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ENERGY ANALYSIS OF A PERSONALIZED VENTILATION SYSTEM IN A COLD CLIMATE: INFLUENCE OF THE SUPPLIED AIR TEMPERATURE

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ABSTRACT

In this study the influence of temperature of the supplied air of a personalized ventilation system on energy need has been investigated by means of simulations with IDA-ICE software. GenOpt software was used to determine the optimal supply air temperature. The simulated office room was located in a cold climate. The results reveal that the temperature of air supplied by personalized ventilation and its control strategy have a marked influence on energy consumption. The energy consumption with personalized ventilation may increase substantially (in the range: 61-268%) compared to mixing ventilation alone if energy saving strategies are not applied. The results show that the best supply strategy is to provide air constantly at 20°C, the minimum allowed supply temperature. Energy savings (in the range: 32-47%) may be achieved with personalized ventilation in comparison with mixing ventilation when the room temperature is controlled between 18°C and 29°C.

1. INTRODUCTION

Personalized Ventilation (PV) aims to supply clean and cool air at low velocity and turbulence directly at workplaces. Each occupant may be provided with control of the supplied flow rate and/or supplied air temperature. PV beside its ability to decrease the level of pollution in inhaled air, improves occupants' thermal comfort (Melikov, 2004). Large differences exist between people with regard to preferred temperature (Melikov, 2004). When the occupants are not provided with control over the temperature of the supplied personalized air, the building manager has to define the air supply temperature (θ_{SUP}) needed for providing the occupants with thermal comfort at a minimal level of energy consumption. In a single duct constant air volume system, the θ_{SUP} set-point may be constant, or it may be reset based on the outdoor (θ_{ODA}) or indoor (θ_{IND}) air temperature. The purpose of this study is to investigate the influence of the temperature of the supplied personalized air on energy need, by means of simulations with IDA-ICE software.

2. METHODS

2.1 Input data for the energy simulation

The input data are presented according to the European Standard EN 15265 (2006) which defines the data needed for reporting the hourly energy calculations.

2.1.1 Building location and weather data

An office in a building located in Copenhagen (Denmark) was simulated. The weather is characterized by a cold climate. The ASHRAE IWEC Weather File for Copenhagen is used as input data in the simulation model.

2.1.2 Description of the room

The open-space office has a floor surface area of 6 x 20 m. The room height is 3 m. The external walls are constructed with 20 mm of plaster, 150 mm of glasswool, 240 mm of clay brick and 10 mm of internal plaster; the overall U-value of the external wall is 0.2 $WK^{-1}m^{-2}$. The double panes window with internal low-emissivity glass pane has an U-value of 1.2 $WK^{-1}m^{-2}$, a g-factor or Solar Heat Gain Coefficient equal to 0.61, and a light transmittance equal to 0.77. The window has a total area of 36 m^2 (20% of the floor area, height = 1.8 m and width = 20 m). The window faces south. There is a shading device composed by blinds between the window panes. It has a multiplier for a total shading coefficient equal to 0.39. It is activated when the incident light on the windows is higher than 200 W/m^2. The internal walls, floor and ceiling are adiabatic. The effect of thermal mass is taken into account.

2.1.3 Internal temperature, ventilation and infiltration rate

The thermal comfort conditions and ventilation specifications were chosen in order to comply with the values defined in EN 15251 (2007) for the category I for indoor environment in the room during occupation. From 6:00 till 17:00 the heating and cooling systems kept the internal operative temperature within a range between 21 and 25.5°C. During weekends and night-time the temperature set-back was 12°C in winter and 40°C in summer. Only in Case 10 and Case 11 (Table 1) was the room temperature kept within a range between 18 and 29°C. The design airflow rate was supplied during occupation hours. The airflow rate is calculated according to the European standard EN 15251 (2007). The total air flow rate is the sum of the required ventilation rate per person (10 l/s person for the indoor environmental category I) and per floor area (the building is considered to be a low-polluting, therefore the air flow rate per floor area is 1 $l/(sm^2)$). The floor area per occupant is 10 m^2. Therefore the total airflow rate is equal to 20 l/s per person during occupation hours. The total airflow rate is more than double of the one required in the ASHRAE standard 62.1 (2004). The European standard requires higher ventilation rate than the ASHRAE standard. Twelve occupants were present in the room, thus the total outdoor airflow rate is 240 l/s. The infiltration is taken into account by using an Equivalent Leakage Area (Sherman and Grimsrud, 1980) equal to 0.0093 m^2.

