Revolving Type of Calorimeter Test Rooms in Germany and Japan for Estimating Solar Heat Gain and Cooling Load

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Special features of revolving type of calorimeter test rooms constructed in Germany and in Japan nearly at the same time in late 1960s for correct estimation of cooling load caused by solar heat gain from large glass windows in high rise buildings together with some measured results are described. Both calorimeter test rooms are of one room with a full scaled glass window and with five guard spaces to be air conditioned to the set point temperatures equal to that of the test rooms. The test results of thermal characteristics of both rooms turned out almost identical to reveal the significance of the pioneering works accomplished in those days along with the advent of computer application.

Introduction

In 1960s, large windows came to be widely used particularly in high rise buildings and cooling load associated with solar heat gain from windows were considered important. Because of a large thermal capacity of concrete structure, peak cooling load would be delayed and smaller than the diurnal variation of heat gain from windows. Storage load factor was presented by Carrier Handbook[1], but no background was indicated there. Kimura tried to determine those consequences using a simple test room on the roof of Waseda University in 1963[2] and later much more sophisticated apparatus was constructed as a revolving type of test room designed by the co-authors at the Technical Research Institute of Obayashi Corporation, in Kiyose, Tokyo[3]. While at the almost same time quite a unique revolving type of test room much similar to the Japanese one was constructed at Fraunhofer Institute in Holzkirchen, Germany under Dr. Helmut Künzel[4] with identical study purposes. The experiments with both test rooms were conducted under the actual conditions exposed to natural solar radiation quite wonderfully without knowing the existence of the projects each other. This paper describes the outline of both test rooms together with some examples of the test results obtained at these two test apparatuses.

1. Japanese Calorimeter Test Room

1.1 Structure

Figure-1 shows the exterior view of Japanese calorimeter room. This is a revolving type so that the glass window surface can be oriented in any orientation to be identical to the window orientation to the actual building on site.

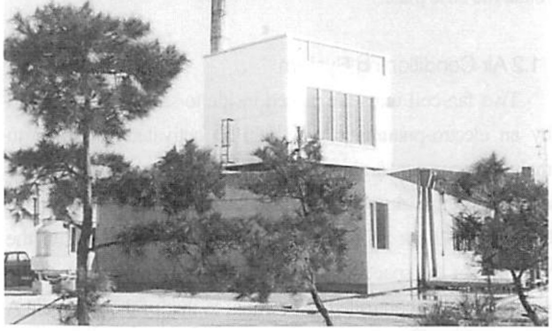

Figure-1 Revolving Type of Calorimeter Test Room of Japan

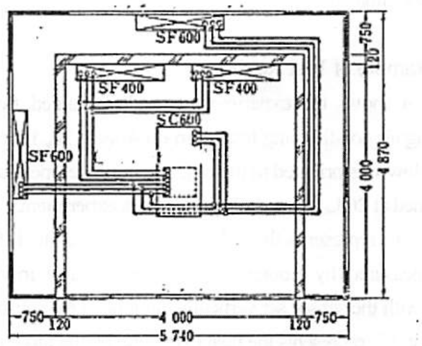

Figure-2 Plan of Japanese Calorimeter Test Room

Figure-2 and Figure-3 show plan and transverse section of the test room respectively. The inside dimensions of the room are 4m×4m×2m constructed of 12cm thick pre-cast concrete panels and the room is surrounded by guard spaces above,

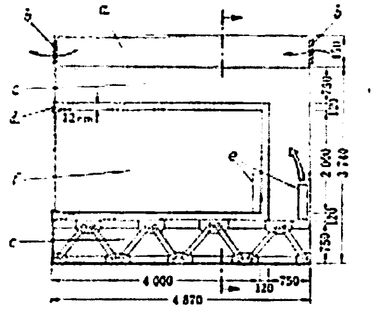

Figure-3 Transverse section of Japanese Calorimeter Test Room
a: attic space, *b*: ventilation grille, *c*: upper and lower guard spaces,
d: concrete slab of 12cm thick, *e*: fan-coil units for room space and guard spaces, *f*: room space to be air conditioned

below, rear, right and left sides provided to simulate the room as part of a multi-storied building. whose temperatures are to be maintained identical to the test room. The revolving mechanism was devised by applying the revolving stage mechanism used in theaters to prove a remarkable success with manual handle to rotate the base plate.

1.2 Air Conditioning System

Two fan-coil units are placed inside to supply air regulated by an electro-pneumatic type of PID activated controller to maintain a constant ambient air temperature. Two-way valves are used to pick up warm water and chilled water in the storage tanks beneath the floor of the machine room to match within the variation of the space cooling load. The air temperature of the guard spaces is controlled to be equal to that of the room air. A large number of thermocouples were embedded in the precast concrete panels to measure the temperature so that the rate of convective heat transfer between inside surface and room air could be estimated.

1.3 Example of Test Results

Fig. 4 shows the experimental results obtained from the revolving air conditioning test room on August 20, 1966 when the window was oriented to the east. The room temperature was maintained at 26℃ for a week prior to this experiment.

