Thermal simulation and cooling load analysis in the apartment unit through building construction elevation review

B Iskandriawan* and A Safaat

1 Department of Industrial Design, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
2 Department of Mechanical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

*Email: bisk@prodes.its.ac.id

Abstract. Air conditioning systems constitute one kind of essential utility at a building. They could still be decreased its electrical cost consumption by way of insistent to continue the performance of its room air cooler system. The achievement of air conditioning system mentioned is very determined by the airflow pattern inner the room. Based on the airflow pattern which is raised furthermore it will be deliberated the cooling load which is determine cooling electricity costs. Construction elevation consideration will be carried out in the framework to obtain the difference of thermal condition each building level. The parameter mentioned is interesting to analyses due to the effect of sun heat will very dependent to the constructions elevation. Methodology which is to be used remains within practice the numeric simulation. The measuring of air temperature directly by means of censors also implemented within several level of construction elevation. The outcome of air temperature measurement will be used as the input value to the numeric simulation execution in the apartment unit with the local air conditioning system. It is obtained the thermal condition and cooling load of local air conditioning system in the apartment building unit within atypical floors.

1. Introduction

Proximate 134 million of new middle class people grew in Indonesia in 2012, five times larger than Malaysian residents or twenty five times more than Singaporean populations [1]. More than 50 % of this number survives in urban areas. This factor initiates a very excessive population density in the city and makes the house prices more overpriced. Apartment proposes a realistic place for those working in the urban region. Many years past, living in an apartment was viewed as a stylish standard of living. Nowadays, however residing in an apartment is a customary lifestyle for any class of people. Due to the quantity of apartment is enhance noticeably on the other hand they practically definite operate artificial air conditioning (AC) system. That's why it is needed the AC electricity energy consumption exploration of them. The biggest portion of controlling of it is the cooling load analysis. At least there are three approaches how to operate air conditioners cost-effectively. Firstly, the improvement of the AC performance by using several additional parts or equipment. Second, the selection of AC unit type (wall, ceiling suspended, cassette, floor standard or floor suspended). Finally we could recommend the surroundings arrangement of position where the AC unit will be used therefore they possibly will run most beneficial [2-5].
Accurate determination of stratification air conditioning practice for the building where the indoor air quality escalation could perform several advantages. It could be saved electricity energy consumption of AC system significantly [6]. An experiment of large space building under summer situations was accomplished to confirm the estimate effects of indoor vertical temperature spreading. The stratified air conditioning cooling load determined by the model was related with real air conditioning cooling capacity [7]. The displacement ventilation is great means its capability to bring heat through the exhaust diffuser is higher than that of mixed ventilation. They proficient to decrease the room air temperature. The existing of interior mass at the certain area will produce death air area where the room temperature becomes higher are their weakness [8 and 9]. The furniture arrangement inside the room possibly will control the performance of air conditioning system specifically their capability to decrease room air temperature [10]. Hence it could to be contemplated to cut down the cooling load of apartment unit room. This examination shows us the opportunity to save AC energy consumption based on the elevation difference of an apartment building.

2. Method

It was carried out the air temperature measuring by means of censor in the real time technique. The measuring was implemented start from 8.00 to 16.00 o’clock every day for ten days on floors 3, 4, 5, 6, 7, 8, 9 and 10 (eight floors) of the building. 8 floors are adequate to exemplify the dissimilar thermal condition of each floor. Subsequently it is obtained the average for one day. Instrumentation illustration of air temperature measuring could be seen on Figure 1a. It is expected there are no shades from the others obstacle such as building or trees which are block the sun ray to the temperature censor. Figure 1b shows us the censor the temperature sensor mounted to the glass of the building in the particular floor.

![Flooring plan of air temperature measurement](image1a)

![Air temperature censor mounted on the window glass](image1b)

**Figure 1.** Flooring plan of air temperature measurement on floors 3, 4, 5, 6, 7, 8, 9, and 10 (a). Air temperature censor is mounted on the window glass of building for each floor (b).

On the other hand as the parallel work it is generated a model of apartment unit in the computational fluid dynamics software (Figure 2). Structured mesh used cells in the form of hexagonal fields while unstructured using tetragonal fields. The result of air temperature measuring will be applied as the input for thermal simulation as well as cooling load inside apartment model. Several iterations are completed to obtain 40 (forty) results of numerical simulation in line to the quantity of apartment unit with different construction floor and time.
Mesh Size

| Level | Cells  | Faces   | Nodes  | Partitions |
|-------|--------|---------|--------|------------|
| 0     | 374472 | 772160  | 73909  | 2          |

1 cell zone, 21 face zones.

