An Analysis of Shortened Experiments for Environmental Chamber

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Key words: Environmental chamber, Shortened experiments, Thermal response of building, Scale factor

Abstract

Environmental chamber (EC) is an experimental facility used to analyze the characteristics of thermal response of testing objects by the artificial control of weather conditions. The EC in KIER can simulate the weather conditions by the control of temperature, humidity, and solar radiation. A two-storied testing building is located inside EC. For the exact thermal response analysis of testing building, monthly or yearly scheduled operations are necessary. Although this long term operation gives the exact experimental data, it requires a high operational cost, long duration, and lots of manpower. Therefore it is necessary to perform the shortened experiments without sacrificing the validity of the obtained results. Since the characteristics of thermal response from the shortened experiments are different from the full time results, the analytical method to analyze the thermal response from the shortened experiments to estimate a full times results is developed in this study. The thermal response of testing building is performed using commercial software TRNSYS.

Nomenclature

c_p : specific heat capacity [J/kgK]
h : convective heat transfer coefficient [W/m^{2}K]
k : thermal conductivity [W/mK]
$\dot{m}$: mass flow rate [kg/s]
$\dot{Q}$: heat transfer rate [W]
t : thickness [m]
T : temperature [K]

Subscripts

c : convective heat transfer
i : specific zone
in : indoor
out : outdoor

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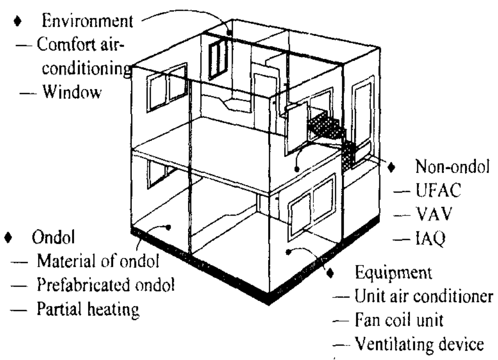
1. Introduction

An environmental chamber (EC) is an experimental apparatus to simulate the artificial indoor air conditions, basically temperature and humidity of air, and is used to examine the thermal characteristics of the testing object for the variation of thermal conditions. Korea Institute of Energy Research (KIER) has an EC for the thermal test of small house. The EC has a capacity to control the temperature of −25 to 50℃, humidity range of 30 to 90%. The EC also has equipped with solar radiation device.[1] The EC tests the dynamic and static thermal characteristics under artificially controlled climate and ultimately can be used to obtain energy savings of building and comfortable living conditions in a building. To test the exact thermal characteristics of a building the exterior and interior climate has to be controlled separately and it needs a long duration experiments under daily or monthly scheduled climate conditions.

Even this long duration experiments give the accurate data for the thermal characteristics of building, it needs a lot of time and money to do the experiments. Therefore it is necessary to perform the shortened experiments under appropriately controlled weather conditions. Since this shortened experiments, for example, the shortened 6 hours experiments simulating 24 hours results give the different thermal characteristics corresponding to the exterior weather conditions, it is necessary to verify the different behavior and similarity between long and shortened experiments. This can give the real time thermal characteristics from the shortened experiments and by controling the exterior conditions the shortened thermal characteristics of the building can be analyzed as a real time data.

2. Environment chamber and testing building

The used EC is established in KIER. The volume of the EC is about 1,400 m^3 (12.6 m × 10.8 m × 10.5 m (H)) and the maximum size of the testing building is about 120 m^3 (6.9 m × 8.7 m × 10.5 m (H)). Table 1 shows the dimensions of existing testing building, which has 2 stories and each floor has 80 m^2.[1] The building has 4 rooms and aisle. Each room is set up for the test of the Ondol room, air-conditioned room, and office. Figure 1 shows the schematic diagram of the testing building.



♦ Experiment for thermal performace of the structure related to a building and an air conditioning facility.

Fig. 1 Structure of experimental building in the environmental chamber.

