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EXPERIMENTAL EVALUATION OF THE EVAPORATIVE COOLING EFFECT PRODUCED BY PRACTICAL APPLICATION OF A FEEDWATER-SUPPLIED PASSIVE COOLING WALL MADE OF WATER-PERMEABLE VENTILABLE BRICKS

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Abstract

Heat island is a phenomenon peculiar to the urban areas. Characteristics of the phenomenon are both consistent rising in temperature and decreasing in relative humidity in the urban atmosphere. A major factor of this phenomenon is to decrease evaporative cooling effect because of covering ground surface with building materials which have less water-retentive at urban area .Furthermore, the phenomenon is caused by waste heat from the air-conditioner in summer.

So, building materials with water-retentive have been developed and the method with this material has been studied to create comfortable environment. A product of "passive cooling wall(PCW)" system , consists of water-permeable ventilable bricks with evaporative cooling effect offer a comfortable spot at outdoor and semi-outdoor space, has been developed and investigated the micro-climate in experimental setup of a partially enclosed, shaded, outdoor structure with PCW.

It is cleared that the PCW is cooled as wet-bulb temperature and the cooled air emanating from the PCW decreases the temperature at the whole space. For example, at the measurement point 0.5m away from the PCW and 1m above the ground, the temperature of indoor air was reduced about 3 to 3.5 °C from that of outdoor air.

Key Words: urban environment, Passive cooling, wall, micro-climate, outdoor and semi-outdoor space

1. INTRODUCTION

In the recent trend of the urban climate is getting uncomfortable for the people who has to endure the scorching heat in the summer season, such as "Heat Island". A major factor of this phenomenon is to decrease evaporative cooling effect because of covering ground surface with building materials have less water-retentive at urban area. Furthermore, the phenomenon is caused by waste heat from the air-conditioner in summer because of indoor air influenced by urban climate tend to be high.

Under such circumstances, building materials must be developed not only under conventional concepts of "being kind of humans" but also considered environmental issue. Furthermore, it is expected to have new properties or performance at the same time.

On the other hands, an open or semi-open places in the midst of buildings such as a courtyard, verandah or the like serves are highly expected to be the urban area to function as "an oasis in the desert". Regarding passive cooling methods for outdoor and semi-outdoor spaces, evaporative cooling can be as effective as shading or ventilating.

So porous ceramics with high water-permeability and water-retention have attracted. As the means to incorporate an evaporative cooling function into architectural elements, we developed a passive cooling wall (PCW) constructed of water-permeable ventilable bricks[1)2)].

Here towards applying the PCW unit more practically, we describe a more suitable design, while also experimentally evaluating its cooling effect by measuring the temperature distribution within a partially enclosed structure incorporating a PCW unit prepared outdoors.

2. DESIGN OF PASSIVE COOLING WALL (PCW)

The brick materials for PCW is porous ceramics with high water-permeability and water-retention. It is a product which is a mixture of about 88% clay and 12% calcium carbonate burned about 1100 degree centigrade. Table1 shows main specifications of the brick materials.

As shown in Fig. 1, the PCW is formed of stacked layers of the water-permeable bricks each provided with (i) vertical air ventilation channels parallel running across the width of the brick and (ii) short rectangular-shaped grooves each formed into the top and bottom surfaces of the brick along its length. Thin-walled and rectangular-shaped steel liners are so set to fit tightly into the grooves formed in the top and bottom surfaces, respectively. These steel liners serve as cross-flow feedwater channels. Feedwater is pumped from a tank at the bottom and supplied to a pan provided on the top section. The supplied feedwater sequentially overflows from the top pan, which flows through the inside of the side column to another pan set on a lower section and finally reaches the tank again. When feedwater is continuously supplied, it only permeates through the upper face such that the bricks are maintained water-saturated condition. This provides maximum evaporative cooling capability, i.e., the possible largest temperature decrease under given conditions. All drain water is collected and recycled. In addition to the temperature decrease through humidification of air in the PCW unit, reduction in thermal radiation emitted from the wall and generation of gentle air movement contribute further improvement of comfort. The steel liners also serve to enhance wall strength in a longitudinal direction functioning as the reinforcement. The steel liners are so configured not to interrupt the design of ventilation channels.

Two types of ventilation channels are applied to the water-permeable ventilable bricks for investigation. One type has a plurality of narrow slit-like channels (slit type) and the other type has wide-opened square channels (open type). Compared with the open type, the slit type is able to reduce the temperature of flow-through air nearly to the outdoor air wet-bulb temperature. Fig. 2 shows each appearance of the water-permeable ventilable bricks of both types.

