KIEAE Journal, Vol. 15, No. 4, Aug. 2015, pp.29-35

KIEAE Journal 74

Korea Institute of Ecological Architecture and Environment

Survey evaluation of thermal boundary condition in the inside and outside of double skin facade

Shin, Hyun-Cheol* · Jang, Gun-Eik**

* Energy Environment Technology Center, Korea Conformity Laboratories, South Korea (theshc@kcl.re.kr)
** Corresponding author, Advanced Materials Engineering, Chung-Buk National University, South Korea (gejang@chungbuk.ac.kr)

ABSTRACT

Purpose: Double skin facade is a representative advantageous passive technology of building skin in the aspect of energy saving and environment improvement, reduces heat loss with buffer space in winter season and enhances indoor air and comfort of residents by activating natural ventilation in mid-season. However, in summer season, temperature increase in the intermediate space due to solar energy from exterior transparent skin could be a potential problem; also, relatively weak buoyancy of air caused by low density difference between double-skin facade could increase cooling load as air of intermediate space in high temperature hangs. However, proof data is insufficient to objectify such phenomenon. **Method:** In this study, researchers surveyed air temperature of intermediate space and airflow and diagnosed its cause targeting on applied multistory facade in the building which gives thermal uncomfort to residents. Also, the researchers produced Solar-air heat transfer coefficient meter, measured thermal boundary condition of double-skin facade, and presented the result of measurement as an objectified verification material regarding overheating phenomenon in the intermediate space of double-skin facade in summer season. **Result:** Inefficient condition was verified that total heat increases and overheating due to insufficient natural ventilation in multistory facade. In addition, logic behind preceding research was objectified and verified regarding high temperature phenomenon in the intermediate space which could increase cooling load in summer season.

KEYWORD

Double skin facade
Natural ventilation
Boundary condition
Solar-air heat transfer coefficient

ACCEPTANCE INFO

Received April 29, 2015
Final revision received June 24, 2015
Accepted June 26, 2015

1. INTRODUCTION

Double skin facade is a representative advantageous passive technology of building skin in the aspect of energy saving and environment improvement, reduces heat loss with buffer space in winter season and enhances indoor air and comfort of residents by activating natural ventilation in mid-season. Also, use of proper natural lighting would be available by combining with shading device and the double-skin has good sound proof effect(1).

However, in summer season, temperature increase in the intermediate space due to solar energy from exterior transparent skin could be a potential problem; also, relatively weak buoyancy of air caused by low density difference between double-skin facade could increase cooling load as air of intermediate space in high temperature hangs. However, proof data is insufficient to objectify such phenomenon(2).

Once air flow in the intermediate space of double-skin facade becomes active, the problem on increase in cooling load could be improved in summer season as essential function of double-skin facade performs that could solve problem in primary solar shading and lumped heat condition(3), (4), (5).

pISSN 2288-968X, eISSN 2288-9698
http://dx.doi.org/10.12813/kieae.2015.15.4.029

It would be important to diagnose physical cause with survey management data to objectify the phenomenon for the problem on increase of cooling load in summer season. In this study, researchers surveyed air temperature of intermediate space and airflow and diagnosed its cause targeting on applied multistory facade in the building which gives thermal uncomfort to residents. Also, the researchers produced Solar-Air Heat Transfer Coefficient Meter ("SAHTCM"), measured thermal boundary condition of double-skin facade, and presented the result of measurement as an objectified verification material regarding overheating phenomenon in the intermediate space of double-skin facade in summer season.

