# MEASUREMENT OF LOCAL VAPOR TRANSFER FROM THE VERTICAL WETTED SURFACE

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## ABSTRACT

The experimental design for measuring the rate of water vapor transfer from the surface of a vertical wetted model is described. The original wall model, 1.8m high and 1m wide, consists of sixteen wetted surfaces and is set up in climate chamber. In result, the vertical distributions of local vapor transfer coefficients in natural convection are obtained. The distributions are characterized by surface air flows which is induced by the combined force of thermal and humid buoyancy.
Furthermore, the experimental values agree with computed values by the Navier-Stokes equations in natural convection.

## 1. INTRODUCTION

The problems of water vapor transfer for air-conditioning or equipments, in general, can be analyzed by the Lewis relation (ref.1) which has developed the relation between heat and mass transfer. For the surface condensation problems in buildings, however, there is no experimental study to measure directly the rate of water vapor transfer from a actual wetted building wall or a surface with condensation to its atmosphere.
The purpose of this study is to obtain experimentally local vapor transfer coefficients and their vertical distribution from the surface of a wetted wall model with actual size under the steady-state condition and to compare with the experimental data and numerical solution by the Navier-Stokes equations for the wall model.

## 2. THE EXPERIMENTAL SYSTEM AND METHOD

**Figure 1** shows the front, the side view and the cross sectional detail of the original experimental model. The vertical surface model, approximately 1.8m in height and 1m in width, consists of sixteen pieces of oblong aluminum plate with a reservoir below. Each plate is covered with a sheet of filter paper as wick, which bottom edge hangs down in the reservoir. Pure water continuously flows up the filter paper by capillary action and saturates the paper completely. Temperature of the plate surfaces can be controlled by heaters on the back of the plates.
A thermo-couple is set between the paper and the center of each plate. The experimental cases and their conditions of the surface temperature are listed in **TABLE 1.**