Table 1 Dimension of environmental chamber

Content	Experimental chamber
Effective volume	12.6 m (L) × 10.8 m (W) × 10.5 m (H)
Temperature range	−25 ~ 50℃
Humidity range	15℃ DB: dew point 2℃ ± 1℃
	24℃ DB: dew point 10 ~ 22℃ ± 1℃
	24℃ DB: dew point 10 ~ 22℃ ± 1℃
Temperature variation rate	Temperature decrease rate 8℃/h at 0℃
	Temperature increase rate 10℃/h at 20℃

Table 2 Thermal properties of building materials and insulations

Material	Conductivity (kJ/hmK)	Capacity (kJ/kgK)	Density (kg/m^3)
Concrete	7.56	1.0	2400
Cement brick	5.44	0.84	1922
Brick, fired clay	2.55	0.84	1650
Sand-gravel	2.52	1.0	1800
Pumice-gravel	0.68	1.0	1000
Styrofoam	0.13	-	30
Plastercard	0.76	1.0	900
Air layer	0.047	-	-
Cement-mortar	5.04	1.0	2000
Plywood	0..54	1.2	800
Copper	1340	0.419	8300

Table 2 shows the material properties of wall of testing building.[(2-4)]

3. The thermal analysis of building

3.1 TRNSYS for analyzing thermal characteristics

The commercial software TRNSYS is widely used to analyze the thermal characteristics of testing building.

This software can simulate the energy demand for the building and the accuracy is determined by the complexity of the testing building.[(5)] Type 56 (multi-zone model) in TRNSYS is used to analyze the thermal characteristics of the building. Figure 2 shows the schematics of IlsiBat window model for TRNSYS simulations. This system is consisted with Data Reader to obtain the climate conditions, Psychrometrics, Sky temperature calculator, and multi-zone building information.

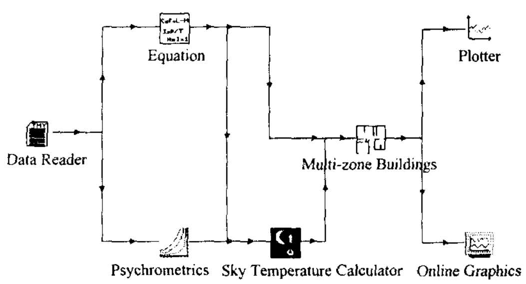


Fig. 2 Schematic of IlsiBat window model for TRNSYS simulation.

3.2 Typical meteorological year (TMY)

TRNSYS uses the data reader or weather data generator to obtain the necessary weather conditions. The Data reader reads the Typical Meteorological Year (TMY) type weather and can generate the hour weather conditions from the monthly averaged values by some manipulation.[(6)] In this study user-defined TMY data was used to simulate the various weather conditions. Figure 3 shows the typical weather data of Los Angeles in USA at August first. The shortened data of 6 hour and 12 hour are also shown together. To analyze the thermal characteristics of building the information on the testing building, cooling and heating load, obtained thermal load by human and electronic devices, ventilation amount, and solar radiation are necessary. PREBID and BID in TRNSYS are used to describe these.