2. MEASUREMENT METHOD

2.1. Double-skin facade of measurement target

Measurement target DSF is a multi-stories type which is installed in steel structured 5-story business building. In summer and mid -season, overheating air in the intermediate space will be expelled by opening upper and lower openings of DSF completely. Especially in mid-season, inside vent can be opened for natural ventilation. In winter season, the intermediate space of double-skin facade can be used as buffer space by closing upper opening; also,

Table 1 Double skin facade for measurement

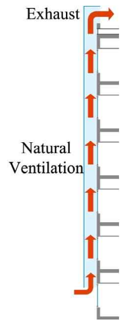
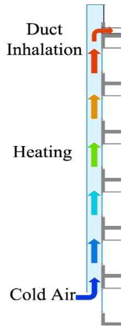
<table>
<tr><td rowspan="7"></td><td rowspan="7"></td><td rowspan="7"></td><td colspan="2">Dimensions</td><td>16 m (W) × 23.5 m (H) × 1.2 m(D)</td></tr>
<tr><td colspan="2">Direction</td><td>South</td></tr>
<tr><td rowspan="2">Window composition</td><td>Exterior</td><td>9 mm GN (Glazing)
AL Curtain wall (Frame)</td></tr>
<tr><td>Interior</td><td>22 mm CL (Glazing)
AL + Fix & PJ (Frame)</td></tr>
<tr><td colspan="2">Inner wall finish</td><td>30mm granite
burner finishing</td></tr>
<tr><td colspan="2">Lower air inlet area</td><td>44.6 m²</td></tr>
<tr><td colspan="2" rowspan="2">Upper air outlet area</td><td rowspan="2">37.1 m²</td></tr>
<tr><td>Overview</td><td>Summer & Intermediate</td><td>Winter</td></tr>
</table>

Table 2 Details of measurement factors

<table>
<tr><th>Class.</th><th colspan="2">Measurement Factor</th><th>Measuring Device</th></tr>
<tr><td rowspan="4">External Environment</td><td colspan="2">Insolation on external vertical surface (IVS_E)</td><td>The epply laboratory Inc. Pyranometer
(Wavelength range : about 300~2800nm)</td></tr>
<tr><td colspan="2">Outdoor dry bulb temperature (OT)</td><td>EI-1050
(Temperature range: -40~120℃)</td></tr>
<tr><td colspan="2">Outdoor relative humidity</td><td>EI-1050 (Range: 0~100%)</td></tr>
<tr><td colspan="2">External SAHTC meter</td><td>Making referenced to NFRC 201</td></tr>
<tr><td rowspan="8">Internal Environment</td><td colspan="2">Air temperature at Inlet and outlet</td><td rowspan="5">T-type thermocouple wire
(Temperature range: -200~350℃)</td></tr>
<tr><td rowspan="4">Measurement Factors for Each Floor</td><td>Temperature of outer glazing (OGT)</td></tr>
<tr><td>Temperature of intermediate air (IAT)</td></tr>
<tr><td>Temperature of inner glazing (IGT)</td></tr>
<tr><td>Temperature of inner wall (IWT)</td></tr>
<tr><td colspan="2">Air velocity at inlet and outlet</td><td>Kanomax multi-channel anemomaster
(0.1~50 m/s)</td></tr>
<tr><td colspan="2">Insolation on internal vertical surface (IVS_I)</td><td>The epply laboratory Inc. Pyranometer
(Wavelength range : about 300~2800nm)</td></tr>
<tr><td colspan="2">Internal SAHTC meter</td><td>Making referenced to NFRC 201</td></tr>
</table>

