Development of load calculation algorithm for large space building based on RTS method

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Abstract. Since a large space building has distinguished characteristics, to analyze and predict the peak load these should be considered. The existed building energy simulation cannot reflect the characteristics of large space building, especially vertical temperature distribution. Therefore, to analyze the large space building, it is inevitably used the methods which requires high knowledge skills and economic cost. The goal of this research is suggesting the peak load calculation algorithm for a large space building. With RTS(Radiant Time Series) and simplified model for predicting vertical temperature distribution, the algorithm is expected to show highly applicability with minimum input data and consisted with clear calculation process. The calculation process is composed with three steps. 1) calculation for preparing initial condition, 2) calculation of air movement, 3) calculating peak load for occupied space. With the Energyplus applying airflow network, the result of algorithm is assessed. The predicted temperature and peak load for an occupied zone at each cases are compared. The result applying proposed algorithm shows 33.64 °C at 15 hour and the peak load is 50.92 kW. In case of applying Energy plus, 35.59 °C, 63.93 kW at 16 hour is predicted. For the further research, vertical temperature measurements in large space building will be proceeded. By comparing the measured vertical temperature distribution and predicted temperature in a large space building, the algorithm will be assessed.

Nomenclature.

\[\alpha_c\] Convevtive heat transfer coefficient
\[C_p\] Specific heat of air [J/kg·K]
\[\rho\] Density of air [kg/m³]
\[r_0\] Latent heat of vaporization [kJ/kg]
\[Q_{IP\theta}(n)\] Infiltration load [W]
\[Q_{IO\theta}(n)\] Ventilation load [W]
\[t_{e\theta}\] Sol-air temperature [°C]
\[t_{rc}\] Set-point temperature [°C]
\[t_d(n,K)\] Temperature of movable air in zone [°C]
\[t_{zone\theta}(n)\] Zone temperature [°C]
\[t_{m}(n,K)\] Temperature of compounded air [°C]
\[V_{MP}(n,K)\] Volume of moving air to upper zone [m³]
\[V_{m}(n,K)\] Volume of compound air [m³]
\[V_{OUT}(n,K)\] Volume of movable air in zone[m³]
\[x_{\alpha\theta}\] Relative humidity in a peak day [%]
\[x_{rc}\] Set-point relative humidity [%]

1. Introduction
A requirement for a large space building such as stadium are continuously increasing according to an cultural, economic growth. Since it consumes gigantic building energy compared with general building, predicting the building load of large space building at construction design phase is important. In building energy simulation, the building load is a required energy for maintaining indoor environment to set-point environment. It is calculated at the point that analysis space reaching steady-state. Since the large space building has distinguished characteristics, these should be considered to predict the building load. These can be summarized with three parts. 1) large volume space for air-conditioning control, 2) limited space for occupancies, 3) vertical temperature distribution.
When the large space building is analysed with general building energy simulation, it brings over-size HVAC system design and uncomfortable environment for occupancies by assuming the whole space maintains same indoor environment. Although, researches about large space building has focused on the vertical temperature distribution in a large space. The absence of the load calculation method for a large space building imposes to apply method requiring high professional knowledge and economic cost, e.g. Computational Fluid Dynamics (CFD) or building energy simulation applying vertical airflow network.

The goal of the research is to suggest the large space building’s load calculation algorithm which predicts not only the vertical temperature distribution but also appropriate building load for an occupied space. By applying simple calculation methods showing high availability in a research field, the proposed algorithm is expected to show highly applicability with minimum input data and consisted with clear calculation process.

**Figure 1.** Calculation process of load calculation algorithm for a large space building

### 2. Outline of proposed algorithm

By assuming the analysis space (large space) divided with 10 imaginary zones, the vertical temperature distribution, which is occurred from a differences temperature between each zones, is considered. In the proposed algorithm, zone 1 (lower part) is assumed to be an occupied space, and Zone 10 is higher space. The load calculation algorithm for a large space building is composed with three calculation phases[Fig 1]. At first step, initial condition at each zone is prepared by calculating the heat gain through building component, internal gain. Secondly, the calculation of air movement is processed. The air movement is consisted with 1) indoor (vertical) air movement, 2) air movement occurred from the difference between in and out-door environment. Finally, the building load is calculated targeting on the occupied space.