**Figure 2.** Mesh generated and meshes size of apartment unit within the dimension of 7m length x 4m wide x 3m high.

Furthermore it could be concluded the thermal performance of air conditioning system in each the apartment unit. One has the capability more than the other in the case of reducing room air temperature inside the apartment unit. Finally, it could be informed the cooling load for air conditioning system of every single apartment unit within different floor.

### 3. Result and discussion

The results of air temperature measurements for eight floors from 08.00 to 16.00 o’clock can be seen at Figure 3. It is assumed that the air temperature measured is equal to glass window temperature, \( T_g \). They tend to rise according to the increase in building elevation/floor. The lowest air temperature occurs at 08.00 for floor 3 up to 10. While the highest temperatures occur around 12.00 and 13.00. It surprising that the air temperature surpasses that of 12.00 at 11.00 o’clock on floors 9 and 10. The highest glass window temperature, \( T_{g\ max} = 34.00 \, ^\circ C \), happened on floor 10 at 13.00 o’clock. Where the lowest glass window temperature, \( T_{g\ min} = 27.68 \, ^\circ C \), occurred on floor 3 at 08.00 o’clock. Interesting events occurred at the times 09.00 and 16.00, the air temperature exceeds each other on floors 3 to 10.

The boundary layer is determined before the iteration process is carrying out according to the apartment unit model that was created (Table 1). There are several heats where they will control the total of cooling load inside the apartment unit. All of them are similar except the glass window temperature. Figure 4 shows us the apartment unit model has been determined in such a way as well as laying the poles/lines inside the room (lines 1, 2, 3, 4, and 5). It is expected that the position of the pillars already represents area part of the room.

**Figure 3.** The results of median air temperature measurements for eight floors from 08.00 to 16.00 o’clock.
Table 1. Thermal numerical simulation boundary condition of apartment building.

| No. | Heat source         | Explanation                                                                                                                                 |
|-----|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Apartment room      | Free stream temperature, $T_s = 25^\circ$C (298 K)                                                                                         |
| 2   | Glass windows       | Temperature was taken from the measurement results (Figure 3)                                                                             |
| 3   | Air Conditioner     | Air velocity, $V_{AC} = 1.15$ ms$^{-1}$; Temperature, $T_{AC} = 20^\circ$C (293 K)                                                          |
| 4   | Refrigerator        | Temperature, $T_f = 30^\circ$C; Heat flux, $h_f = 10$ Wm$^{-2}$.K                                                                         |
| 5   | Television          | Temperature, $T_f = 35^\circ$C; Heat flux, $h_f = 5$ Wm$^{-2}$.K                                                                           |
| 6   | Lamp                | Temperature, $T_f = 50^\circ$C; Heat flux, $h_f = 5$ Wm$^{-2}$.K                                                                          |
| 7   | Stove               | Temperature, $T_f = 70^\circ$C; Heat flux, $h_f = 10$ Wm$^{-2}$.K                                                                         |
| 8   | People (lie down)   | Temperature, $T_f = 36^\circ$C; Heat flux, $h_f = 12.73$ Wm$^{-2}$.K                                                                        |

Checking the air temperature contours inside the apartment unit as well as the air velocity that has been done according to the planes that has been made before (six planes, Figure 5). The distance of each plane is around 0.5 meter where the height of the apartment unit room, $h=3$ meter.

Afterward it will be examined the effect of differences in glass windows temperature settings on the thermal conditions of apartment unit in all volume (airflow), planes (countur) and lines. Airflow pattern occurred inside the apartment unit for the specified floor, glass window temperature ($T_g$) and time could be seen at Figure 6. In this case the representatives are floor 3 (the lowest), $T_g=31.26 ^\circ$C at 12.00 and floor 10 (the highest), $T_g=33.52 ^\circ$C at 12.00. In truth, it is quite difficult to find any differences in thermal conditions of airflow pattern inside apartment units. The two look the identical even though there are small differences among them. Subsequently likewise happens if contours are observed in the planes, very hard to distinguish them. This happens because of the very small difference of glasses window temperature.

Figure 4. Position of five poles/lines on the space inside the apartment unit.

Figure 5. Situation of six planes inside the apartment unit.

Figure 6. Airflow pattern occurred inside the apartment unit for the specified floor, glass window temperature ($T_g$) at 12.00 o’clock (a and b).
Air temperature gradient of 5 (five) lines inside apartment unit for certain floors could be seen at Figure 7a. Likewise line 1 for each floor can be seen at Figures 7b. Again, the air temperature gradient variances are so tinny that the graphs overlap. The time difference is not too changed in the graph. Air temperature tends to rise with increasing position of the point in the room. Highest air temperature occurs at line 1, around 24 °C at height 2.4 meter.