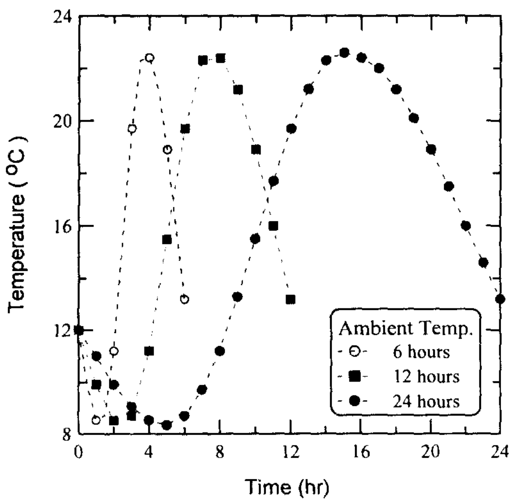


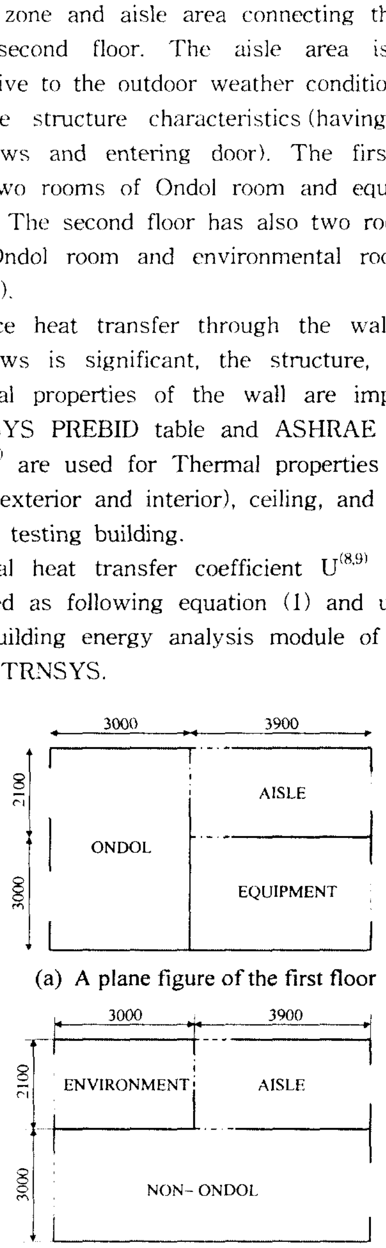
Fig. 3 Ambient temperature for a various time in L.A.

3.3 Zoning and wall structure

The zoning in a building for the proper air conditioning is important.[7] In this study the testing building is specified by the separate room zone and aisle area connecting the first and second floor. The aisle area is very sensitive to the outdoor weather conditions due to the structure characteristics (having large windows and entering door). The first floor has two rooms of Ondol room and equipment room. The second floor has also two rooms of non-Ondol room and environmental room (see Fig. 4).

Since heat transfer through the walls and windows is significant, the structure, arrays, thermal properties of the wall are important. TRNSYS PREBID table and ASHRAE Handbook[2] are used for Thermal properties of the wall (exterior and interior), ceiling, and bottom of the testing building.

Total heat transfer coefficient U[8,9] is expressed as following equation (1) and used in the building energy analysis module of TYPE 56 of TRNSYS.



(a) A plane figure of the first floor

(b) A plane figure of the second floor

Fig. 4 Zoning of an experimental building for PREBID.

$$\frac{1}{U} = \frac{1}{h_{c,in}} + \sum_{k=1}^{n} \frac{t_k}{k_k} + \frac{1}{h_{c,out}} \tag{1}$$

Here $h_{c,in}$ is internal convective heat transfer coefficient, and $h_{c,out}$ is external convective heat transfer coefficient.

3.4 Thermal analysis model of building energy

Type 56 of TRNSYS is multi-zone analyzing model for thermal energy of the building. This also includes the solar energy absorption and can calculate the detailed energy flow in the building. Type 56 has an ability to calculate maximum 25 thermal zones.

The thermal energy in a specified zone can be expressed as equation (2) using the transfer coefficient in PREBID.

$$\begin{aligned}
\dot{Q}_i &= \dot{Q}_{surf,i} + \dot{Q}_{inf,i} + \dot{Q}_{v,i} + \dot{Q}_{g,c,i} + \dot{Q}_{cplg,i} \\
\dot{Q}_{surf,i} &= U_{w,i} \cdot A_{w,i} \cdot (T_{wall,i} - T_{air}) \\
\dot{Q}_{inf,i} &= \dot{V} \cdot \rho \cdot c_p \cdot (T_{outside} - T_{air}) \\
\dot{Q}_{v,i} &= \dot{V} \cdot \rho \cdot c_p \cdot (T_{ventilation} - T_{air}) \\
\dot{Q}_{cplg,i} &= \dot{V} \cdot \rho \cdot c_p \cdot (T_{zone,i} - T_{air}) \\
\dot{Q}_{g,c,i} &= f\ (\text{man, heater, any heation device...})
\end{aligned} \tag{2}$$

Here $\dot{Q}_{surf,i}$ is the convective heat transfer from the interior wall, $\dot{Q}_{inf,i}$ is the heat transfer by infiltrating air flow, $\dot{Q}_{v,i}$ is heat transfer due to ventilation, $\dot{Q}_{g,c,i}$ is the internal heat generation, and $\dot{Q}_{cplg,i}$ is the heat gain from the air flow of the other zone.