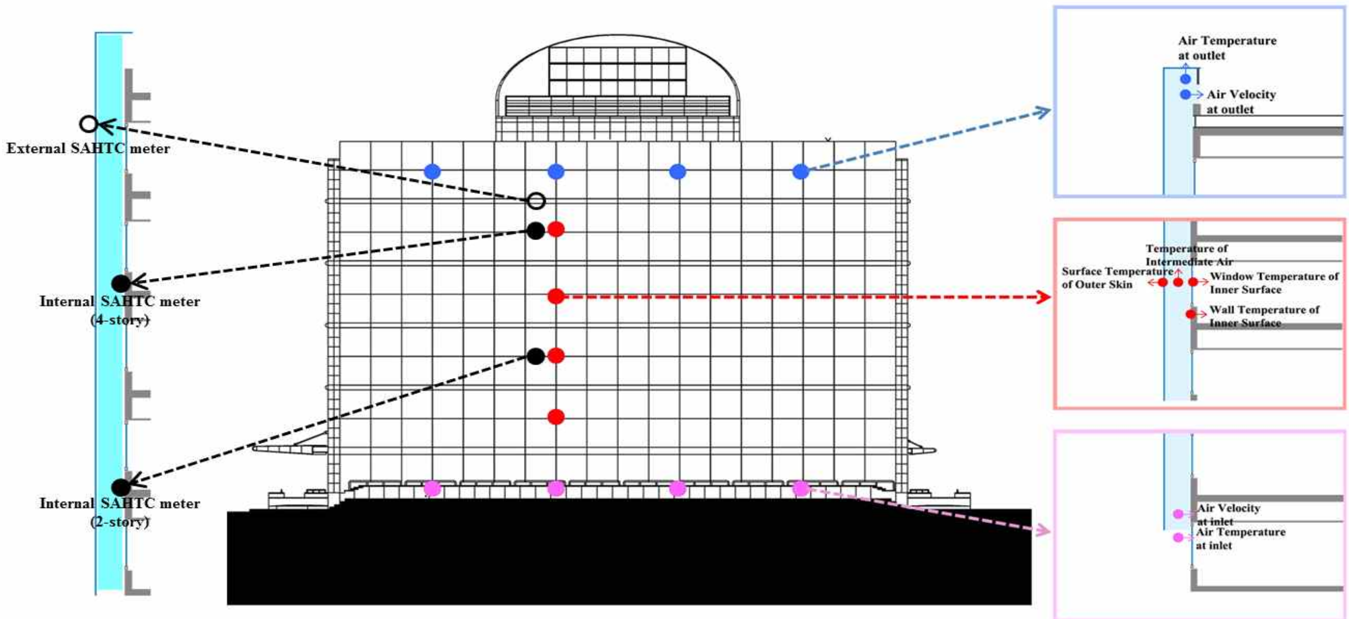


Fig. 1 Locations of Measurement factors

Fig. 2 Photographs of Measuring Devices

air conditioning load can be reduced by inducing heating air to OA of AHU through the intermediate space.[Table 1]

2.2. Environmental measurement factor and location

Thermal environmental factor was measured as Table 2 to analyze management condition of DSF depending on solar radiance and outside condition in summer season. Total amount of solar radiance and external temperature were measured for external environmental factor which highly influence upon management. Also, the researchers installed external SAHTCM and analyzed thermal boundary condition of external skin by solar energy and air.

As internal environment factor of DSF, Surface temperature, air temperature in the intermediate space, window surface temperature, and wall surface temperature of each story were measured. Additionally, the researchers measured solar irradiance into the intermediate space through external skin, installed internal SAHTCM in the intermediate space of 2-story and 4-story height, and analyzed thermal boundary condition by inflow solar irradiance and air temperature. Also, velocity and temperature of in/outflow air in outlet on top and inlet in bottom were measured to analyze airflow in double-skin facade. Measurement was performed in closed condition of ventilation to measure only natural ventilation generaged in the intermediate space. The measurement period would be during June ~ October (summer, mid-season) and the measured date was collected by RS-232 communication with Agilent 34970A DAQ system every 1 minute interval. Fig. 1 and Fig. 2 are showing measurement location of measuring factor and installation picture of measuring device.

2.3. Solar-Air Heat Transfer Coefficient meter

In natural environment, heat gain and loss are caused by complex mechanism of radiation, convection, and conduction. However, field test has its limit to classify and measure total heat by mechanism. Therefore, in this study, the researchers suggested SAHTCM to figure out thermal boundary condition of skin by complex total heat caused by solar radiation, air temperature, and current in the natural environment and analyzed relative heat condition inside and outside of double-skin facade through survey.

