Numerical Investigation of Air Conditioners' Control Unit Position On Temperature Distribution and Energy Consumptions of a Room

Mustafa Mutlu^{1,*}, Emre Çalışkan²

Uludag University, Vocational School of Yenisehir Ibrahim Orhan, 16900, Bursa, Turkey
Daikin A.Ş., Technical Department, 34750, İstanbul, Turkey

Abstract. Minimum temperature difference should be achieved in conditioned rooms to meet comfort criteria. It is desired that the temperature set by a user from the control unit, should be the same in the entire room. Therefore, the position of the control unit plays a significant role in order to achieve a homogeneous temperature distribution in the room. In this study, the effect of control unit positioning on temperature and velocity distributions in a room, where a cassette type indoor unit was applied, was numerically investigated. Blowing temperature and speed of the indoor unit has been adjusted by the temperature value that measured by a control unit which was placed at five different locations, in order to examine positioning effects of the control unit. Predicted percentage dissatisfied (PPD) values were calculated, and uncomfortable zones were determined by 2-dimensional analyses. Cooling loads, as well as energy consumptions, were calculated and their variations according to the position of control unit was figured out in steady state conditions. The results showed that control unit positioning not only influences the comfort levels or temperature distributions in a room but also energy consumptions.

1 Introduction

The appropriate hygiene, thermal comfort and indoor air quality conditions must be met in order to live a quality life in terms of in the environments where human live and work. Indoor climate is very important in terms of health and comfort when the working and living habits of today's city people is considered. The air-conditioning system design, which is suitable for the building, has become important in order avoid building syndrome diseased. The design, production and automation of the heat pump systems as well as their heating and cooling performance are increasing every year and heat pumps are preferred in central air-conditioning systems. Today's air conditioning devices are designed as a central system in terms of performance and efficiency and the use of cassette-type indoor units is becoming widespread. There is a limited number of studies on the effect of such systems on temperature and velocity distribution in the environment and on thermal comfort. Aynur et al. [1] examined experimental methods of Variable Refrigerant Volume (VRV) system and compared them with Variable Air Volume (VAV) system. They found that in the individual control mode of the VRV system, the cooling performance factor was between 3% and 15% higher than the master control mode and stated that it was not possible to provide thermal comfort in each zone by temperature control with a single thermostat. It is shown that energy consumption can be reduced by integrating the VRV system with a heat pump principle [2]. Noh et al. [3]

determined the effect of air flow angles and flow of the indoor unit by measuring thermal comfort and CO₂ in a class where cassette-type indoor unit is used. They found that thermal comfort worsened with increasing air blowing angle, whereas CO₂ concentration did not change much. They showed that if the air flow rate is higher than 800 m³ / h, the CO₂ concentration remains within acceptable limits. The performance of cassette type indoor units and the temperature and velocity distributions occurred in the room, where they are used, can be determined by using the Computational Fluid Dynamics (CFD) method, and the thermal disturbance zones can be easily calculated by using these data [4]. Bamodu et al. [5] determined that, the cassette type indoor unit distributed the air better than the wall type split air conditioners with numerical method, and emphasized the energy saving potential of the cassette type indoor unit. However, it has been stated that it is possible to improve the thermal comfort in the environment by controlling the blowing speed and temperature of the cassette type air conditioner [6]. Noh et al. [7] studied the effect of air blowing amount of a cassette type air conditioner in a class, where mixed ventilation system is applied, using experimental and numerically. They concluded that, ventilation performance was improved in a room where a mixed ventilation systems was installed due to presence of a momentum source, such as a cassette type air conditioner.

The positioning of the room thermostats is important for the comfort of the environment and energy saving, because these devices can change the air blowing speed

* Corresponding author: mustafamutlu@uludag.edu.tr

and temperature of the indoor unit. If a thermostat is placed in a room that is warmer than other regions or exposed to direct sunlight, the device will detect the environment warmer than it is and increase the blowing speed or decrease the blowing temperature. This may cause uncomfortable areas. In order to determine the most suitable thermostat position, Tian et al. [8] developed an optimization method using simulations. Du et al. conducted a similar study that described the optimal thermostat placement using a CFD program integrated with the BES simulations [9]. In this study, the effect of thermostat placement on the velocity and temperature distributions in a room, using cassette type air conditioner, was investigated by CFD analysis. In this study, the effect of thermostats, placed in seven different locations and controlling discharge rates and temperature, on PPD values in the room was investigated by a 2-dimensional numerical model.