3. EXPERIMENTAL SETUP

The experiment was conducted on the roof of the two-storied building to set an open space to which outside wind sufficiently blows. Fig.3 shows the experimental setup and the arrangement of the PCW. Bricks having the respective types of ventilation channels were used to build the PCW unit (Floor area size of a partially enclosed structure : 3×4.5 m) that faces southwest direction to partially enclose and shade the small space defined thereby. Accordingly the PCW unit can be so set to face the wind in the direction mostly expected to blow in the hot summer afternoon in Japan. The side walls made of insulating styrene foam are extended toward the front of the PCW. This structure is configured to increase the flow rate of air through the ventilation channels. The open space was formed in the rear section of the side surface. The Fig.4 shows the outer appearance of the PCW unit.

In the thus constructed small partially enclosed space, the cross-section temperature distribution on the centerline vertical to the PCW was measured. Distributions of the temperature and wind velocity at a point 1 m above the ground were also measured. Those measurements were conducted for about 20 minutes in the afternoon of a clear day by moving the sensor to the slit type first and then the open type. The measurement data were recorded at every 2 seconds. Outside wind direction and wind velocity were also measured at a point 1.5 m above the ground and 3 m ahead of the PCW using the ultrasonic anemometer.

Table 1 Specifications of ventilable brick

Firing temperature	1100℃
Compounding ratio of ingredient	Clay : Calcium carbonate = 88 : 12
Absorption coefficient	14.8% (Slit type) 14.3% (Open type)
Permeation through capillary rise	57 mm/h (15℃)

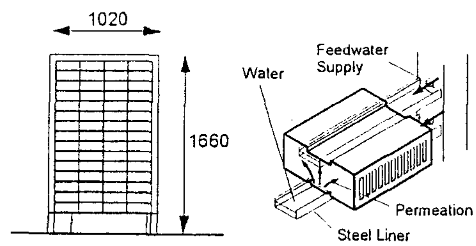
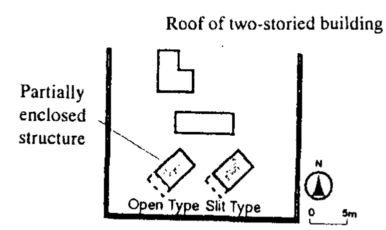


Fig.1 Passive Cooling Wall (PCW) Unit Ventilable Bricks



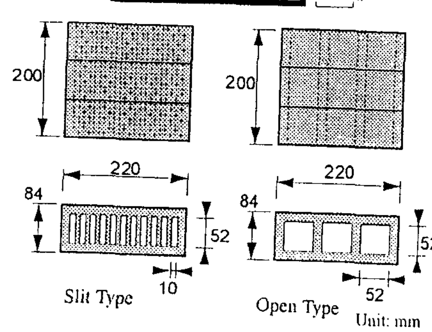


Fig.2 Types of water-permeable ventilable bricks.

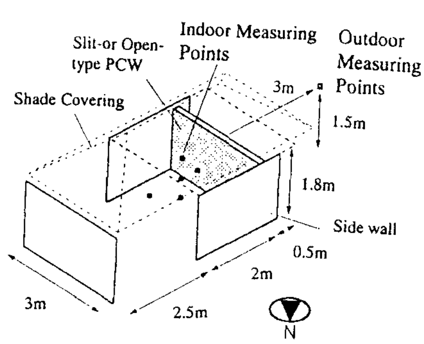


Fig.3 Experimental setup of a partially enclosed structure incorporating PCW

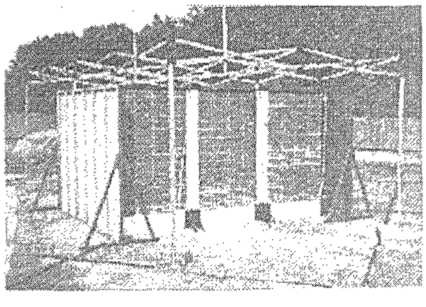


Fig.4 View of the PCW, doubly shaded by nylon tent and urethane sheet on the day of the experiment.