3.5 Infiltration and ventilation

The ratio of infiltration and ventilation can be calculated by the time variation of the amount of air. The infiltration is determined by the exterior conditions and the ventilation occurs at the specified temperature.

The equations (3) and (4) show the heat obtained by the infiltration and ventilation.

$$\dot{Q}_{inf,i} = \dot{m}_{inf,i} c_p (T_a - T_i) \quad (3)$$

$$\dot{Q}_{v,i} = \dot{m}_{v,i} c_p (T_v - T_i) \quad (4)$$

Here T_a is the atmosphere temperature, T_v is the ventilation temperature, T_i is the specified zone temperature, and $\dot{m}$ is the mass flow rate.

4. Analysis of shortened experiments for environmental chamber

4.1 Thermal response characteristics of EC

TRNSYS calculated the thermal response of the testing building corresponding to the specified exterior weather conditions (temperature, humidity, and wind velocity).[10] To verify the accuracy of TRNSYS the calculated results are compared to the experimental results. The comparison gives the relatively good agreement of maximum difference of 20% (0.2℃ temperature difference). For this bench marking problem, the ratio of 0.4 for the infiltration and ventilation was used in TRNSYS.

Figure 3 shows the exterior weather conditions for 24 hour duration. At 0 hour, the temperature is 12℃ and it decreases to about 8℃ at 4 hour. After this, the temperature increases to 22℃ at 14 hour and decreases again and completes the temperature cycle. The initial temperature of the testing building was set to be 20℃. Figure 3 also shows the shortened weather conditions for the duration of 12 hours and 6 hours.

Figure 5 shows the Ondol zone temperature variation corresponding to the exterior weather changes (cycle duration of 24, 12, and 6 hours). For this calculation, no infiltration and ventilation through the windows, door, and wall are assumed. The other zones also show the similar thermal response to the exterior weather condition variations.

Figure 6 shows the simply expanded results to the 24 hour duration for the shortened results of Fig. 5. The final temperature of the expanded 6 hour results is 19.7℃. The temperature of 24 hour duration gives 19.1℃.

The expanded results to 24 hour duration of the other zones give the different temperature profile but show the similar behavior. Since the expanded temperatures show the similar behavior when they are simply expanded to 24 hour duration, there is a possibility of extend-

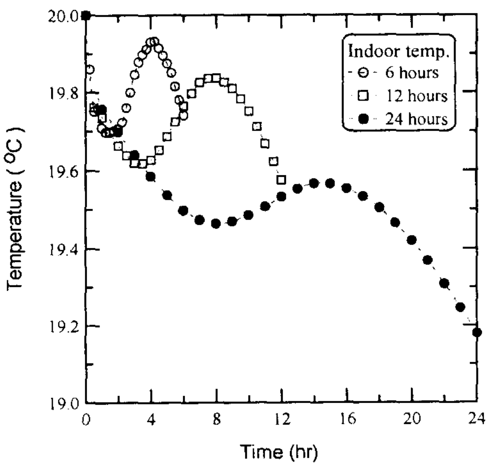


Fig. 5 Distribution of indoor temperature in the Ondol (infiltration rate=0).

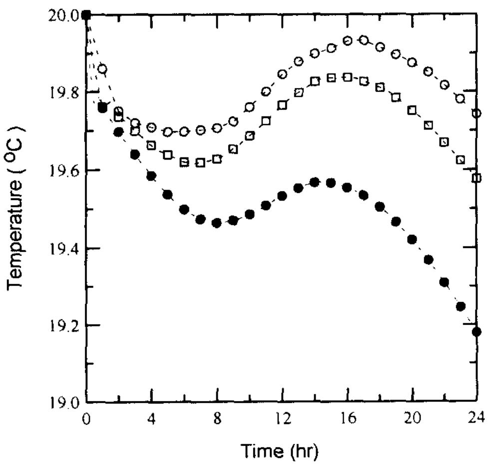


Fig. 6 Expanded temperature profile to 24 hour duration in Ondol.

ing this shortened results to long hour duration by introducing some experimental factor.