2.1.4 Internal heat gains, occupancy and description of the HVAC system

The twelve occupants contribute to both sensible and latent heat load in the room. The activity level of the occupants was 1.2 met (1 met = 58.15 W/m^2). The balance between sensible and latent heats is calculated by the program. The occupants were present in the room from Monday to Friday, from 8:00 to 17:00 with an hour as break at noon. Saturday and Sunday were free days and no public holidays were involved. The heat load due to office equipment was 6 W/m^2. According to ASHRAE (2005), this value corresponds to a "light load office". The loads follow the schedules of the occupants. The lighting load was 10 W/m^2 during working hours (8:00-17:00). Outside these hours the light was switched off. Two independent systems are used to control the indoor air quality and the thermal comfort in the room. The operative room temperature was controlled by four-pipe fan coil units. An air handling unit with a heat recovery exchanger (efficiency of 0.7) was used to provid the needed outdoor air. The humidity was not controlled during the simulations since this is not common practice in Denmark. A free-cooling strategy during night-time (from 18:00-6:00) from 1 May to 30 September was used. The supplied airflow was 3 l/(sm^2). The free-cooling starts when the outdoor air temperature is at least 5°C cooler then indoor air and the indoor air temperature is at least 25°C. It stops if the indoor air temperature is lower than 21°C or the difference between indoor and outdoor is less than 3°C.

2.1.5 The simulation software

IDA Indoor Climate and Energy (ICE) is a tool for simulation of thermal comfort, indoor air quality and energy consumption in buildings. The mathematical models are described in terms of equations in a formal language, NMF. This makes it easy to replace and upgrade program modules (Vuolle and Sahlin, 2000). GenOpt is an optimization program designed for finding the values of user-selected design parameters that minimize a so-called objective function (or cost function), such as annual energy use, leading to optimal operation of a given system (Wetter, 2001).

2.2 Simulated cases

The temperature of the supplied personalized air (θ_{SUP}) is the parameter investigated in this study. The supply air temperature may be constant, or may vary as a function of the outdoor or indoor air temperature. The simulated cases are listed in Table 1. A mixing ventilation system supplying the air at a constant temperature (16°C) throughout the year is the reference case.

2.2.1 Constant supply air temperature

PV supplies the air close to occupants. Therefore the lowest and highest allowed supply air temperatures are limited by comfort issues. In this study it has been chosen that θ_{SUP} may vary in the range 20-26°C. All the personal supply air temperature profiles presented in the following are restricted within this range. Three cases with constant supply air temperature were investigated (Case 1, 2, 3).

2.2.2 Supply air temperature set-point controlled by outdoor air temperature

Four profiles in which θ_{SUP} is reset based on θ_{ODA} were investigated (shown in Figure 1 A). Three of them were defined by authors (Cases 4, 5 and 6) and the last one, "Case 7", was obtained using GenOpt. GenOpt software was used to find the optimal supply air temperature profile (Case 7) within the boundaries of the room air temperature given by En 15251 (2007) for category I of the indoor environment. GenOpt was set to minimize the sum of energy needed for heating and cooling of the supplied personalized air and the room (mathematically named cost function). In order to minimize the cost function, GenOpt changes the supply air temperatures corresponding to the following fixed outdoor temperatures (-20, 10, 15, 18, 20, 21, 23, 25, 26, 27, 30, 40°C) by choosing an integer value within the range 20-26°C.

Table 1. Simulated cases with PV.

Case	Control strategy of the air supply temperature	Air supply temperature profile	Room temper.[a] [°C]
1	Constant	20°C	21 - 25.5
2	Constant	23°C	21 - 25.5
3	Constant	26°C	21 - 25.5
4	Outdoor	Figure 1A	21 - 25.5
5	Outdoor	Figure 1A	21 - 25.5
6	Outdoor	Figure 1A	21 - 25.5
7	Outdoor	Figure 1 A	21 - 25.5
8	Indoor	Figure 1 B	21 - 25.5
9	Indoor	Figure 1 B	21 - 25.5
10	Constant	20°C	18 – 29
11	Indoor	Figure 1 B	18 – 29

[a] The heating and cooling systems keep the internal operative temperature within the reported range.

