Cooling Load Estimation in the Building Based On Heat Sources

Chairani\textsuperscript{1,2}, S Sulistyo\textsuperscript{1} and Widyawan\textsuperscript{1}

\textsuperscript{1}Dept. of Electrical Engineering and Information Technology, Faculty of Engineering, Universitas Gadjah Mada, Grafika Street No. 2 Kampus UGM, Yogyakarta, 55281, (0274) 552305, Indonesia
\textsuperscript{2}Informatics and Business Institute Darmajaya, Faculty of Computer Science, Z.A. Pagar Alam Street No. 93, Labuhan Ratu, Bandar Lampung, Lampung, 35141, Indonesia

chairani@mail.ugm.ac.id, selo@ugm.ac.id, widyawan@ugm.ac.id

Abstract. Heating, ventilation and air conditioning (HVAC) is the largest source of energy consumption. In this research, we discuss cooling load in the room by considering the different heat source and the number of occupancy. Energy cooling load is affected by external and internal heat sources. External cooling load in this discussion include convection outdoor/exterior using the DOE-2 algorithm, calculation of heat using Thermal Analysis Research Program (TARP), and Conduction Transfer Function (CTF). The internal cooling load is calculated based on the activity of the occupants in the office, a number of occupants, heat gain from lighting, and heat gain from electrics equipment. Weather data used is Surakarta weather and design day used is Jakarta design day. We use the ASHRAE standard for building materials and the metabolic of occupants while on the activity. The results show that the number of occupancies have an influence of cooling load. A large number of occupancy will cause the cooling load is great as well.

1. Introduction
The issue of global warming has become a particular concern in the world of research. To reduce the effects of global warming it have been developing of green building with the aim of energy saving [1]. For example, in the use of excessive cooling or heating of the building in addition to causing energy waste also causes inconvenience occupants. For saving energy, some researchers have also conducted research for occupancy detection [2][3], and natural lighting effects are also influenced by occupancy [4]. Setting the temperature in the room is affected by the cooling load. Cooling load is an expenditure of heat energy in the room to be cooled. Heat sources energy are affected by external and internal heat loads. External heat load is heat caused due to conduction, radiation and convection. Internal heat load is the heat caused by the occupants and electrical devices in the room [5]. External heat load include solar radiation transmitted through the glass, the solar radiation on the walls and roof, conduction in the room with irregularities through the walls, heat conduction and convection through the door and window glass due to the temperature difference, the heat caused by air infiltration due to the opening of the door and through gaps of the window. Internal heat load include heat from occupants, heat from lighting and electrical equipment, heat generated by other equipment [5]. Considering the importance temperature settings in smart building to support the objectives of green building, it is necessary doing
research to determine the condition of heat in buildings for air conditioning. Heating load in the building is not only influenced by the number of occupancies, but other factors such as the condition of external and internal environment of the building. Furthermore, we also studied the effect of a number of occupancy for the cooling load in the room.

The purpose of this research was to determine the required cooling load of the building and to maintain an optimal state of the building considering with the number of occupancy effect. The reminder of the paper is organized as follows. In Section II, we provide the basic theory of the external cooling loads. While the internal cooling loads are presented in Section III. Before we conclude this research in Section V, we present and discuss our result in Section IV. Finally, in Section VI, we discuss the future work.

2. External Cooling Load

The external cooling load is affected by the heat transfer from/to the environment through the building envelope. It is also influenced by sensible heat load, latent heat load, and the total heat load. The sensible heat load is the heat of the temperature difference between the outside of the building to inside the room. Latent heat load generated by the phase change of water vapor contained in the air in the room. Total heat load is the total accumulation of sensible heat load and latent heat load. Heat balance method is the calculation of sensible cooling load method which apply the law of conservation of energy and principles of matrix algebra [5].