4.2 Scale factor for shortened experiments

Figure 6 shows it needs a relating equations between the results of 24 hour duration and those of shortened duration. Here this relating equation is called scale factor and obtained from the calculated results. The results show that there are two different scale factors when each zone temperature is going down and up. When the temperature of each zone goes down, TRNSYS calculates the temperature variation of each zone with initial zone temperature of 20℃ corresponding to the steady exterior temperature of 15℃, 10℃, 5℃, and 0℃. For the given exterior temperature, the calculated zone temperature of 6 hour, 12 hour, and 24 hour duration is simply expanded to 24 hour duration. Then the scale factors are obtained to give the same temperature profile for these results. Figure 7 shows the obtained scale factor for the downward temperature of Ondol zone with no infiltration and ventilation. Figure 7 shows that the obtained scale factors are almost the same regardless the temperature difference between the Ondol zone and exterior conditions. When the temperature difference is small, the scale factors show little different values compared to the others.

Figure 8 shows scale factors for the Ondol zone when the zone temperature goes up. The initial zone temperature is 0℃ and the exterior temperature is kept at 5℃, 10℃, 15℃, and 20 ℃. TRNSYS calculates the temperature change for 6 hour, 12 hour, and 24 hour duration and these results are expanded to 24 hour duration. To match the expanded temperatures to those of the 24 hour duration the scale factor was obtained. The upward scale factors also give the asymptotic values as downward case, but the scale factor values are different from upward and downward cases.

Figure 9 shows the scale factors for downward mode with the variation of infiltration ratio for the Ondol zone. The initial temperature difference between the zone and outdoor is 10 ℃. Here the infiltration ratio is the fraction of the inflow air per hour to total air volume of the zone. The infiltration ratio 1 means total air of the zone is exchanged with the outdoor air for 1 hour. As the infiltration ratio increases the scale factor becomes small. This

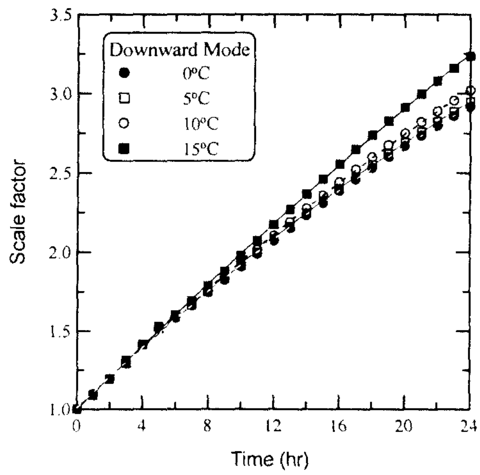


Fig. 7 Scale factor for downward mode between 6 hours and 24 hours in the Ondol (infiltration rate=0).

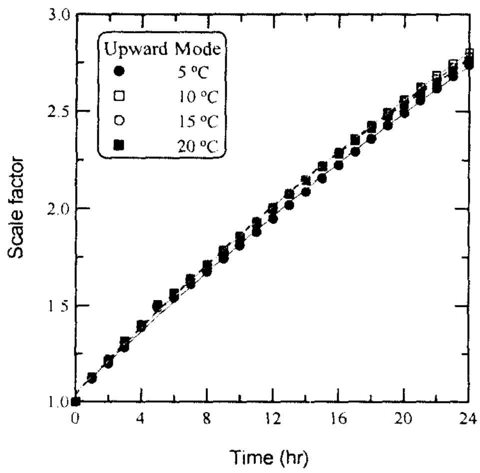


Fig. 8 Scale factor for upward mode between 6 hours and 24 hours in the Ondol (infiltration rate=0).

