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Bivolarova, Mariya Petrova; Kehayova, Nushka ; Melikov, Arsen Krikor

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ENERGY SAVING BY NOVEL BED-INTEGRATED LOCAL EXHAUST VENTILATION

Mariya P. Bivolarova1), Nushka Kehayova1,2) and Arsen Melikov1)

1) International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark

2) Department of Hydroaerodynamics and Hydraulic Machines, Technical University of Sofia, 1000 Sofia, Bulgaria

ABSTRACT

High quality indoor environment in hospitals is important for patients' healing and performance of the personnel. A novel method for minimizing spread of bio-effluents generated from hospitalized patients lying in bed was developed. The method consists of ventilated mattress (VM) which is able to suck the human bio-effluents at the area of the body where they are generated before they spread in the room. The air polluted with released bio-effluents is exhausted into the mattress near the body and is either cleaned and released back in the room or is removed from the room by connecting the mattress to the exhaust of the room background ventilation system. Comprehensive research reveals that the method is highly efficient for removal of bio-effluents. The energy saving potential of the VM combined with constant air volume (CAV) ventilation operating at reduced ventilation rate in a single-bed hospital patient room (1.3 air changes per hour (ACH)) and double-bed patient room (1.6 ACH) was assessed by means of dynamic computer simulations. The estimated annual energy consumption for the rooms using the VM combined with CAV was compared to the annual energy consumption when the CAV ventilation was used alone at 4, 6 and 12 ACH. The air exhausted through the mattress was 1.5 L/s. The occupants were present 24 hours every day including weekends. Compared to the CAV ventilation used alone at 4, 6 and 12 ACH the use of the VM in the single-bed room decreased the annual energy consumption respectively with 55%, 71.1% and 85.9% and in the double room with 39.3%, 60.0%, and 80.4%. The use of the VM with reduced background CAV ventilation is an effective energy saving strategy for both double and single patient hospital rooms.

Keywords: Novel hospital ventilation; Patient rooms, Ventilated mattress; Energy saving

1. INTRODUCTION

A novel method for minimizing spread of bio-effluents generated from hospitalized patients lying in bed was developed (Bivolarova et al. 2014, 2015). A ventilated mattress (VM) sucks the human bio-effluents at the area of the body where they are generated before they spread in the room (Figure 1). The air near the body polluted with released bio-effluents is exhausted into the mattress and is either cleaned and released back in the room or is removed from the room by connecting the mattress to the exhaust of the room background ventilation system.

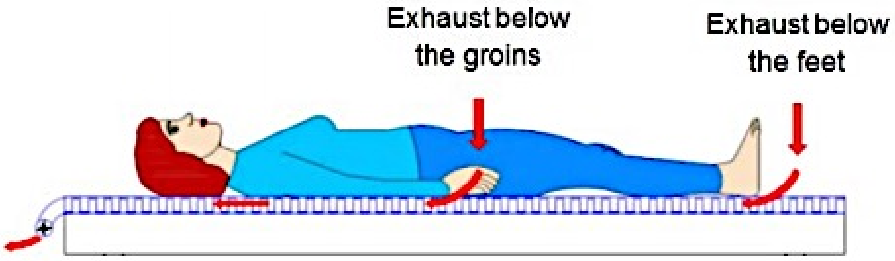

Figure 1. Operation principle of the ventilated mattress.

Comprehensive experiments (Bivolarova et al. 2014) in a full scale room (simulating double-bed hospital patient room) reveal that the ventilated mattress exhausting 1.5 L/s and operating together with background mixing ventilation at 1.5 ACH (27 L/s) reduces greatly the concentration of bio-effluents in the room compared to background mixing ventilation performing alone at 3 and 6 ACH (respectively 54 and 109 L/s).

The energy saving potential of the novel method combined with constant air volume (CAV) ventilation operating at reduced ventilation rate in a single and double-bed patient rooms was assess my means of dynamic computer simulations. Some of the results are reported in the present paper.

2. METHOD

2.1 Simulation tool

In order to analyse the energy consumption of the VM, the building performance simulation software IDA ICE 4.6.2 was used (EQUA Simulation, IDA Indoor Climate and Energy).

2.2 Simulated hospital rooms

The simulations were performed for single bed and double bed hospital rooms respectively with dimensions 3 m x 6 m x 3 m and 4 m x 6 m x 3 m (L x W x H). The minimum required floor area for a single patient room and multiple patients' room is 10.8 m^2 and 9.29 m^2 respectively (AIA Guidelines 2006). Thus the floor area of the simulated rooms meets the minimum area requirements.