2 Material and method

The model used in present study was created using the dimensions of a class where measurements were done by Noh et al [3]. The 2-dimensional model, based on the plane in the middle of the class, is given in Figure 1. The commercial software ANSYS FLUENT is used to solve mass, momentum and energy equations.

The walls in which contact with the interior environment were taken as 297 K at the indoor temperature while the wall in contact with the external environment was considered to be 302 K. The cassette type air conditioner was assumed to have a size of 0.90 m × 0.90 m and a width of 0.05 m for airflow channels [3]. The discharge angle of the air was assumed as 30°, and the speed and temperature vary according to the information taken from the thermostat. As the temperature difference between set value (T_{set}) and temperature at thermostat position increases, the temperature of the discharge air decreases and its flow rate increases (Table 1).

Standard k- ϵ turbulence model was used in the analyzes and the radiation in the environment was solved by Discrete Ordinates method. The standard k- ϵ turbulence model was preferred because it has been widely preferred in temperature and velocity distributions as well as thermal comfort studies in an enclosed

environment. The density of air is solved by the incompressible ideal gas approach which cannot be compressed and other properties are considered as fixed. (Table 2).

Table 1. Discharge rates and temperatures according to temperature difference between measured and set values

ΔT ($T_{set} - T_{meas}$)	Discharge Rate [m ³ /h]	Air Temperature [°C]
0 – 2.49	744	20
2.5 – 7.49	1170	15
7.5 – 12.49	1590	10
>12.5	1590	5

Table 2. Properties of air used in simulations

Specific Heat	1006.43 J/kgK
Thermal Conductivity	0.0242 W/mK
Viscosity	1.7894×10^{-5} kg/ms
Molecular Weight	28.966 kg/kmol
Absorption Coefficient	0.1 1/m

The SIMPLE algorithm for the pressure-velocity coupling, PRESTO method for pressure discretization, and second degree discretization was applied for other quantities. Convergence criteria for residuals except energy was chosen as 10^{-4} while 10^{-8} was chosen for energy convergence.

3 Validation

The solution was run with three different mesh size that has different node numbers for mesh independence, and no significant change was observed (Fig. 2). In this study the mesh with 423000 node number was preferred considering the calculation time and computer capacity since the results did not change significantly with node numbers.

There are limited number of studies in terms of detailed experimental results that velocity and temperature distribution has been revealed in a room where cassette type air conditioner has been used. Therefore, the data obtained by Noh et al. [3] were compared with the results of present study (Fig. 3).

Fig. 1. 2-dimensional model and boundary conditions

3 Thermostat locations and PPD

In order to investigate the effect of the thermostat location on the uncomfortable areas within the room, 7 different point thermostat location were determined (Fig. 4).

Fig. 2. Temperature and velocity comparison among different mesh sizes

At the end of each iteration step, the temperature at these points was calculated with the help of a user-defined function and the air inlet speed and temperature of the cassette type air conditioner were changed according to the values in Table 1. PPD values in the room were calculated according to the ISO 7730 standard [10]. The velocity, temperature and radiation temperature values were obtained from the analysis results and the metabolic activity and clothing insulation was taken as 60 W / m² and 1 clo, respectively. In steady state, the cooling power

values of the air conditioner were calculated from the enthalpy difference between discharge air and the suction air.

Fig. 3. Comparison of simulation data and experimental measurements

4 Results

Average PPD values were given in Fig. 5 in case the T_{set} was 19 °C. It is seen that the PPD values of the thermostats in T6, T1, T5, T7 position are very close. It can be said that, the reason for diversity of the T3 thermostat point from the other positions was being in the same position as the cassette type air conditioner. As the thermostat at point T3 sensed the absorbed air closer to the set point, the fan stage was reduced and more warm air was discharged, which resulted in a one-third reduction in electricity consumption. It has been seen that system automation should be designed well in order to keep the device at acceptable point in terms of efficiency and comfort.