Plot ① represents the solar radiation transmitted through glass, measured by Eppley pyrheliometer placed inside and outside with the sensor set vertically, multiplied by 8m^2 of glass area. Plot ② represents the heat extraction by the fan-coil units measured by a calorimeter knowing the water flow rate and the temperature rise across the coil. Plot ③ represents the total space cooling load estimated from the temperature data measured inside which is supposed to coincide with Plot ②. Plots ④, ⑤, ⑥ and ⑦ are breakdown components of plot ③. The inside surface

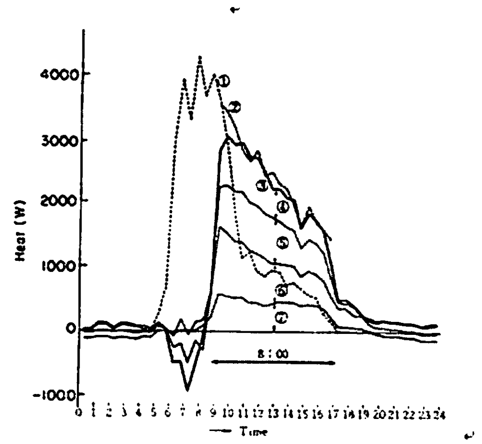

Figure-4 Solar Radiation, Cooling Load and Heat Extraction, Measured on Aug. 20. 1966, Window Oriented East

temperature was measured at about 50 points and averaged surface by surface. Then, the convective heat transfer to the room air from the wall surfaces was calculated from the temperature difference between the surface and the room air multiplied by the convective heat transfer coefficient of 9.3 W/(m^{2}K) and the surface area, which is shown as Plot ④. Similarly, Plots ⑤, ⑥ and ⑦ represent the convective heat transfer to the room air from the ceiling surface, floor surface and glass surface respectively. The fact that the total convective heat transfer coincided with the heat extraction by the fan-coil units when the value of convective heat transfer coefficient was assumed to be 9.3 W/ (m^{2}K) , which indicates that the air movement in this room was quite large compared with what it would have been in ordinary rooms[5].

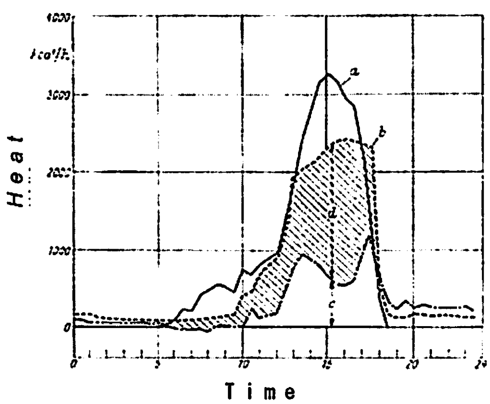

Figure-5 Heat dissipation by convection from the interior blind
a: solar radiation through 8m^2 window,
b: absorbed heat of fan coil units in the test room,
c. total heat convection from the surrounding walls,
d: heat convection from the interior blind to room air

Figure-5 shows the heat dissipation by convection from the interior with horizontal type of blinds half open measured on August 18, 1966.

3. Calorimeter Test Room of Germany

3.1 Contribution of Dr. Künzel

Dr. Helmut Künzel of Fraunhofer Institute for Building Science is a well-known building scientist esteemed as the father of building science, having published a large number of excellent papers for the last more than fifty years. He designed and built a calorimeter test room of Germany quite similar to that of Japan sometime in 1966-67 without knowing the existence of Japanese one. Fig. 6 shows the exterior view of the test room of Fraunhofer Institute in Holzkirchen.

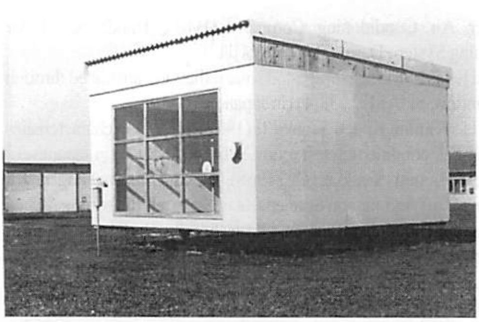

Figure-6 Revolving Type Calorimeter Test Room of Germany

Figure-7 and Figure-8 show plan and transvers section of the test room respectively. The inside dimensions of the room are 4m×4m×2.50 m. Guard spaces are provided above, below, rear, and right and left sides as same as Japanese one.

While the rotating mechanism is different. The test room structure itself is supported by wheels just placed on the circular plate on the ground.