#### 2.1. RTS (Radiant Time Series) Method

ASHRAE suggested simple calculation (RTS) method for predicting peak building load. A type of heat occurred in a building is composed with conduction, radiation and convection. In RTS, the convection heat is assumed to be immediately converted to load. Therefore, whole type of heat should be converted to the convection heat to predict peak load. During the conversion, some of time-delay are occurred.
The advantage of RTS is the time-delay can be easily calculated by applying coefficient. With applying CTS(Conducted Time Series) coefficient, the time-delay of conduction heat(storage effect) is calculated. And the time-delay occurred during conversion of radiation to convection heat, is considered by applying RTS(Radiant Time Series) coefficient. By sum up the total convection heat from whole type of heat gain, the hourly building load is calculated.

2.2. Simplified model for predicting vertical temperature distribution

Togari et al. suggested the simplified numerical model for predicting the vertical temperature distribution by dividing imaginary zones. The concept of generating temperature differences within a subdivided single space, is actively used for analyzing the heat and air movement in a large space building. The vertical air movement is calculated with three processes. 1)calculating the movable air from each zone, 2)calculating the compounded air, 3)decide the direction of compounded air. It predicts the temperature variation according to the height by assuming steady-state.

Since each calculation has different time unit, the proposed algorithm predicts the peak load by repeating the air movement calculation until reach steady-state based on initial condition. The time-step is decided according to the number of repetition to reach steady-state in indoor temperature.

3. A Proposal of load algorithm for a large space building

3.1. Calculation for preparing initial condition

The occurred heat gain within a building is calculated to temperature value. The heat gain is occurred by conduction from building component, internal gain(people, light, equipment). With U-value, area of building component, and differences of indoor and outdoor temperature, the conduction heat is calculated. The conduction heat from building component should be applied a CTS coefficient to consider the time-delay. The internal heat gain is calculated by multiply an usage profile(%) and hourly sensible heat of each internal heat(W).

The hourly(θ) occurred heat is summed by type of heat gain(qr,θ), and it is divided to radiation(\( R_{fraction} \)) and convection part(\( C_{fraction} \)) by ratio(eq 1). The calculated convection heat(\( Q_{c,θ} \)) is directly converted to building load. The radiation(\( q_r,θ \)), on the other hand, should be converted to convection part. As time elapsed, the radiation heat is converted to the convection heat. With RTS coefficient(\( r_h(n:1−23) \)), the converted convection heat(\( Q_{r,θ} \)) from radiation heat is calculated [eq 2]. The total convection heat(\( Q_{init} \)) is summed according to the 10 imaginary zones. By applying eq 4, the total convection heat is calculated with temperature differences.

\[
Q_{c,θ} = q_{r,θ} \cdot C_{fraction}, \quad Q_{r,θ} = q_{r,θ} \cdot R_{fraction} \\
Q_{init} = Q_{c,θ} + Q_{r,θ} \\
\Delta T_{zone(n),θ} = \frac{Q_{init.zone(n)}}{V_{zone(n)} \cdot c_p} 
\]

3.2. Calculation for air movement (Indoor air movement)

According to Eckert et al.\(^9\), the movable air from zone(n) is calculated based on the relationship between temperature at zone(n) and sol-air temperature. The convective heat transfer coefficient for calculating the volume of movable air is 20 W/m²K is applied\(^10\).

\[
\ell_d(n, K) = 0.75 \cdot \ell_{zone,θ}(n) + 0.25 \cdot \ell_{c,θ} \\
V_{OUT}(n, K) = \frac{\ell_d A_m(n, K)}{c_p} 
\]

When the airflow goes upwards, the movable air(\( V_{OUT} \)) from zone(n) is compounded with moved air from zone(n-1). The compounded air’s temperature is decided with the ratio of each air volume.

\[
V_M(n, K) = V_{M,comp}(n − 1, K) + V_{OUT}(n, K) \\
t_M(n, K) = \frac{V_{M,comp}(n − 1, K) \cdot \ell_{M,comp}(n − 1, K)}{\ell_M(n, K)} 
\]

The compounded air moves continuously to upper zone(n+1) or return to zone(n). Depending on the temperature between zone(n) and zone(n+1), the amount of air is calculated. Since the pressure and

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temperature show inverse relation, the amount of moving air from zone(n) to zone(n+1) is decided with temperature in zone(n+1). The rest of amount of air returns to zone(n).

\[
V_{IN}(n, K) = V_M(n, K) \cdot \frac{t_{zone, \theta(n+1)}}{(t_{zone, \theta(n)} + t_{zone, \theta(n+1)})}, \quad V_{MD}(n, K) = V_M(n, K) - V_{IN}(n, K) \quad (9)
\]

![Flowchart of air movement](image)