4. RESULTS AND DISCUSSION WITH RESPECT TO TEMPERATURE/HUMIDITY DISTRIBUTION

Using corresponding experiments, we comparatively evaluated passive cooling derived from each type of ventilation channel. Fig.5 shows main results. Indicated are time-dependent (Δ t=5min.) distributions of outdoor air temperature measured in the mid-afternoon along with those corresponding to the measurement points shown in Fig.3, i.e., profiles of air temperature along horizontal (Fig.5a) and vertical (Fig.5b) planes. Also indicated are values of wind velocity measured indoors at the point 1 m above the ground and 0.5/1.0 m away from the centerline of the inner surface of the PCW and wind velocity/direction correspondingly measured outdoors at the point 1.5 m above and 3 m away (Fig.5c). Although the measurement times are slightly different, wind conditions and outdoor air temperatures are almost the same.

4.1 Variation in temperature/humidity and wind velocity at indoor point

The outside wind was blowing from the southern west with slight variation. The wind velocity varied in the range from 0.2 to 2 m/s. The wind velocity at the outlet of the open type is slightly higher than that of the slit type. The indoor wind velocity widely varied dependent on the ratio of opening of the respective types. In case of the open type, the wind velocity measured about 1.5 m/s. While in case of the slit type, the wind velocity measured about 1 m/s or less and further reached almost zero at low wind.

If the wind shifts to the southern west so that the air ventilates the PCW unit, the indoor temperature will be decreased. At the measurement point 0.5 m away from the PCW and 1 m above the ground, the temperature difference between indoor and outdoor measured 3 to 3.5° C (slit type) and about 1.5° C (open type), respectively. Taking the temperature variation of the slit type measured at around 2:20 p.m. as an example, the temperature decreases noticeably except the upper measurement points far away from the PCW unit. The incoming of cold air was observed. The temperature began to rise from the upper section after the air flow became low. However at the point 0.5 m above the ground, the cold air resided at least for 20 seconds. At around 2:20'20" p.m., the wind direction was reversed to ventilate the point 0.5 m above the ground. The resultant indoor temperature became

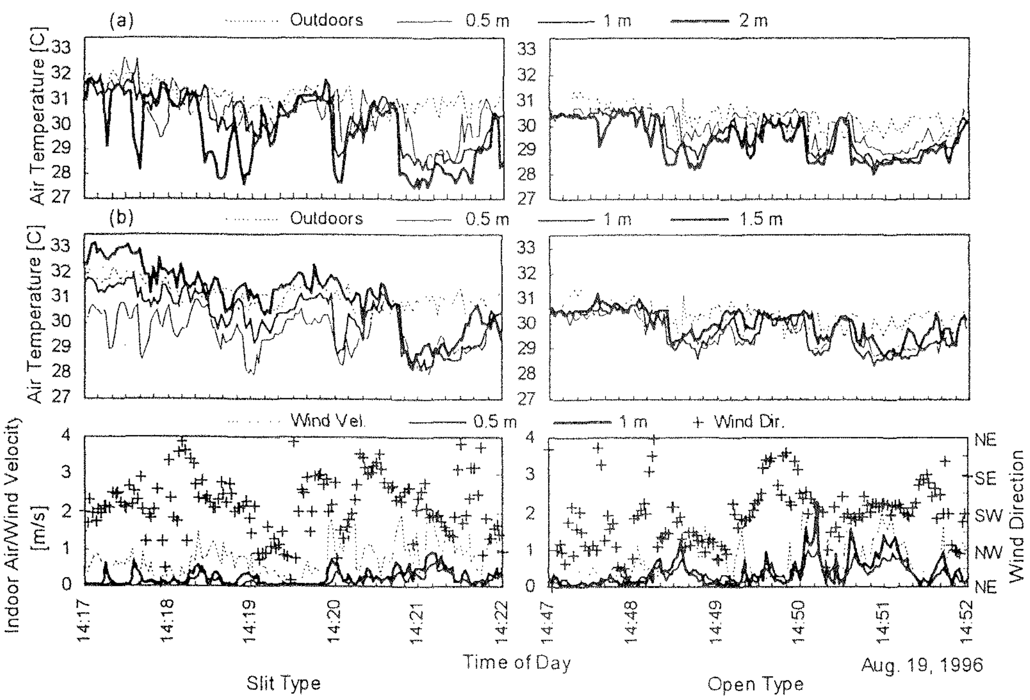


Fig.5 Time-dependent distributions of indoor air temperature at indicated distances (a) away from centerline of indoor surface of PCW when measured 1 m above ground and (b) above ground when measured 1 m away from indoor surface centerline of PCW for open- and slit-type ventilation channels. Also indicated (a, b) is measured outdoor air temperature.
Time-dependent distributions of indoor air/wind velocity and wind direction in which indoor air measurements were taken 1 m above ground at 0.5 and 1.0 m away from indoor surface centerline of PCW and those outdoors taken 1.5 m above ground at 3.0 m away from outdoor surface centerline of PCW.

equivalent to the outdoor air temperature. At around 2:21 p.m., the temperature decreased and the relatively strong wind blew continuously. As a result, the low temperature period was prolonged. While the temperature at the upper section far away from the PCW began to rise first.