2.1. Outdoor/Exterior Convection

2.1.1. Outside Surface Convection Algorithm : DOE-2. The DOE-2 convection model is a combination of the MoWiTT and BLAST detailed convection models [6]. Total convection coefficient is:

\[ h_{c,\text{glass}} = \sqrt{h_n^2 + [a V_Z^b]^2} \]  

Where \( h_{c,\text{glass}} \) is convective heat transfer coefficient for very smooth surfaces (glass), \( h_n \) is calculated using Equation or Equation. Constants a and b are given in Table 1.

| Wind Direction (Unit) | \( c_t \) \( W/(m^2K^{4/3}) \) | a \( W/(m^2K(m/s)^b) \) | b |  
|-----------------------|-----------------|-----------------|---|
| Winward               | 1.143           | 0.286           | 0.286 |
| Leeward               | 1.143           | 0.067           | 0.067 |

For less smooth surfaces, the convection coefficient is modified according to the equation:

\[ h_c = h_n + R_f(h_{c,\text{glass}} - h_n) \]  

Where \( R_f \) is the surface roughness multiplier (Table 2), \( h_c \) is surface exterior convective heat transfer coefficient, \( h_n \) is natural convective heat transfer coefficient.

2.2.2. Inside Surface Convection Algorithm : Thermal Analysis Research Program (TARP). Thermal Analysis Research Program (TARP) is a model developed by Walon. TARP is a comprehensive model for convection exterior by combining experimental flat plate (Sparrow et al) were correlated with ASHRAE [7]. The total convection coefficient is the sum of these components:

\[ h_c = h_f + h_n \]  

The forced convection component [8] is used:

\[ h_f = 2.537 W_f R_f \left( \frac{p V_Z^2}{A} \right)^{1/2} \]
$W_f$ is 1.0 for window ward surfaces or 0.5 for leeward surfaces, $V_Z$ is local wind speed calculated at the height above ground of the surface centorid (m/s).

**Table 2. Surface Roughness Multipliers [7]**

| Roughness Index | $R_f$  | Example Material |
|-----------------|--------|------------------|
| 3 (Medium Rough) | 1.52   | Concrete         |
| 4 (Medium Smooth) | 1.13   | Clear Pine       |
| 5 (Smooth)      | 1.11   | Smooth Plaster   |
| 6 (Very Smooth) | 1.00   | Glass            |

If the temperature is no difference or a vertical surface, then used:

$$h = 1.31|\Delta T|^{1/3}$$

(5)

where $\Delta T = \text{Air Temperature} - \text{Surface Temperature}$, for $(\Delta T < 0.0$ and upward facing surface), OR $(\Delta T > 0.0$ and downward facing surface) an enhanced convection correlation is used:

$$h = \frac{9.482|\Delta T|^{1/3}}{7.283 - |\cos \Sigma|}$$

(6)

Where $\Sigma$ is the surface tilt angle. For $(\Delta T > 0.0$ and upward facing surface), OR $(\Delta T < 0.0$ and downward facing surface) an reduce convection correlation is used:

$$h = \frac{1.810|\Delta T|^{1/3}}{1.302 + |\cos \Sigma|}$$

(7)

This research applies simulation on the energy plus software, using weather data Surakarta region. Latitude is -0.15 degrees, longitude is -78.48 degrees, the time zone is -5 hours, and elevation is 2812 meters. We use weather data in Surakarta region as the area most closely coordinates with the Jogjakarta region. The design day of Surakarta region is empty. We are using the design day of Jakarta region to completely of weather data Surakarta region. For summer design day, maximum dry blub temperature is 33.2°C, the daily dry-bulb temperature range is 7.5 deltac, humidity condition type is a wetbulb with the utmost wetbulb or dewpoint at maximum with the maximum drybulb is 25.9°C, barometric pressure is 101228.9 Pa, and sky clearness is 0.98. Design holiday using holidays in Indonesia region for one year. Surface inside and outside face temperature in Room21 at KPFT Building such as window1 can be seen in Figure 1.