**Figure 2.** Flowchart of air movement

### 3.3. Calculation for air movement (Indoor-Outdoor air movement)

The air movement from the differences between indoor and outdoor temperature is divided with ventilation (intended) and infiltration (unintended). In the algorithm, the type of air movement is changed depending on the occupancy schedule. When there is un-occupied condition, the infiltration is assumed to whole zone. The volume of infiltration air is decided with differences between volume of air in zone(n).

\[
Q_{IF,\text{sensible}, \theta}(n) = C_p \cdot \rho \cdot (V_{IN}(n, K) - V_{OUT}(n, K)) \cdot (t_{e, \theta}(n) - t_{rc}) \quad (10)
\]
\[
Q_{IF,\text{latent}, \theta}(n) = r_D \cdot \rho \cdot (V_{IN}(n, K) - V_{OUT}(n, K)) \cdot (x_{0, \theta} - x_{rc}) \quad (11)
\]

When there is occupied, the ventilation is applied to zone(1). The amount of ventilation is decided with the required air for number of people. For the rest zones, the infiltration is applied, and it is calculated according to the movable air’s pressure per each zone. Sum of infiltrated air is same with ventilated air.

\[
Q_{DA,\text{sensible}, \theta}(n) = C_p \cdot \rho \cdot \frac{V_{IN}(n, K)}{\sum_{n=2}^{N} V_{IN}(n, K)} \cdot (t_{e, \theta}(n) - t_{rc}) \quad (12)
\]
\[
Q_{DA,\text{latent}, \theta}(n) = r_D \cdot \rho \cdot \frac{V_{IN}(n, K)}{\sum_{n=2}^{N} V_{IN}(n, K)} \cdot (x_{0, \theta} - x_{rc}) \quad (13)
\]

### 3.4. Calculation peak load for occupied space

When the air movement calculation based on initial condition is repeated 60 times, the temperature for each zones show low variability, namely steady-state. Therefore, the calculation for 1 hour is proceeded with 1 cycle, 60 time-steps. For each occupied zone temperature per hour is converted to the building peak load \(Q_{peak, \theta}\).

\[
Q_{peak, \theta} = (t_{zone(1), 60} - t_{rc}) \cdot V_{zone(1)} \cdot \rho \cdot C_p \quad (14)
\]
Table 1. Information of target building

| Category               | Input data                        |
|------------------------|-----------------------------------|
| **Outdoor condition**  |                                   |
| Location               | Seoul, Korea                      |
| Condition\(^{11}\)     |                                   |
| Month / Day            | July / 22 th                      |
| Peak DB                | 34.2 °C                           |
| DB range               | 9.9 °C                            |
| **Building condition** |                                   |
| Size                   | Area / Height                     |
|                        | 100 m*100 m*20 m                  |
| U-value\(^{12}\)       |                                   |
| Wall                   | 0.24 W/m²·K                      |
| Roof                   | 0.15 W/m²·K                      |
| **Indoor Condition\(^{12}\)** |                   |
| DB / RH                | 26 °C / 50%                       |
| Internal gain\(^{7}\)  |                                   |
| People                 | 0.5 p/m²                          |
| Lighting               | 4.6 W/m²                          |
| Equipment              | N/A                               |
| Ventilation            | 12.5 CMH/p                        |

\(DB = \) Dry-bulb temperature, \(RH = \) Relative humidity, N/A = Not applicable

4. Conclusions

The occupied zone temperature per hour, building peak load are predicted with proposed algorithm. By comparing the results with existed analysis method for a large space building, the algorithm is assessed. Generally, a building energy simulation applying vertical air movement is used for predicting peak load for a large space building. In this paper, the Energyplus applying airflow network is used for comparison. The analysis is proceeded with an imaginary large space building. The outdoor condition and building information is written on Table 1. The case analysed with proposed algorithm is named as case LARGE, and analysed with Energyplus is named as case EP. The same input data is applied to both cases. The temperature for occupied zone shows 33.64 °C at 15 hour. The temperature difference between occupied zone and upper zone (zone 10) shows 3.81 °C. At the same time, the peak load is calculated to 50.92 kW. The result predicted with Energyplus shows some difference with case LARGE. At 16 hour, the highest occupied zone temperature is predicted. It is 35.59 °C, and the peak load is calculated to 63.93 kW. The temperature difference for occupied zone between each cases shows 1.95 °C, and the error rate is about 5.8 %. At the point of peak load, the difference is 13.01 kW, the error rate is about 25 %. In this paper, the algorithm for predicting peak load in a large space building is proposed, and is assessed with existed analysing method. For the further research, a measurements of vertical temperature distribution in a large space building will be proceeded and the algorithm will be assessed.
Figure 3. Comparison of zone temperature(upper) and peak load(lower)

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