Solar-Air Heat Transfer Coefficient ("SAHTC") has been suggested to measure complex heat transfer coefficient by solar radiation and air temperature in the natural environment in 'Procedure for Interim Standard Test Method for Measuring the Solar Heat Gain Coefficient of Fenestration Systems Using Calorimetry Hot Box Methods' of US 'National Fenestration Rating Council' A measuring device of SAHTC shown in Fig. 3 is treated with black dull coat on exposed part (0.95 of absorption coefficient and 0.9 of irradiation rate) of copper and aluminum metal plate. A surface thermometer is installed on an opposite side and 105mm insulator shall be attached. Also, finishing touches will be done from the corner of metal plate to the insulator not to be exposed to external environment. A material with 0.04 W/mK and less of heat conductivity is recommended for finishing touches[(6)]. Adjust the black dull coat side to look out on solar radiation and calculate total heat by solar radiation, air temperature, and current condition with Eq.(1) indicated below.

$$h_{h-sun} = \frac{E_s \cdot \alpha_{plate}}{t_{plate} - t_c} \quad (1)$$

In here,

h_{h-sun} : Solar-Air Heat Transfer Coefficient, W/m²K
E_s : Incident solar radiation of coated surface, W/m²
α_{plate} : Solar absorption factor on coated surface
t_{plate} : Surface temperature of metal plate, ℃
t_c : External air temperature, ℃

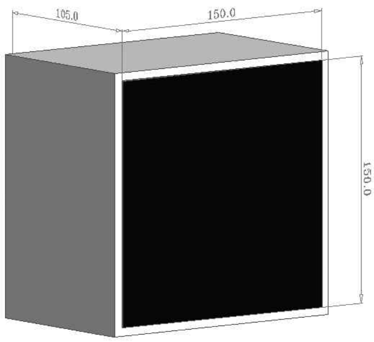


Fig. 3 Solar-Air Heat Transfer Coefficient meter

A black dull surface of SAHTC measuring device assumes black body and calculated heat transfer coefficient by Eq.(1) is not the absolute value of heat transfer coefficient generated by solar radiation and air condition in surface of certain building skin. However, heat transfer boundary condition of inside and outside of double-skin could be relative compared in real-time.

3. MEASUREMENT RESULT

3.1. Temperature distribution of intermediate space in summer season

Fig. 4 indicates air temperature distribution of intermediate space in summer depending on solar radiation. As solar radiation increases, temperature difference of inlet/outlet of ventilation located in upper and lower part increased gradually; also, stratification of air temperature on each story relatively became clear. Temperature difference of inlet/outlet in upper and lower part was indicated at 5.76℃ in 13:00 on representing date with highest solar radiation, 5.65℃ in 13:00 on representing date with mid solar radiation, and 3.3℃ in 16:00 on representing date with lowest solar radiation. Stratification of air temperature by height was indicated most clearly on the date with highest solar radiation; also, as solar radiation decreases, temperature gradient decreased. However, as solar radiation increases, temperature distribution shows difference clearly between 1-story and 4-story height, but the difference considerably decreased in section between 4-story height and top of ventilation outlet. Such phenomenon; a problem possibly occurred from double-skin in summer season, is the overheating phenomenon that high temperature focused on upper story. This phenomenon shows that heating boundary condition of air conditioner in upper stories (4~5-story) can become weaker than lower stories (1~3-story).

Fig. 5 is the temperature distribution by solar radiation in the intermediate space on representing date in summer that shows average value of measured temperature between 11:00 and 16:00 (time period occupying approximately 60% of a day accumulated solar radiation). Generally, internal temperature distribution of intermediate space formed higher than external temperature distribution. Surface temperature of primary exposed exterior skin to solar shows highest temperature distribution. As height of intermediate space increases, the temperature increased by showing relatively regular temperature distribution between 1-story and 4-story. On the other hand, upper double skin in 4-story and 5-story shows analogous temperature distribution. In general, as solar radiation decreases, temperature distribution of each part also deceased analogous to air temperature distribution in the intermediate space.

3.2. Temperature distribution of intermediate space in mid-season

Fig. 6 indicates air temperature distribution of intermediate space in mid-season depending on solar radiation. As solar radiation increases, temperature difference of inlet/outlet of ventilation located in upper and lower part increased gradually; also, stratification of air temperature on each story relatively became clear. Temperature difference of inlet/outlet in upper and lower part was indicated at 11.31℃ in 13:00 on representing date with highest solar radiation, 9.69℃ in 13:00 on representing date with mid solar radiation, and 3.65℃ in 12:00 on representing date with lowest solar radiation. It is relatively great temperature difference compared to summer season. Stratification of air temperature by height was, in common with summer season, indicated most clearly on the date with highest solar radiation; also, as solar radiation decreases, temperature gradient decreased. As solar radiation increases, temperature distribution between stories maintains clearly by certain difference. Also, overheating phenomenon was not shown between 4-story and top of ventilation outlet unlike shown in summer season. Such phenomenon is indicated due to relatively enough natural ventilation and activation of inner airflow in the double-skin as temperature difference and inflow solar radiation increase.

