relative performance of the ON/OFF system in proportion to the relative performance of the ACB at a given time point. It can be seen that when the relative performance of the ACB system equals to 0.990, the relative performance of the ON/OFF system is 0.982. This trend is valid through all time points within the occupancy periods. The same trend is observed when looking at the yellow circle, where it has a relative performance of 0.990 and 0.954 for ACB and VAV systems, respectively.

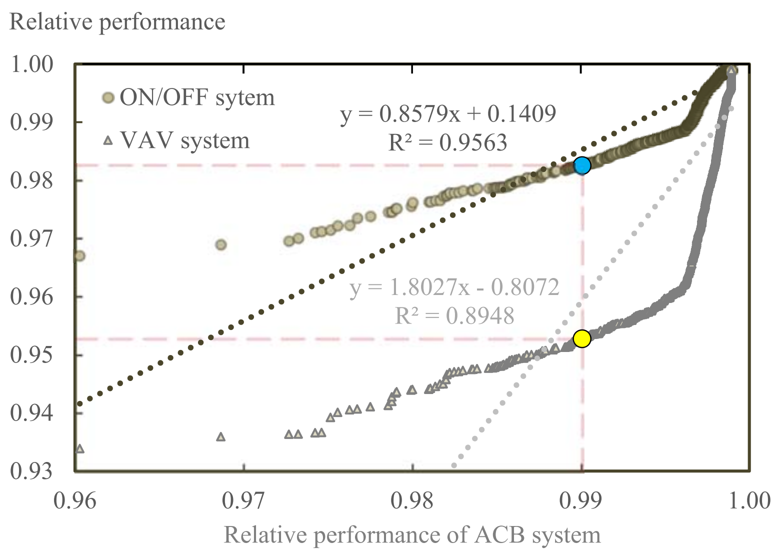

Figure 4: Variance of relative performance proportional to the relative performance of ACB system.

Figure 5 shows the relative energy of the three systems. All three systems have an operating energy use below the limits prescribed by the Swedish building regulation. The ON/OFF system corresponds to the highest energy use in comparison to the other two systems. Thus having a relative energy use of 100 %. The reduction in total energy use for VAV and ACB systems in comparison to the ON/OFF system is 50 % and 67 %, respectively. The ACB systems is the only system that requires a pump to circulate the water flow into the cooling and heating batteries in the chilled beams. A slight increase in the cooling energy related to the ACB system can be observed. This is due to the optimization of this system to lower the operative temperatures in offices to avoid higher task performance loss. In this optimization process, the ACB is regulated by a lower thermostat control point in comparison to the base case. This gives the opportunity for the chilled beam to operate in a wider time span. Therefore, the chilled beams play a major role in decreasing the surface temperature in offices due to their combined effect of radiative and convective cooling. Hence, the operative temperature perceived by the occupants is decreased.

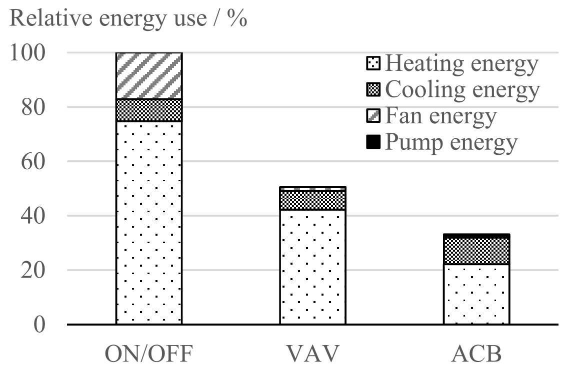

Figure 5: Relative energy use of the three systems.

4 CONCLUSIONS

The paper suggested a process to be implemented during the early design stage of buildings. The process facilitates the role of all parties included in the building project. Those parties are for example; architects, HVAC designers, and property owners. By following a well-defined process, the project was flexible enough to adapt new changes in the design, in addition to avoiding extra costs once the execution phase gets started. The study provided three alternatives for the HVAC system for a modern Swedish office building; ON/OFF system, VAV system, and ACB system. The ACB system proved to have the least amount of space required for the installation of the system, when compared against ON/OFF and VAV systems. All three systems had an energy use that complied with the latest Swedish building regulations. A more detailed distinction between the three systems was carried out by evaluating the relative task performance of the occupants in each system. The ACB system had the lowest energy use and provided the office environment with the best operative temperatures that led to higher relative performance, when compared against the other two systems. This fact would contribute significantly to a better IAQ perceived by the occupants, as well as reducing the energy costs.

5 REFERENCES

Boverkets byggregler. (2018). *Boverkets föreskrifter om ändring i verkets byggregler (2011:6) - föreskrifter och allmänna råd;*. BFS.

Bragança, L., Vieira, S. M., & Andrade, J. B. (2014). Early Stage Design Decisions: The Way to Achieve Sustainable Buildings at Lower Costs. *The Scientific World Journal*.

British Standards Institute. (2007). *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.* British Standards Institute.

Halvarson, J. (2012). *Occupancy Pattern in Office Buildings, Consequences for HVAC system design and operation.* Doctoral theses at NTNU.

Lindab AB. (9 de 6 de 208). *Lindab IT solutions*. Obtido de http://www.lindab.com/global/pro/downloads/software/ventilation/pages/default.aspx

Seppänen, O., Fisk, W. J., & Lei, Q. (2006). *Effect of Temperature on Task Performance in Office Environment.*