### 2.2. Conduction Through The Walls

The process of conduction through the wall or the building envelope connecting the outside and the inside of the time heat balance. Conduction Transfer Function (CTF) is a function of time series that connecting the heat transfer conduction flux at a coating with a surface temperature and heat flux previous [9]. CTF for inside heat flux is:

$$q_{\text{in}}(t) = -Z_0 T_{0,t} - \sum_{j=1}^{n_\text{f}} Z_j T_{t,j-\delta} + Y_0 T_{0,t} + \sum_{j=1}^{n_\text{f}} Y_j T_{0,t-j-\delta} + \sum_{j=1}^{n_\text{f}} \Phi_j q_{\text{in}}(t-j-\delta)$$

(8)
CTF for outside heat flux is:

\[ q_{ko}^o(t) = -Y_0 T_{o,t} - \sum_{j=1}^{nz} Y_j T_{i,t-j} + \sum_{j=1}^{nz} X_j T_{o,t-j} + \sum_{j=1}^{nq} \Phi_j q_{ko,t-j} \]  

(9)

where \( X_j \) is outside CTF coefficient, \( j=0,1,...,nz \), \( Y_j \) is cross CTF coefficient, \( j=0,1,...,nz \), \( Z_j \) is inside CTF coefficient, \( j=0,1,...,nz \), \( \Phi_j \) is flux CTF coefficient, \( j=1,2,...,nq \), \( T_i \) is inside face temperature, \( T_o \) is outside face temperature, \( q_{ko}^o \) is conduction heat flux on outside face, \( q^* \) is conduction heat flux on inside face.

3. Internal cooling load

The internal cooling load is affected by the heat sources in the building. The cooling load consists of three types that are internal heat gain from occupancy, heat gain from lighting, and heat gain from electric equipment.

3.1. Heat gain from occupancy

Heat gain occupancy consisting of latent and sensible heat gain. Latent heat gain and an estimate sensible heat gain emitted from the body according to age and activity (equation (10))[6].

\[ S = 6.461927 + 0.946892 M + 0.000255737 M^2 + 7.139322T - 0.06279909 TM + 0.0000589172 T M^2 - 0.198550 T^2 + 0.000940018 T^2 M - 0.0000149532 T^3 M^3 \]  

(10)

\[ \text{LatenGain} = \text{MetabolicGain} - \text{SensibleGain} \]

where \( T \) is air temperature (celsius), \( M \) is the metabolic rate (Watt), and \( S \) is a sensible gain (Watt) [6]. Simulations performed by the numbers of occupancy are 0, 10, 15, 25, 35 and 50. A period of 1 year in working time from 07:00 am to 16:00 pm. Criteria schedule is activity in the office. Holiday time for one year by the Indonesian state included in the design setting holiday. People laten gain rate in September and sensible heat gain rate in August can be seen in Figure 2 and Figure 3. People total heating energy in January can be seen in Figure 4.

3.2. Heat gain from electrical equipment

Electric equipment in the room21 at building KPFT UGM include LCD projector Sonny and speaker audio controls. LCD projector sonny amounted to two pieces. Each is having power 405 watts and the duration of the operation for 8 hours/day. Speaker audio controls amounted to two pieces. Each is having a power of 40 watts and duration of operation during 8 hours/day. The total heating rate of electric equipment and lighting can be seen in Figure 5. Energy used by electrical appliance turned into heat energy and worked energy. Energy is turned into heat energy. Heat energy is affected by latent heat, radiation, and convection, \( f_{\text{conveded}} = 1.0 - (f_{\text{latent}} + f_{\text{radiant}} + f_{\text{lost}}) \), with \( f_{\text{conveded}} \) is a fraction of the heat is distributed by convection, \( f_{\text{latent}} \) fraction of the latent heat, \( f_{\text{radiant}} \) fraction of the radiation heat, dan \( f_{\text{lost}} \) the fraction of energy is turned into work [10].