It is seen that when the thermostat set temperature (T_{set}) is 15 °C in steady state conditions, PPD is around 30 at the discharge zone of the air conditioner and parallel to the ceiling, whereas other areas of the room do not show much variation (Fig. 6). PPD has an almost rigid distribution in the range of 7-9 from the ground up to a height of 150 cm. The reason for the PPD approaching 0 is that the temperature distribution shows a homogeneous distribution in this region at 21 °C - 22 °C. The maximum PPD value was calculated as 23 at the height of 150 cm from the floor, except the discharge zone. The reason for the high PPD value in this region is that the warm air is rising and interacting with the air conditioner's discharged air.

Fig. 4. Positions of thermostats

Fig. 5. Average PPD values variation according to thermostat positions in the room while $T_{set} = 19\text{ }^{\circ}\text{C}$

It is seen that when the thermostat set temperature (T_{set}) is $25\text{ }^{\circ}\text{C}$ in steady state conditions PPD was found to be 30 in a certain area where the wall of the ceiling and the ceiling intersect, and the other regions of the room PPD did not approach to zero. The PPD value reached 30 in this area due to the fact that, air in that area could not be cooled by $20\text{ }^{\circ}\text{C}$ of cooling air. It was observed that the $20\text{ }^{\circ}\text{C}$ air discharge temperature was insufficient to cool the place near to the hot wall. Thermostats should be positioned at a height of no more than 150 cm above the ground due to irregularities in velocity and temperature distribution at the top of the room.

The ambient temperature in steady state conditions is within the desired values and the same discharge temperature and velocity values have been calculated for the different thermostat positions, because the airflow rates and temperatures of the air conditioner are set according to the values in Table 1. Therefore, it can be concluded that the control approach and the algorithms used in air conditioning devices have a significant effect on the uncomfortable areas within the room.

Fig. 6. Temperature and PPD distributions

Fig. 7. Transient simulation results of temperature and PPD

In this study, the changes in the temperature and velocity distributions in the room were investigated under transient conditions in order to examine how the control algorithm switched between the values given in Table 1. Initial temperature and thermostat set temperature were taken as 310 K and 294 K, respectively. It can be said that the temperatures in the room have reached comfort values within about 300 s (Fig. 7). The temperature of the suction side of the air conditioner has reached the desired value faster than the other parts of the room, and when PPD values examined in terms of comfort, it was found that PPD was lower than the other regions. Due to the high temperature differences at the beginning of the calculations, the blowing temperature is low and the blowing speed is high (Fig. 8).

Fig. 8. Variation of airflow rate and temperature according to time

When the change in the average PPD values in the room is examined, the effect of the thermostat position is clearly seen (Fig. 8). In the first 300 seconds, the PPD value increases by 35% when the thermostat is in position T6 instead of T1. Due to the T6 position is closer to the hot wall, it senses high temperature thus, the discharge rate is high and discomfort levels is occurred.

Fig. 9. Average PPD variation in time

6 Conclusion

In this study, two-dimensional numerical analysis of cooling of a room with cassette type air conditioner and the effect of thermostat position on PPD were investigated. Following conclusions were made:

- It has been observed that the thermostat position affects the velocity and temperature distribution within the room, and the discharge air velocity and temperature may change even under the same setting conditions. It has been concluded that, the effect of the control algorithm of the air conditioner on the uncomfortable areas inside a room is as important as the thermostat placement.
- It is calculated that, preferring lower fan stages doubles PPD values while cooling load reduced to one third of the cooling load.
- When the temperature and PPD values were examined in the room, it was seen that the thermostat position should be positioned at maximum to 150 cm from the floor and it was important for comfort in the room.
- It can be said that the thermostat placement is more effective on the air conditioner reaction under time-varying outdoor and indoor conditions, and the level of discomfort in the room is related to the thermostat position.
- In terms of energy consumption and comfort, the constant and low evaporation temperature creates discomfort in the room. Variable Ratio Temperature should be considered, and the evaporation temperature should be changed according to need, thus cooling can be carried out at a value close to room temperature

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