There were no internal partitions in the rooms. The internal walls of the rooms consisted of a layer of plaster with thickness 0.02 m (heat conductivity λ=0.61 W/m·K), followed by brick with thickness of 0.15 m (thermal conductivity λ=0.58 W/m·K), plaster. The overall U- value of the walls was 2.019 W/ m^2·K. The external wall of the rooms consisted of a layer of plaster with thickness 0.026 m (heat conductivity λ=0.61 W/m·K), followed by an air gap with thickness of 0.032 m (thermal conductivity λ=0.17 W/m·K), light insulation with thickness of 0.03 m (thermal conductivity λ=0.036 W/m·K), another air gap and finally a layer of gypsum. The overall U- value of the walls was 0.6187 W/ m^2·K. The outer wall of the simulated rooms was facing south and included a window with dimensions of 1.2 m x 1.7 m (W x H) and surface area of 2 m^2 for the single bed room and 3 m x 1.7 m (W x H) and surface area of 5.1 m^2 for the double bed room. The remaining walls, ceiling and floor were considered as internal walls. The windows were composed of external clear glass pane (thickness 4 mm), air gap of 12 mm and internal clear glass pane of thickness 4 mm. The overall U-value of the windows was 2.9 W/m^2·K. The solar transmittance was set to 0.7 and the visible transmittance was 0.81. There was no integrated window shading. Windows were equipped with external solar shading blinds. The blinds were activated when the room air temperature rise above 24 °C.

2.3 Building location and weather data

The building with the simulated rooms was located in Copenhagen (Denmark). The weather is characterized by a cold climate. The weather files used in IDA ICE were Test Reference Year (TRY) for Copenhagen (Vaerloese). The TRY weather data are composed from measured data of representative months to form a whole representative year.

2.4 Air conditioning systems

Each room was conditioned using constant air volume (CAV) ventilation system and a water radiator (1.16 m^2). Mixing ventilation with ceiling supply air diffusers was used.

2.5 Simulated conditions

The annual energy consumption was estimated for the rooms when using the VM combined with background ventilation at reduced ventilation rate. The estimated under this condition energy consumption was compared to the annual energy consumption when the CAV ventilation was used alone at different ventilation rate.

Heat gain from occupants, lights, medical equipment and mattress fans was simulated. The heat gain is listed in Tables 1 and 2 for the simulated cases with and without VM. The heat gain from the medical equipment was considered to be 114 W (ASHRAE 2003). Each occupant was set to have metabolic rate of 0.8 met (0.46 W/m^2), which corresponded to a person being in reclined position (ISO 7730, 2005). The fan power of the VM was set to consume 20 W (enough to provide exhaust airflow rate in the range of 1.5 - 5 L/s).

Table 1. Room heat load for the simulations with the VM combined with background ventilation.

Room type	Type of heat source	Number of heat sources	Heat per unit [W]	Total heat [W]
Single bed (1.3 ACH)	Occupant	1	73.6	73.6
	VM fan	1	20	20
	Lights	6	12	72
	Equipment	1	114	114
				Total: 279.6
Double bed (1.6 ACH)	Occupant	2	73.6	147.2
	VM	2	20	40
	Lights	9	12	108
	Equipment	2	114	228
				Total: 523.2

Table 2. Room heat load for the simulations with background ventilation only at 4, 6, and 12 ACH.

Room type	Type of heat source	Number of heat sources	Heat per unit [W]	Total heat [W]
Single bed	Occupant	1	73.6	73.6
	Lights	6	12	72
	Equipment	1	114	114
				Total: 276
Double bed	Occupant	2	73.6	147.2
	Lights	9	12	108
	Equipment	2	114	228
				Total: 516

The ASHRAE standard for ventilation of health care facilities (ASHRAE standard 170 2013) recommends minimum total ventilation rates for general patient rooms to be from 4 to 6 ACH and 12 ACH for infectious wards. Therefore the annual energy consumption in the simulated cases when the CAV ventilation was used alone was estimated at 4, 6 and 12 ACH. For the simulated cases with the VM the airflow rate supplied by the background ventilation was estimated based on the air quality requirements defined in European norms (EN 15251 2007) for category I very low polluting building. The total supply air flow rate was estimated from the following formula:

$$Q_{tot} = n*q_p + A*q_b \tag{1}$$

Where: Q_{tot} - Total volume ventilation rate of the room [l/s], n - Number of persons in the room, q_p - Ventilation rate per person based on occupancy [l/s per person], A - Room floor area [m^2], q_b - Ventilation rate for emissions from buildings [$l/s.m^2$].