3.3. Heat gain from lighting

The lighting system in a building of which generate heat is the part that generates light, which is light. The energy consumed by the lighting system is transformed into heat energy in three section, namely the short-wave radiation, long-wave radiation, and convection. The three factions there that are distributed into the room (space fraction) and some are distributed to the ceiling so that it interacts with the air through the air system (plenum/return water fraction) [10]. \( f_{\text{conveded}} = 1.0 - (f_{\text{ret}} + f_{\text{lw}} + f_{\text{sw}}) \) where \( f_{\text{conveded}} \) is a fraction of distributed heat by convection, \( f_{\text{ret}} \) is a fraction of the heat absorbed by the air through, \( f_{\text{lw}} \) is a fraction of long-wave radiation, and \( f_{\text{sw}} \) is a fraction of short-wave radiation [10].

4. Result
Total internal heating energy (joule) is count from zone lights total heating energy, zone electric equipment total heating energy, and zone people total heating energy. People Air Temperature is the zone temperature of people by Fanger Model Thermal Comfort. Fanger Model was developed using thermal sensation votes and Prediction Mean Vote (PMV) thermal sensation scale based on how energy lose (L) deviates from metabolic rate (M) in the following from $PMV = (0.303e^{-0.036M} + 0.028H - L$ [6]. Where H is internal heat production rate of an occupant per unit area (H=M-W). W is the rate of heat loss due to the performance of work (in the Fortran or Energy Plus variable name is WorkEff) [11]. Metabolic rates for office activities such as reading (seated), writing, typing, filing (seated), filing (standing), walking, and lifting (packing) can be seen in [10]. People air temperature in January can be seen. Of internal and external factors that have been discussed above, the cooling load estimates obtained in 1st August as follows.

5. Conclusion
From the above results, it can be concluded that in addition to the cooling load is influenced by external factors and internal factors, also affected by a number of occupancies. Figure 8 shows that the greater number of occupancy required cooling load will also be significant.

6. Future Work
Our next research shall be developing a knowledge base on the rule for conservation energy in the smart building.
7. Acknowledgments

Our thanks to Acoustics Laboratory at the Department of Physics, Universitas Gadjah Mada, for allowing us to information about weather data in Surakarta and Jakarta region.

8. References

[1] EIA 2003 Washington US. Commercial buildings energy consumption survey (cbecs). Technical report, US Department of Energy

[2] Pratama A R and Putra G D 2014 An Infrastructure-less Occupant Context-Recognition in Energy Efficient Building. in IEEE, International Conference on Information Technology and Electrical Engineering (ICITEE)

[3] Corna A, Fontana L, Nacci A and Sciuto D 2015 Occupancy Detection via iBeacon on Android Devices for Smart Building Management. In Automation & Test in Europe Conference & Exhibition 629–632

[4] Edwards L and Torcellini P 2002 A Literature Review of the Effects of Natural Light on Building Occupants a Literature Review of the Effects of Natural Light on Building Occupants.

[5] Hittle D 1981 Calculating Building Heating and Cooling Loads Using the Frequency Response of Multilayered Slabs.

[6] EnergyPlus Documentation 2016 Engineering Reference Version 8.6.

[7] Walton G N 1983 Thermal Analysis Research Program Reference Manual NBSSIR 83-2655. Thesis. National Bureau of Standards.

[8] Sparrow E M, Ramsey J W and Mass E A 1979 Effect of Finite Width on Heat Transfer and Fluid Flow about an Inclined Rectangular Plate. Journal of Heat Transfer. 101. p. 204.

[9] ASHRAE 2009 ASHRAE Handbook Fundamentals (SI). American Society of Heating, Refrigeration, and Air Conditioning, Engineers Inc. Atlanta. Georgia. America Serikat.

[10] EnergyPlus Documentation 2016 Input Output Reference Version 8.6

[11] Yazdanian M and Klems J H 1994 Measurement of the Exterior Convective Film Coefficient for Windows in Low-Rise Buildings ASHRAE Transactions. 100. Part 1. p.1087.