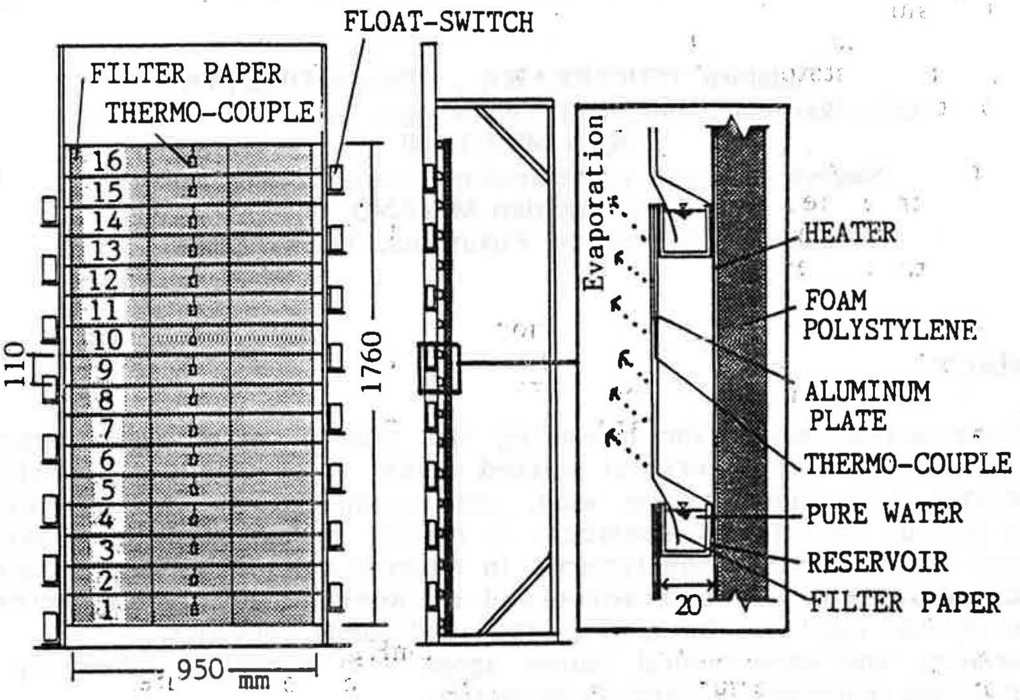


**FIGURE 1** The Vertical Wetted Surface Model

**TABLE 1** Experimental Conditions

| | surface's temp.(Ts) | | air temp.(Ta) | RH | air velocity |
|---|---|---|---|---|---|
| CASE 1 | Ts=Ta | 20 °C | | | |
| CASE 2 | Ts=Ta-5 | 15 | 20 °C | 35%rh | <0.1m/s |
| CASE 3 | Ts=Ta+5 | 25 | const. | const. | const. |
| CASE 4 | Ts=Ta+10 | 30 | | | |

As shown in **Figure 2**, water level in each reservoir is kept just under full by means of the original float-switch, a magnetic valve and an electric relay. Under this system the rate of water evaporation from the filter paper at each plate equals the decrease in weight of each measuring cylinder which supplies water to the reservoir.

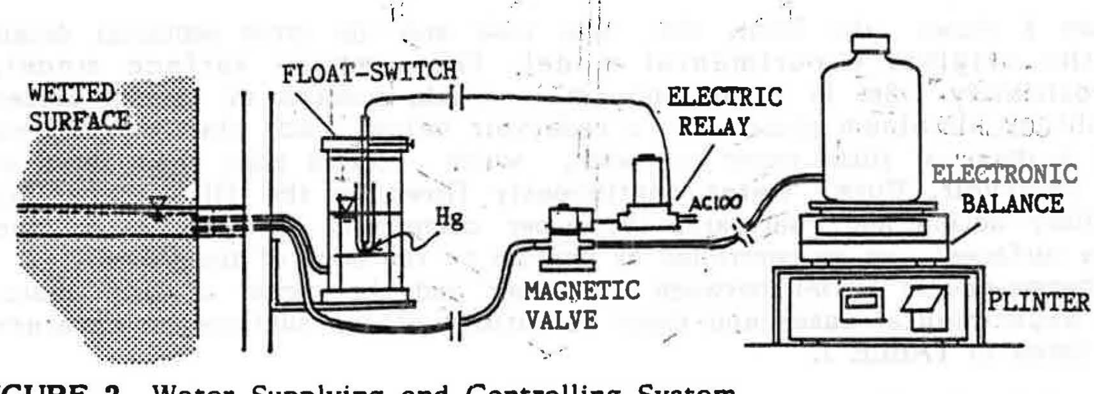


**FIGURE 2** Water Supplying and Controlling System

In order to neglect the radiation exchange between the wetted surface and surrounding surfaces and to avoid the effect of free convection in the climate chamber, the guard box is prepared as illustrated in **Figure 3.**
Under the steady-state condition in the climate chamber, temperatures of sixteen plate surfaces, an ambient air and a relative humidity at the center of the guard box are recorded once every 30 minutes by a digital data-recorder. Three electronic balances and printers indicate the weights of three measuring cylinders, No.1, No.9, No.16, once every 60 minutes. For another cylinders, the heights of water level are measured accurately with a ruler and are recorded.

For the design of a wetted surface model, it is assumed that evaporation from the surface is unaffected by thermal radiation and by heat conduction within the wall model. The rate of evaporation from each wetted area in the steady-state condition can be represented by following simple equation.

$$W = h_m( Fs - Fa )A \qquad \text{Eq.(1)}$$

where
W = the rate of water evaporation (kg/h)
$h_m$ = local vapor transfer coefficient ($kg/m^2hmmHg$)
Fs = saturated vapor pressure at each wetted surface temperature (mmHg)
Fa = vapor pressure of ambient air (mmHg)
A = area of a wetted surface ($m^2$)