The open type shows similar variation pattern of the temperature distribution except the slight temperature decrease only by 1 to 1.5° C. The wind velocity within the enclosed space is markedly higher as expected. Results of the vertical profile with wind blowing in the usual direction indicate that the indoor air temperature is decreased at all heights.

4.2 Relationship between wind velocity and temperature down wind

Figure.6 is a graphical representation each showing the relationship between the wind velocity and the temperature difference (outdoor/indoor) so as to clarify variations of the air stream and the temperature accompanied therewith at the respective points behind the PCW unit. The measurement was conducted at the outlet of the PCW unit and points 0.5 m/1m away from the PCW unit and 1m above the ground, respectively where the wind velocity and temperature were measured simultaneously. The values obtained by removing variable components at a cycle less than 60 seconds are used to represent variation in the outdoor air temperature so as not to be affected by the short-cycled variation in the outdoor air temperature.

The measurement points are plotted with a solid line in a time-dependent manner. The data measured at the outlet indicates that the cooling efficiency is enhanced as the velocity of the wind in the normal direction is decreased. When the direction of the wind is reversed, the temperature is observed to rise nearly to the outdoor air temperature. The measurement points 0.5m and 1m away from the PCW show that the wind velocity is increased to lower the temperature owing to the cold air incoming thereto. It is observed that the reversed wind increases only the wind velocity.

5. CONCLUSION

In this study, water-permeable ventilable bricks made of porous ceramics are developed and the effect of forming micro-climate with the PCW unit was measured in the small space prepared outdoors. The conclusions are as follows.

1)The brick materials which is a mixture of about 88% clay and 12% calcium carbonate burned about 1100 degrees centigrade has sufficient water-permeability and water-retention for PCW.

2)The PCWs formed of the slit type exhibiting excellent evaporative cooling performance and formed of the open type exhibiting excellent ventilation performance presented the respective micro-climate formation effects satisfactorily as expected.

3) The small enclosed space is cooled as a whole when the outdoor wind ventilates the PCW unit. However in the absence of wind, the temperature difference at the open space behind the PCW increases the indoor temperature nearly to the outdoor air temperature. Therefore utilizing structural openings and moving the vertical air flow is regarded as quite important factors.

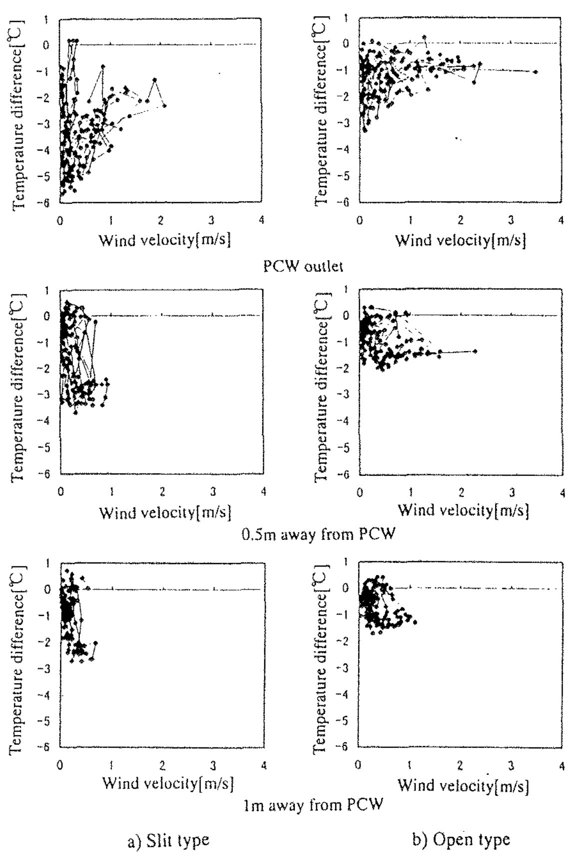


Fig.6 Relationship between wind velocity and temperature at each measurement point

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