2.2.3 Supply air temperature set-point controlled by indoor air temperature

In a constant air volume system the θ_{SUP} set-point can be controlled by the indoor air temperature (θ_{IND}), which in a mixing ventilation principle is also equal to the return air temperature. Two temperature profiles (see Figure 1 B) were analysed. The “Case 8” profile aims to optimize occupants’ thermal comfort. In “Case 11” the air is supplied as in “Case 8” within an expanded room air temperature range 18-29°C. In “Case 9” the air is supplied isothermally within the rage 20-26°C, based on recent findings that indicate that elevated velocity at the breathing zone improves inhaled air quality and compensates for the negative impact of increased temperature on perceived air quality (Melikov et al. 2008).

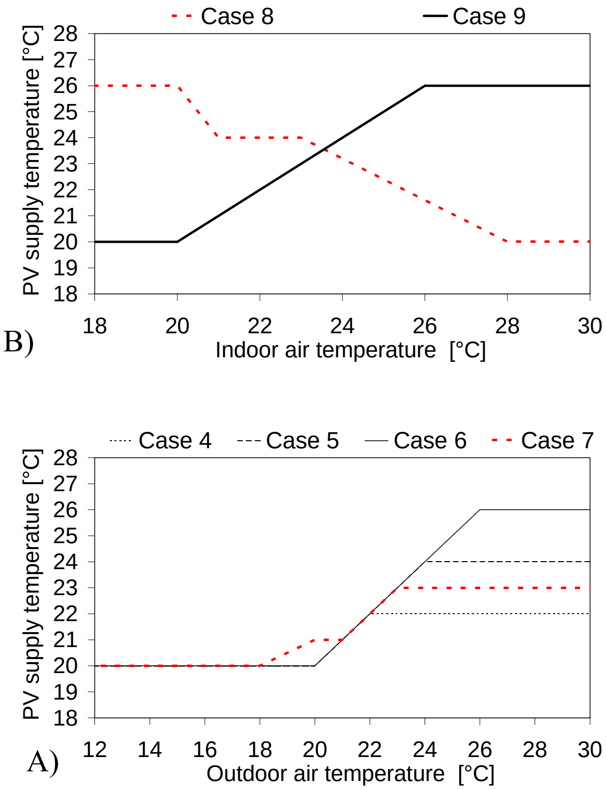

Figure 1. A) PV air supplied temperature profiles as a function of the outdoor air temperature for cases 4, 5, 6, 7. B) PV air supply temperature profiles as a function of the indoor air temperature for “Case 8” and “Case 9”.

3. RESULTS

The “energy need” is the sum of energies for heating (AHU Heating) and cooling (AHU Cooling) of the supplied air in order to obtain the needed θ_{SUP} and for heating (Room Heating) and cooling (Room Cooling) of the conditioned space in order to maintain the intended temperature conditions during a given period of time. The energy need obtained for the simulated cases is shown in Figure 2.

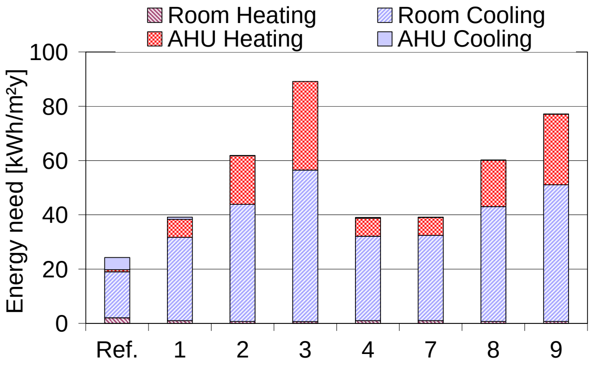

Figure 2. Energy need for the simulated cases (Table 1).