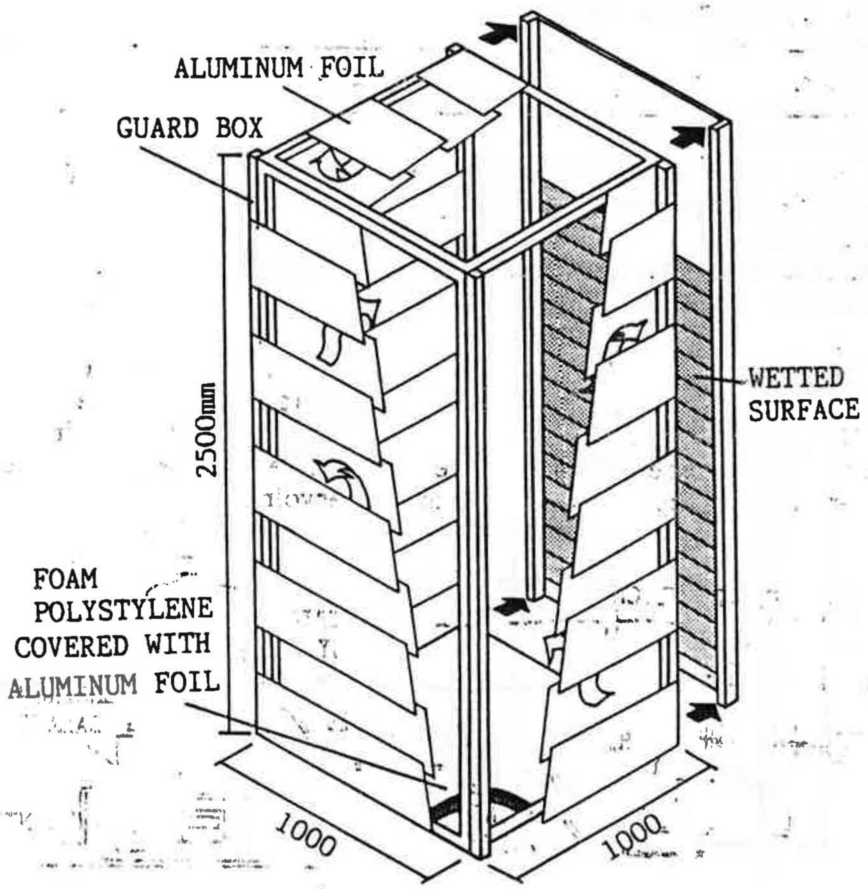


**FIGURE 3** The Wind Guard Box for The Wetted Surface Model

## 3. NUMERICAL ANALYSIS

Local water vapor transfer coefficients and their distributions are calculated by a two-dimensional laminar flow model and its boundary conditions which governed by the Navier-Stokes equations as shown in **Figure 4.** The equations for the model disregard the terms concerned with pressure.

continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad \text{Eq.(2)}$$

momentum equation

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-g\frac{\rho-\rho_\infty}{\rho_\infty} \qquad \text{Eq.(3)}$$

concentration equation

$$\frac{\partial f}{\partial t}+u\frac{\partial f}{\partial x}+v\frac{\partial f}{\partial y}=D\left(\frac{\partial^2 f}{\partial x^2}+\frac{\partial^2 f}{\partial y^2}\right) \qquad \text{Eq.(4)}$$

boundary conditions

| $\overline{AB}$ | $\overline{AC}$ | $\overline{CD}$ | $\overline{BD}$ |
| --- | --- | --- | --- |
| $u=0$ | $\frac{\delta u}{\delta x}=0$ | $\frac{\delta u}{\delta y}=0$ | $\frac{\delta u}{\delta x}=0$ |
| $v=0$ | $v=0$ | $v=0$ | $v=0$ |
| $f=fs$ | $f=fa$ | $f=fa$ | $\frac{\delta f}{\delta x}=0$ |

where

u, v : velocity components (m/s)
x, y : coordinates (m)
t : time (s)
g : acceleration of gravity (9.8 $m/s^2$)
f : vapor pressure (mmHg)
fs : saturated vapor pressure (mmHg)
fa : ambient vapor pressure (mmHg)
$\rho$ : density ($kg/m^3$)
$\nu$ : kinematic viscosity ($15.01\times10^{-6}$ $m^2/s$ at 20°c)
D : diffusivity ($24.90\times10^{-6}$ $m^2/s$ at 20°c)