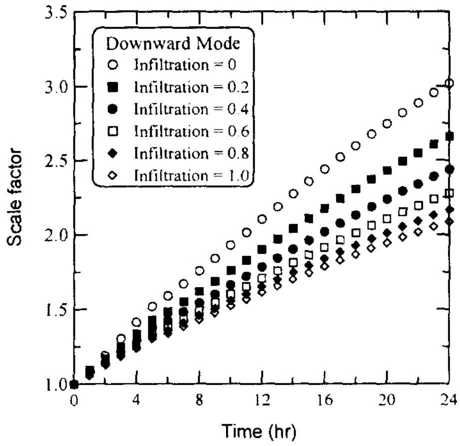


Fig. 9 Scale factor with a variety of infiltration rate between 6 hours and 24 hours in the Ondol.

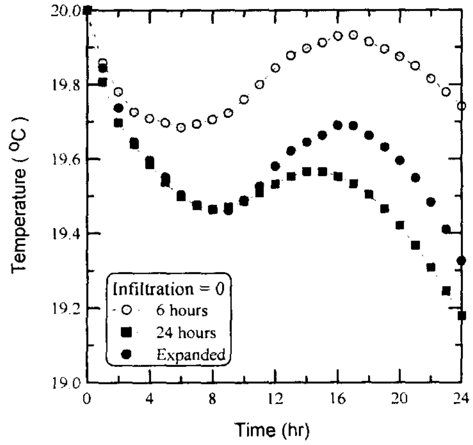


Fig. 11 Expanded temperature profile by multiplying scale factor for 6 hours results in Ondol (infiltration rate=0).

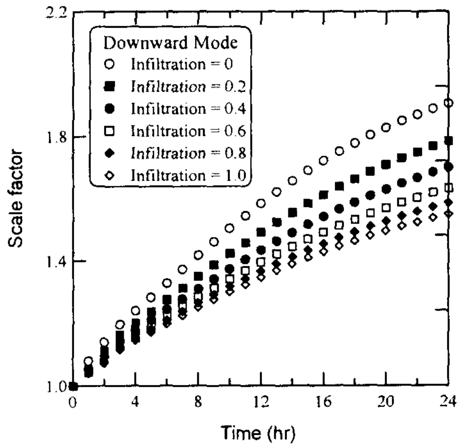


Fig. 10 Scale factor with a variety of infiltration rate between 12 hours and 24 hours in the Ondol.

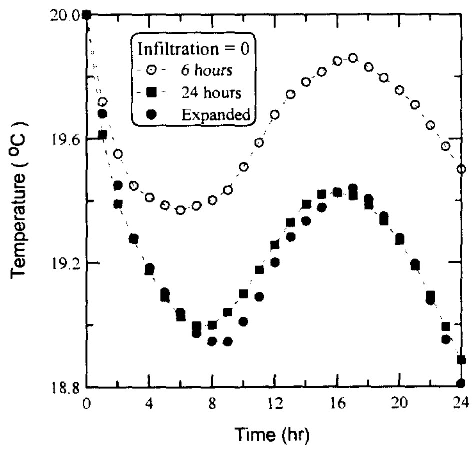


Fig. 12 Expanded temperature profile by multiplying scale factor for 6 hours results in aisle (infiltration rate=0).

means the difference between 6 hour and 24 hour duration becomes small due to the active air circulation. Figure 10 shows the scale factors for upward mode by the variation of infiltration ratio and shows similar results with downward mode.

4.3 Scale factor application

After extending the shortened results of Fig. 5 as 24 hour duration (Fig. 6), the scale factors from Fig. 7 and Fig. 8 are applied. Figure 11 shows the applied results for the Ondol zone with no infiltration and ventilation. The "applied" in figure is the expanded results with scale factors. After 12 hours there shows some difference between original 24 hour duration and expanded results. This is due to the scale factors difference when the temperature difference is small.

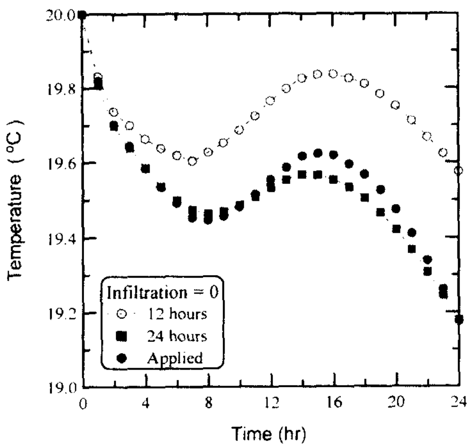


Fig. 13 Expanded temperature profile by multiplying scale factor for 12 hours results in Ondol (infiltration rate=0).