Equally on the air velocity chart in the apartment unit space (Figures 8), the differences in air velocity are very small for each floor. Highest air velocity arises at line 3, around 0.48 ms$^{-1}$ at height 2.25 meter.

![Air temperature gradient](image1)

**Figure 7.** Air temperature gradient of 5 (five) lines inside apartment unit, floor 3 at 12.00 o’clock (a). Air temperature gradient of lines 1 for each floor at 12/00 o’clock (b).

![Air velocity gradient](image2)

**Figure 8.** Air velocity gradient of 5 (five) lines inside apartment unit, floor 3 at 12.00 o’clock (a). Air velocity gradient of lines 1 for each floor at 12.00 (b).

Cooling load calculation using ASHRAE standard. Several assumptions are determined where one difference is glass window temperature of apartment unit for every floor.

It could be seen at Figure 9a that although the highest glass window temperature occurred at times 12.00 and 13.00 o’clock but the highest cooling load rose at the time between 13.00 to 16.00. This happened due to the phenomenon of time flag where the walls of apartment unit need time when removing the heat they contain.

Figure 9b shows us the cooling load of apartment unit as the function time for each floor. The difference among them so closed but still could be distinguished.
Figure 9. Cooling load of apartment unit as the function of building floor for time of 0.8.00 up to 16.00 o’clock (a). Cooling load of apartment unit as the function of time for each building floor (b).

4. Conclusion
There are a lot of works how to decrease cooling load of various home appliances incorporates the air conditioning system. The research was employed to know the consequence of apartment unit elevation to the amount of cooling load inside them. The method using thermal numeric thermal simulation and the calculation based on ASHRAE standard.

There are two main activities in this investigation. First, it was the air temperature measuring at outdoor area for every floor of building. Where the result of them will be used as the data input for numeric simulation. Second, it was implemented simulation process by means of them. The results show us that there are some different air temperatures at the certain place inside the apartment unit due to differentiation of glass window temperature. The variances are very small even some area and zones have similar temperature.

Based on the investigation that has been carried out, it can be concluded that the cooling load of the air conditions will be smaller with the lower floor height. AC capacity should not be equalized for each floor. The differentiation of consumption energy for all apartment units with different floor or elevation could be identified. It can be imagined, this is only one apartment unit but actually the case is there are millions of them.

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References
[1] Apartment Guide, Edition 01/July 2012, (Publisher: Kompas Gramedia)
[2] Uday S W 2009 COP Improvement of Air Conditioning System Using Evaporative Condenser International Journal of Applied Engineering Research 4 (3), ISSN 0973-4562 pp 363-370
[3] Frances H, Rodger E and Geoffrey L 2014 Influence of Display Cabinet Cooling on Performance of Supermarket Buildings Building Services Engineering Research and Technology 35 pp 170-181
[4] Bambang I 2014 Split Air Conditioning Selection of Apartment Unit around Jabodetabek Area to Enhance COP, International Journal of Applied Engineering Research 9(19) ISSN 0973-4562 pp 6277-6290
[5] Bambang I and Mahendra W 2018 Energy Consumption Investigation of Local Air Conditioning System in The Apartment Building Unit Through Construction Orientation
Review ARPN Journal of Engineering and Applied Science 13 (18) ISSN 1819-6608 pp 4905-4911

[6] Alan R K, Mats K and Robert F C 1993 Stratified Air Conditioning of Large Spaces with High Heat Loads Australian Refrigeration, Air conditioning and Heating 47(2) pp 24-29

[7] Ning C, Dongliang Z and Chen H 2018 A Study on Stratified Air Conditioning Cooling Load Calculation Model for A Large Space Building International Journal of Heat and Technology 36 (2) ISSN 03928764 https://doi.org/10.18280/ijht.360210 pp 457-462

[8] Shiping H, Qingyan C and Leon R G 1999 Comparison of Energy Consumption between Displacement Ventilation Systems for Different U.S. Buildings and Climates ASHRAE Transactions 105(PART 2) pp 453-464.

[9] Bambang I 2010 Study of Air Velocity and Temperature Gradient in Lecture Room through Mixed and Displacement Ventilation Systems The Journal for Technology and Science 21(2) ISSN 0853-4098 e-ISSN 2088-2033 pp 77-82.

[10] Bambang I 2016 The Variety of Furniture Arrangement inside Apartment Unit around Jabodetabek Area to Improve COP, ARPN Journal of Engineering and Applied Sciences 11(2) ISSN 1819-6608 pp 851-856.