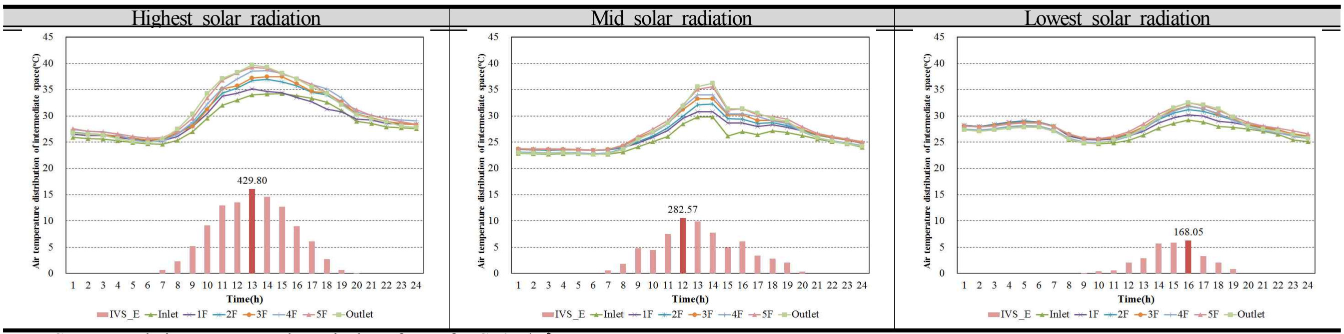
Fig. 7 is the temperature distribution by solar radiation in the intermediate space on representing date in mid-season that shows average value of measured temperature between 11:00 and 16:00 (time period occupying approximately 60% of a day accumulated solar radiation). Generally, internal temperature distribution of intermediate space formed higher than external temperature distribution like summer season; also, surface temperature of primary exposed exterior skin to solar shows highest temperature distribution. As height of intermediate space increases, the temperature increased gradually. Also, as solar radiation decreases, temperature difference by each part decreased as well.

3.3. Amount of natural ventilation in the intermediate space

The researchers relative analyzed interior natural ventilation performance in double-skin depending on solar radiation targeting on summer and mid- season. Wind velocity of inlet/outlet of upper/lower ventilation was measured and amount of natural ventilation was calculated considering opening area. Fig.8 indicates distribution of natural ventilation amount generated depending on change in solar radiation in the intermediated space of double-skin during day time (7:00~19:00) on representing date in summer and mid-season.

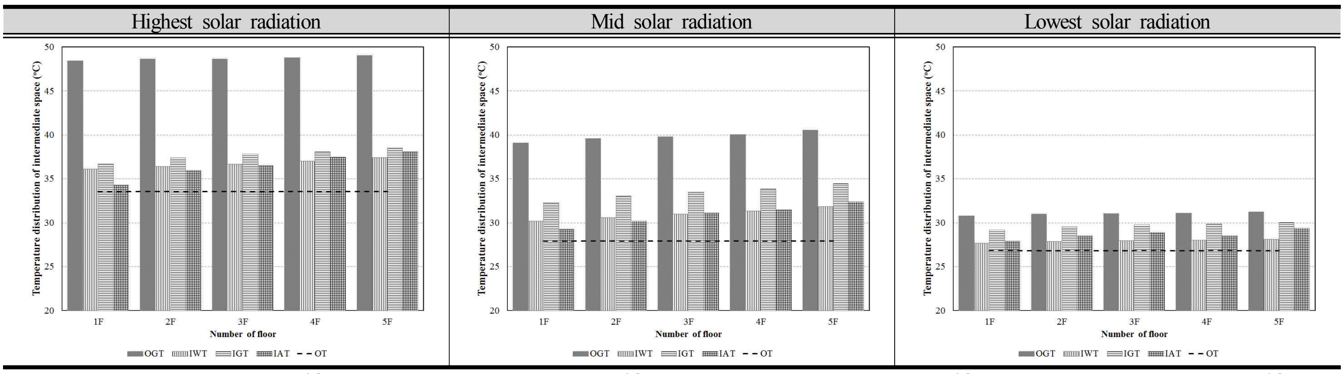
In Summer season, the range of 2 ~ 4 ㎥/s of ventilation was generated; also, as solar radiation increases, its amount increased gradually. Max. 10.04 ㎥/s of natural ventilation was shown in approximately 430 W/㎡ of solar heat environment.