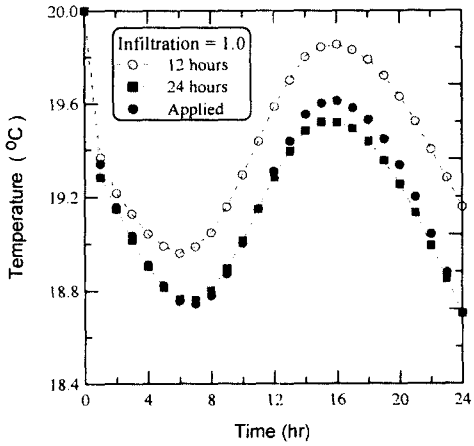


Fig. 15 Expanded temperature profile by multiplying scale factor for 12 hours results in Ondol (infiltration rate=1.0).

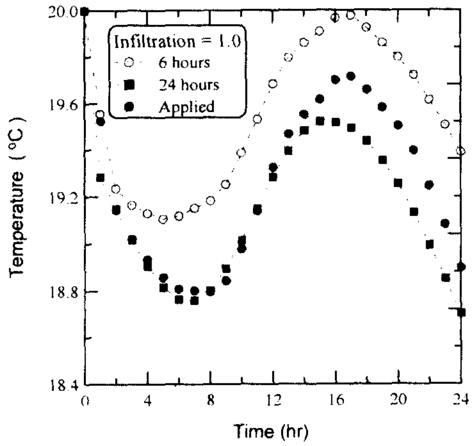


Fig. 14 Expanded temperature profile by multiplying scale factor for 6 hours results in Ondol (infiltration rate=1.0).

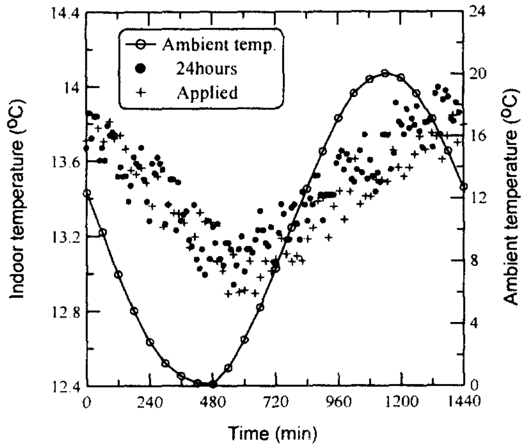


Fig. 16 Comparison of experimental results with current works of simulation using scale factor (infiltration rate=0.4).

Figure 12 shows the expanded results with scale factors for the aisle area. The expanded results show good agreement with those of original 24 hour duration.

Figure 13 shows the expanded results of 12 hour duration to 24 hour with no infiltration and ventilation for Ondol zone. The results show much better agreement compared to those of the expanded 6 hour duration.

Figure 14 shows the expanded 6 hour duration results with infiltration ratio of 1 for Ondol zone. It shows the same behavior with no infiltration.

Figure 15 shows the expanded 12 hour results with infiltration ratio of 1. The results show much better agreement compared to the 6 hour results.

Figure 16 shows the real experimental data for the testing building with 12 hour and 24 hour outdoor temperature variation. The temperatures of 12 hour data are expanded to 24 hour duration by applying the obtained scale factor. In this figure solid line curve is outdoor temperature variations. The results show relatively good agreement for the expanded temperatures. This means that the shortened experiments can be analyzed as an long time experiments with the obtained scale factors.

5. Conclusion

To extend the shortened experimental results to 24 hour temperatures TRNSYS is used to obtain the scale factors by calculating the thermal response of testing building. The scale factors are obtained for the upward temperature mode and downward mode. The scale factors are also obtained for the different infiltration and ventilation ratio. The expanded results of the shortened data with the scale factors show relatively good agreement with 24 hour results.

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