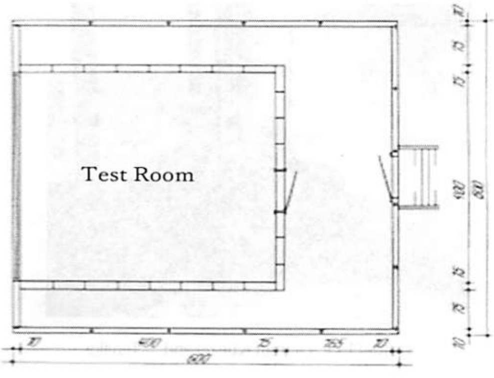

Figure-7 Plan of Revolving Type Colorimeter Test Room of Germany

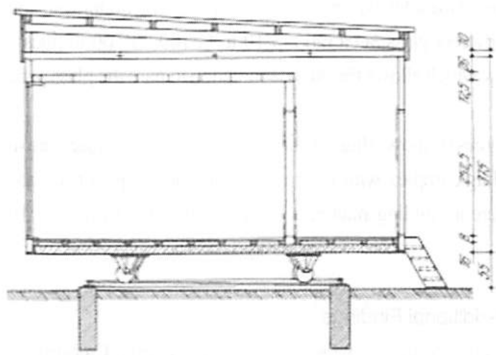

Figure-8 Transvers section of revolving Test Room

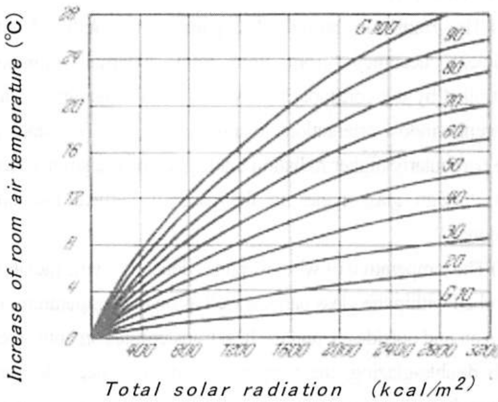

Figure-9 Increase in room air temperature against total solar radiation

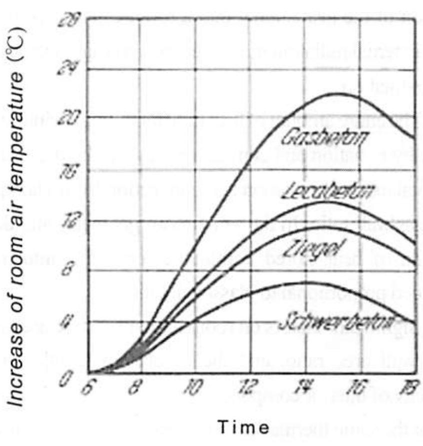

Figure-10 Increase of room air temperature for the different interior components

Gasbeton: pourous concrete
Lecabeton: concretethe fundamental
Ziegel: brick
Schwerbeton: heavy concrete

3.2 Measured Results of Experiment

Figure-9 shows the increase in room air temperature as a function of the total external radiation when using double glazing with different glass /area ratio G 10 to G 100. G 100 implies a window which allows the outside radiation to pass the glass pane freely.

Figure-10 shows diurnal variation of room air temperature in a building complex with 15 cm thick interior components made of different building materials on a summer day from 6 to 19 hours.

3.3. Additional Findings

In addition to the above test results with German Calorimeter Test Room, the following findings are obtained from the results of calculation with some assumptions[4].

1) The irradiation through glass panes can be reduced with sufficient accuracy from the total external radiation multiplied by the constant effective radiation transmittance for different window orientations in summer periods. This leads to give particularly higher radiation loads than the transmitted heat gain through glass panes in the case of vertical radiation incidence."

2) The temperature of window panes depends on the radiation absorbed within the glass pane as well as on the temperatures of room air and outside air, and the heat transfer rates on both sides. With double-glazing, the temperature of the space-side pane surface is higher than the temperature of the room air under summer conditions. This results in a considerable rate of heat transfer from the window surface to the room air by convection and radiation in addition to the direct radiation transmission. This fraction of the heat supply into a room can also be determined from external radiation multiplied by a constant factor with good approximation.

3) The entire amount of heat transfer through windows into the room by radiation and convection can thus be determined from the total external radiation and convection from glass pane with its glass/wall ratio. In the same room geometry and design, the amount of heat stored within the room in summer may be assumed proportional to glass/wall ratio.

4) Significant factors on room air temperature are the exterior glass/wall area ratio, and the absorption ability and thermal capacity of interior components.

For the same thermal storage capacity, the slower the increase in room air temperature becomes, the faster the heat absorbed by the room components becomes. This point has not been taken into account in cooling load calculations.

Conclusion

The two research projects of evaluating thermal characteristics of the room spaces with concrete panels performed in Japan and Germany almost in the late 1960s are introduced. It is remarkable to find out both projects are quite identical in the structure, in the timing of construction and in the purpose of evaluation for practical application.

Although the measured methods and results of both projects are slightly different each other, the thermal behavior associated with the effects of solar radiation through the glass pane into the room space upon the cooling load can be correctly estimated from the measured results together with computer aided calculation methods, thus showing an important significance of these projects.

References

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7) Künzel, H. (2017), Wohnhygiene und Wärmedämmung -Die Geschichite unsere Wohnkurture, Fraunhofer IRB Verlag

Appendix

Tanaka visited Dr. Küntzel in January 2017 to celebrate his 90th birthday. Dr. Künzel handed one book[7] published by him just before his 90th birthday to Tanaka.

Figure-11 Dr. Helmut Künzel and T. Tanaka