In mid-season, the range of 10 ~ 14 ㎥/s of ventilation was generated; also, as solar radiation increases, its amount increased



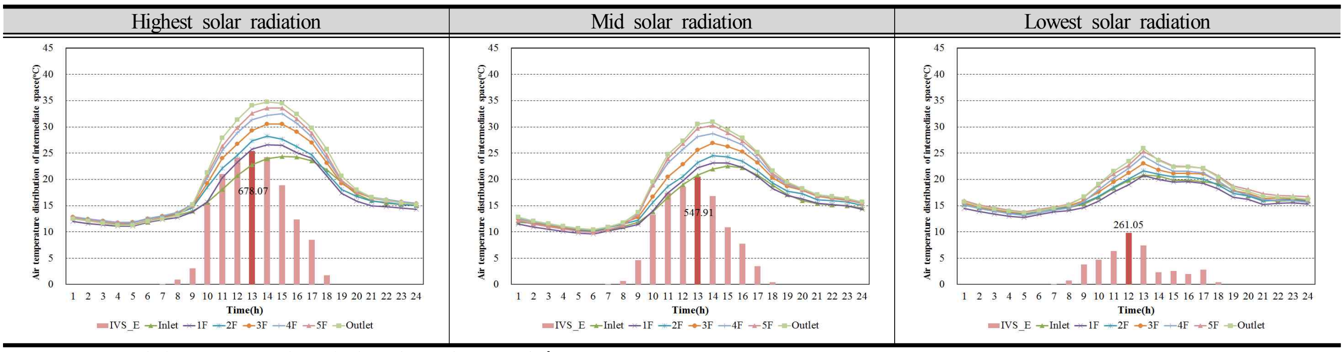
■ IVS_E : Insolation on external vertical surface of DSF(W/m²)

Fig. 4 Air temperature distribution in intermediate space of double-skin in summer season



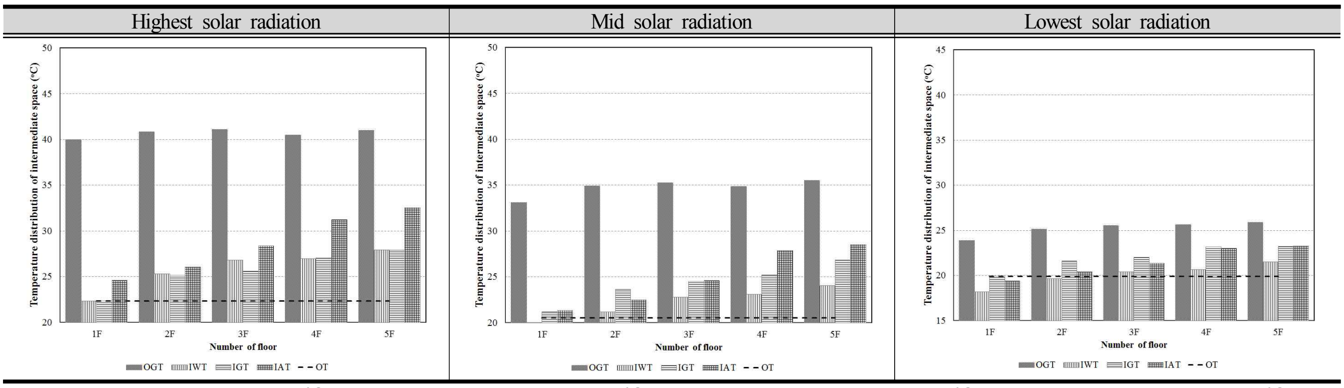
■ OT : Outdoor dry bulb temperature(℃), OGT : Temperature of outer glazing(℃), IAT : Temperature of intermediate air(℃), IGT : Temperature of inner glazing(℃), IWT: Temperature of inner wall (℃)