4. DISCUSSION

4.1Influence of the temperature of the supplied personalized air on energy need

The results shown in Figure 2 reveal that the simulated building does not need Room Heating. The building has a good insulation and air tightness and the internal heat gains are sufficient to maintain the required operative temperature. The supplied personalized air needs to be cooled only sporadically; in fact AHU Cooling is equal to zero except for the reference case (Figure 2). The supply temperature and its control strategy have a marked influence on energy consumption (Figure 2). The energy need for the simulated cases is in the range 39.0-89.2 kWh/(m^{2}y). The energy need for the reference case is 24.3 kWh/(m^{2}y); it means that by using PV the energy need increases from 61% to 268%. This is mainly due to the fact that the lowest supply air temperature for the PV system was set equal to 20°C. In the reference case the air is supplied at 16°C and it has a free cooling effect. If, for thermal comfort reasons, the personalized supplied air has to be warmed up at least up to 20°C, then the free cooling effect is reduced and the heat added to the air (AHU Heating) has to be compensated by the room cooling system. This phenomenon can be seen in Figure 2: by subtracting the AHU Heating to the Room Cooling, the remaining Room Cooling is constant (in the range between 23.2 and 25.2 kWh/(m^2y)).To supply the air at an elevate temperature (23 or 26°C) required a greater amount of energy than to supply at 20°C (see Figure 2). The energy needs for cases 1, 4, 5, 6, and 7 are almost equal. This means that the different supply air control strategies do not differ between them. The reason can be understood by analyzing the outdoor air temperature cumulative profile. In Copenhagen the outdoor air temperature is higher than 20°C only 3.2% of the time in one year, therefore, controlling the θ_{SUP} by the θ_{ODA} using profiles that differ only for θ_{ODA}>20°C does not make any significant difference. Controlling the θ_{SUP} by the θ_{IND} (Case 8 and Case 9) implies high energy consumption. "Case 8" has an energy need almost equal to "Case 2", where the air is supplied constantly at 23°C, but from a comfort point of view, it will perform better because it supplies hot air when it is cold in the room and cool air when it is warm. For the simulated building and for the assumptions made in this paper, the best supply strategy is to provide air constantly at 20°C, the minimum allowed supply temperature.

4.2 Decreased energy need by personalized ventilation

The results presented so far reveal the importance of the control strategy for the energy need. Personalized ventilation may save energy by using the following strategies:

1. Reducing the outdoor airflow rate due to higher ventilation effectiveness (Faulkner et al, 2004; Sekhar et al, 2005).
2. Supplying the personalized air only when occupants are present at the desk (similar to demand ventilation).
3. Expanding the room temperature comfort limits, taking advantage of the ability to create a controlled microenvironment (Bauman et al, 1993; Sekhar, et al, 2003, 2005; Niu et al, 2007).

The energy-saving potential of one of these strategies (no. 3) is demonstrated with Cases 10 and 11, which repeat the simulated Cases 1 and 8 but at expanded room temperature limits between 18°C and 29°C. The energy need for "Case 1", "Case 8", "Case 10" and "Case 11" is shown in Figure 3.

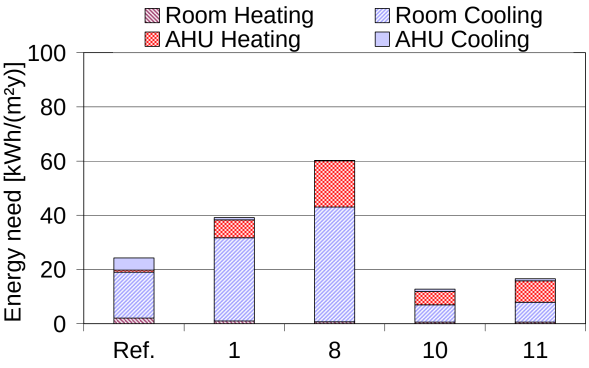

Figure 3. Energy need for the cases 1, 8, 10 and 11.

The energy need for the two cases is strongly reduced, for "Case 10" from 39.2 (Case 1) to 12.8 kWh/(m^2y), for "Case 11" from 60.2 (Case 8) to 16.6 kWh/(m^2y), corresponding to a reduction of 67% and 72% respectively. From Figure 3 it can be seen that the energy need for "Case 10" and "Case 11" is lower than for the reference case; an energy reduction of 47% and 32% has been obtained. It has been documented that personalized ventilation may provide better inhaled air quality, thermal comfort and protection from cross-infection compared to mixing ventilation (Kaczmarczyk et al. 2004, 2006, Cermak and Melikov 2007). The results of this study reveal that in a cold climate, depending on the control strategy this can be achieved with higher, equal or lower energy consumption compared to traditional system.

5. CONCLUSIONS

The main conclusions of this study are:

- The temperature of air supplied by personalized ventilation and its control strategy have a significant influence on energy consumption. The energy consumption with personalized ventilation may increase substantially (between 61% and 268%) compared to mixing ventilation alone if energy saving strategies are not applied.
- For the simulated building and for the assumptions made in this paper, the best supply strategy is to provide air constantly at 20°C, the minimum allowed supply temperature.
- Energy savings (between 32% and 47%) may be achieved with personalized ventilation compared to mixing ventilation when the room temperature is controlled between 18 °C and 29°C.

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