The ventilation rate for emissions from building materials was selected to be $q_b = 0.5$ L/s·m^2. The ventilation rate for occupants was selected to be $q_p = 10$ L/s/person (required ventilation rates for diluting emissions (bio-effluents) from people for category I (EN 15251 2007)).

The calculated in this way ventilation rates for the simulated cases (with and without ventilated mattress) are listed in Table 3. The air exhausted through the mattress was 1.5 L/s.

The temperature of the air supplied by the background ventilation was calculated based on the total heat load, supply air flow rate and set room air temperature of 24 °C. The ASHRAE standard for health care facilities (ASHRAE Standard 170 2013) specifies room air temperature in the ranges 21 °C and 24 °C. The supplied air temperature for the simulated cases is listed in Table 3. The relative humidity in the room was set to be in the range from 30% to 50%, which corresponds to the required in the standards range for patient recovery rooms (ASHRAE standard 170, 2013).

Table 3. Supply air temperature and flow rate at the studied room ventilation rates.

Room type	Supply air flow rate	Supply air temperature
Single	19 L/s (1.3 ACH)	14°C
Double	32 L/s (1.6 ACH)	14°C
Single	60 L/s (4 ACH)	20.4°C
Double	80 L/s (4 ACH)	19°C
Single	90 L/s (6 ACH)	21.6°C
Double	120 L/s (6 ACH)	20.7°C
Single	180 L/s (12 ACH)	22.8°C
Double	240 L/s (12 ACH)	22.3°C

3. RESULTS AND DISCUSSION

Figures 1 and 2 shows results from the simulated cases for the single-bed and the double-bed patient rooms. The annual energy consumption in the cases with VM and background ventilation is compared with the cases when the background ventilation is used alone at 4, 6 and 12 ACH rate. The results in the figures show the delivered energy only for the VM and the total delivered energy which includes the energy used by the other room air conditioning systems, i.e. the CAV ventilation system and the radiator (used during the winter season).

The results of the energy simulations in Figure 1 show that compared to the CAV ventilation alone at 4, 6 and 12 ACH the use of the VM in the single patient hospital room decreased the annual energy consumption respectively by 55%, 71.1% and 85.9% respectively at background air change rate of 4, 6 and 12. In the case of double bed room the decrease of the annual energy consumption was 39.3%, 60.0% and 80.4%.

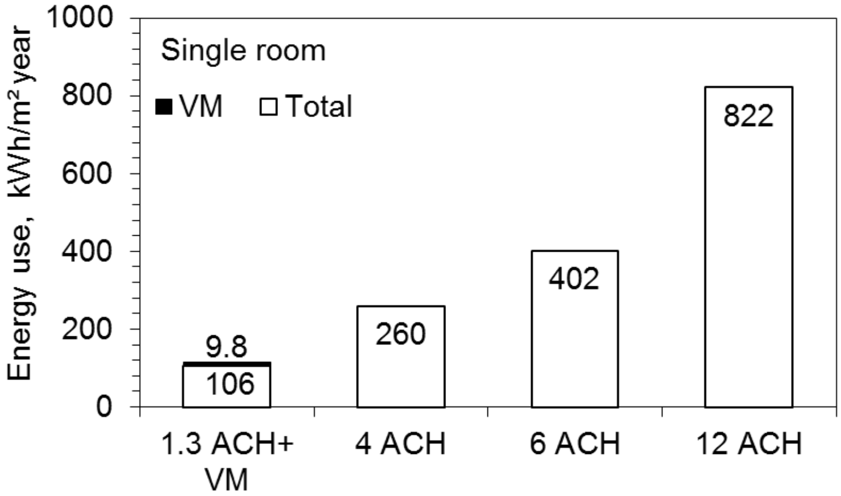

Figure 1. Annual energy use for a single-bed patient room ventilated with CAV system at different installed one ventilated mattress.