Fig. 5 Temperature distribution in intermediate space by story of double-skin in summer season



■ IVS_E : Insolation on external vertical surface of DSF(W/m²)

Fig. 6 Air temperature distribution in intermediate space of double-skin in mid season



■ OT : Outdoor dry bulb temperature(℃), OGT : Temperature of outer glazing(℃), IAT : Temperature of intermediate air(℃), IGT : Temperature of inner glazing(℃), IWT: Temperature of inner wall (℃)

Fig. 7 Temperature distribution in intermediate space by story of double-skin in mid-season gradually. Max. 20.86 ㎥/s of natural ventilation was shown in approximately 700 W/㎡ of solar heat environment.

Unlike overheating phenomenon in top of double-skin in summer season, as relatively low inflow air temperature to the double-skin and lots of inflow solar radiation increase amount of natural ventilation, the thermal gradient is regularly maintained and problem in overheating phenomenon was resolved.

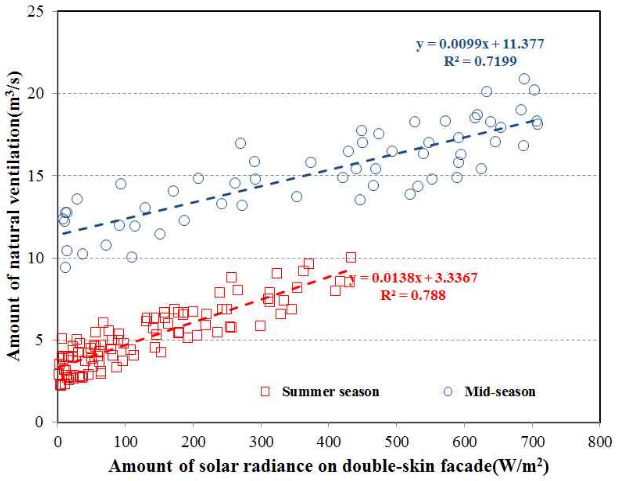


Fig. 8 Distribution of natural ventilation by amount of solar radiation in the intermediate space

3.4. Thermal boundary condition in the inside and outside of DSF

The researchers installed SAHTCM in double-skin of mediolateral side referring to NFRC 201 and analyzed Thermal boundary condition.

Fig. 9 indicates SAHTC of building skin in mediolateral side depending on solar radiance amount in summer. As a result of analysis, as solar radiance increases, total heat by solar radiation increased and SAHTC tended to increase gradually. SAHTC from outer skin generally shows high distribution. However, as SAHTC of inner double-skin on upper part (4-story SAHTC) is indicating higher distribution then lower part (2-story SAHTC) starting from 100 W/㎡ and solar radiance amount increases, the difference between upper and lower part increased and closed to SAHTC of outer skin. Such phenomenon is caused due to insufficient natural ventilation in the intermediate space and is because of increase in heat gain through time to contact with overheating air and inner skin.

Fig. 10 indicates SAHTC of building skin in mediolateral side depending on solar radiance amount in mid-season. Like summer season, as solar radiance amount increases, inner SAHTC of double-skin increased. SAHTC generated in outer skin by direct exposure to solar radiance showed highest distribution. In case of inner skin, compared to lower part (2-story SAHTC), higher part (4-storySAHTC) indicated somewhat higher distribution. Unlike summer season, as solar radiance amount increase on SAHTC of upper part, it is not close to SAHTC of exterior outer skin and maintains much difference. It is because that overheating phenomenon in upper part is relatively relieved due to activation of natural ventilation inside of double-skin.

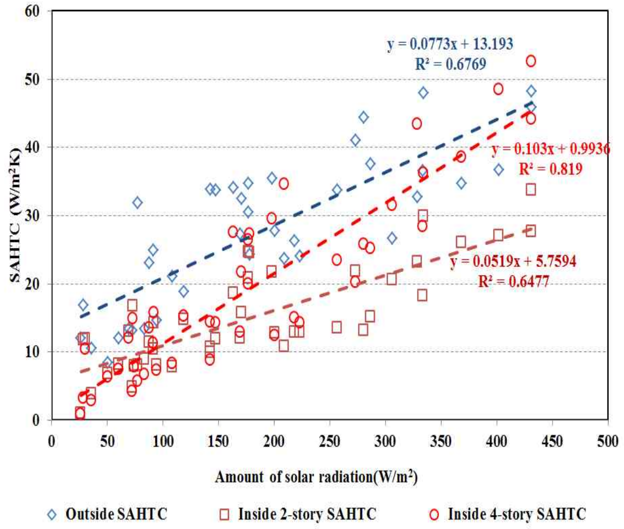


Fig. 9 SAHTC distribution depending on solar radiation in summer

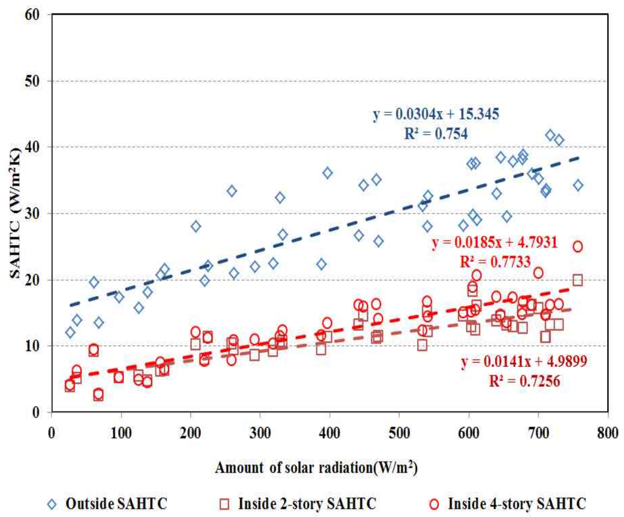


Fig. 10 SAHTC distribution depending on solar radiation in mid-season

4. CONCLUSION

In this study, potential problem; increase in cooling load due to overheating in the intermediate space in summer, was analyzed targeting on multistory double skin facade. Through the result of survey, inefficient condition was verified that total heat increases and overheating due to insufficient natural ventilation in multistory facade. Also, logic behind preceding research was objectified and verified regarding high temperature phenomenon in the intermediate space which could increase cooling load in summer season.

From the research results, it can be concluded that considerations on air inlet and outlet of openings were needed in order to resolve the problem of cooling load increasement and activate natural ventilation from the DSF. In terms of decrease of natural ventilation from the structural limitation, temporary mechanical ventilation which installs SAHTM can solve the problem. In addition, more research on parallel use strategy of mechanical ventilation will be made in the future.

References

[1] Harris Poirazis, "Literature Review of Double Skin Facades for Office Buildings", 2004
[2] Elisabeth Gratia and Andre De Herde, "Optimal operation of a south double-skin façade", Energy and Buildings, 36, pp41-60, 2004
[3] Elisabeth Gratia and Andre De Herde, "Are energy consumptions decreased with the addition of a double-skin", Energy and Buildings, 39, pp605-619, 2007
[4] Wong P. C., Prasad D., Behnia M., "A new type of double-skin facade configuration for the hot and humid climate", Energy and Buildings, 40, pp1941-1945, 2008
[5] Dirk Saelensa, Staf Roels and Hugo Hens, "Strategies to improve the energy performance of multiple-skin facades", Building and Environment, 43, pp638-650, 2008
[6] NFRC, "NFRC 201 - Procedure for Interim Standard Test Method for Measuring the Solar Heat Gain Coefficient of Fenestration Systems Using Calorimetry Hot Box Methods", 2010