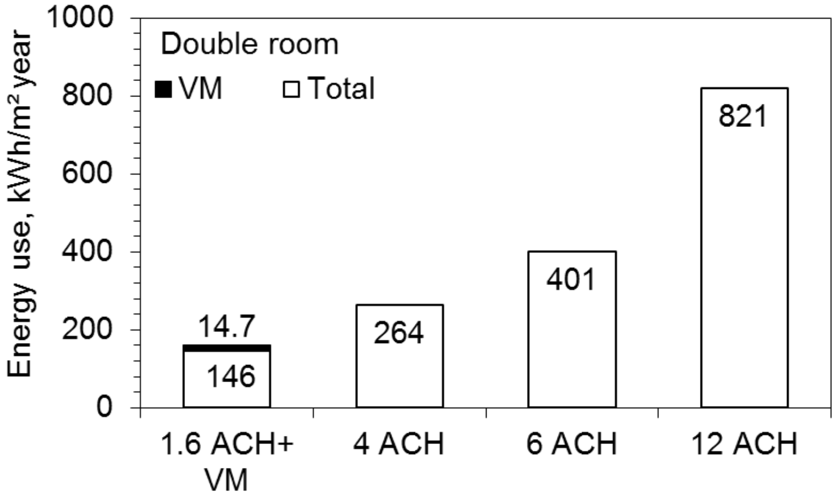

Figure 2. Annual energy use for a double-bed patient room ventilated with CAV system at different rates and installed two ventilated mattresses.

In this paper the energy-saving potential of the ventilated mattress combined with background mixing ventilation at reduced ventilation rate was studied only for the case of mixing air distribution. The energy saving in the case of displacement background ventilation is to be studied. Single-bed and double-bed occupancy was simulated and the results reveal that the energy saving decreases when the number of room occupants increases. In practice, rooms with more than two occupants are used. The maximum number of room occupants when the energy saving potential of the VM is significant will be studied in the future. The simulations were performed assuming that the systems worked 24 hours, i.e. patient(s) occupied the beds for 24 hours. However in real life patients may spend several hours apart of the room. The importance of the room occupancy on the energy savings also needs to be studied.

The use of the VM will reduce the room air pollution but also will affect the thermal comfort of the patients. Physical measurement performed with a full-size thermal manikin with individually heated and controlled 23 body segments reveal that the body segments in contact with the VM, especially the back side and the back, were cooled much compared to the remaining segments (Bivolarova et al. 2014a). The cooling effect increased with the increase of the airflow rate through the VM. These results suggest that in warm environment the VM may improve thermal comfort of people lying in bed. The use of the VM may lead to additional energy saving by operating the background ventilation system at elevated set point for the room temperature or by use of natural ventilation. However the non-uniform body cooling may cause local thermal discomfort. At the comfortable range of room temperature local body heating may be required to counteract the unpleasing cooling. The use of local heating will increase the energy consumption. Further study on this issue is needed.

It was already discussed in the introduction that the polluted air exhausted by the VM can be removed from the room through the exhaust system used for the background room ventilation. In this case modification of the background exhaust system will be required by adding ducting and plugs for connecting the ventilated mattress. The increase of the installation costs may be compensated with the decrease of the costs due to use of smaller air handling and duct systems. The new method however can be used without coupling with the exhaust system. As documented by Bivolarova et al. (2016) local cleaning of the sucked polluted air by a deodorant material(s) installed in the mattress can be very efficient. In this case cleaned air is discharged back to the room. A great advantage of this approach is that the “plug and play” principle is applied, i.e. the bed with the ventilated mattress can be moved from room to room and only plugged in the electrical net.

The most important benefit of the use of the localized bed ventilation will be improvement of occupants’ health and comfort, due to provided better indoor air quality. The improved indoor air quality may have positive effect on the performance of the staff. The advantages and the savings that can result from the improvement in these factors, might be much higher than the achieved energy savings. Another advantage is that individual control of the local body cooling or heating by control of the flow rate through the mattress or power of the local heating device (when used) is easy to be implemented.

The requirements in the present standards are based on the total volume air distribution principles, mainly mixing but also displacement air distribution, which are inefficient (Melikov 2016). The use of advanced ventilation methods that can be beneficial for occupants’ health, comfort and performance is not considered (Melikov 2015). There is urgent need to revise the present standards and to make it possible for further development in the field.

4. CONCLUSIONS

The results of the performed simulations reveal that the use of the ventilated mattress in conjunction with background ventilation rate will lead to substantial saving (between 40% and 85%) of the annual energy consumption in single and double hospital patient rooms.

The saving is greater in rooms with single occupancy and when the required in the standards ventilation rate is higher.

5. ACKNOWLEDGMENTS

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