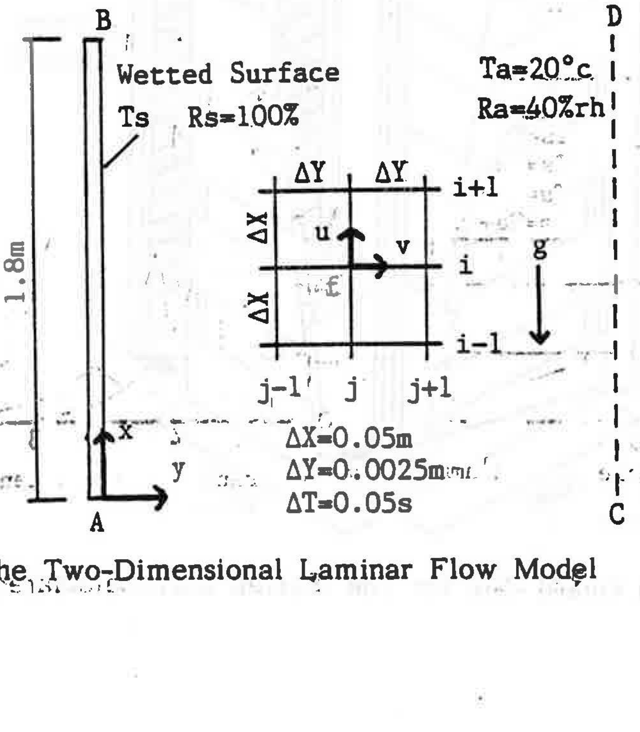


**FIGURE 4** . The Two-Dimensional Laminar Flow Model

## 4. RESULTS AND DISCUSSIONS

As shown in **Figure 5**, The weights of supplied water from three cylinders (No.1, No.9, No.16) to each reservoir increase linearly with time. This result suggests that evaporation at each wetted surface is continuously and uniformly during the experiment.

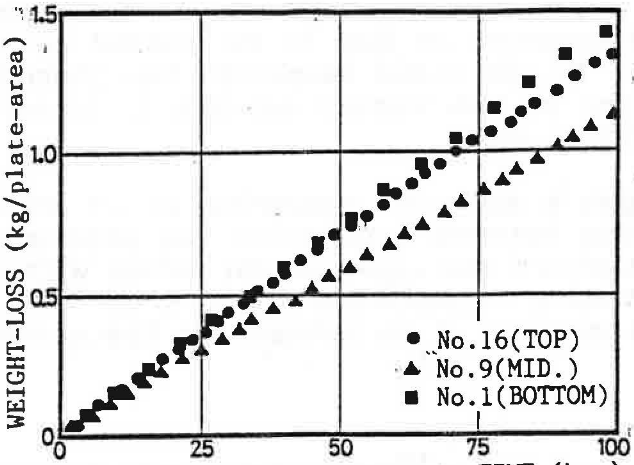


**FIGURE 5** Weight Loss of Water with Time (Ts=Ta+5)

The distributions of local vapor transfer coefficients with respect to the height from the bottom of the model by experiments are shown in **Figure 6**. In the case of Ts=Ta-5, values of the coefficient on the top part is considerably larger than those on the middle and lower parts.
Apparently, this phenomenon is caused by the influence of air flow from the top to the bottom along the surface.
On the other hand, the air flow from the bottom to the top causes the larger values of the coefficient on the lower parts in the case of Ts=Ta+10.

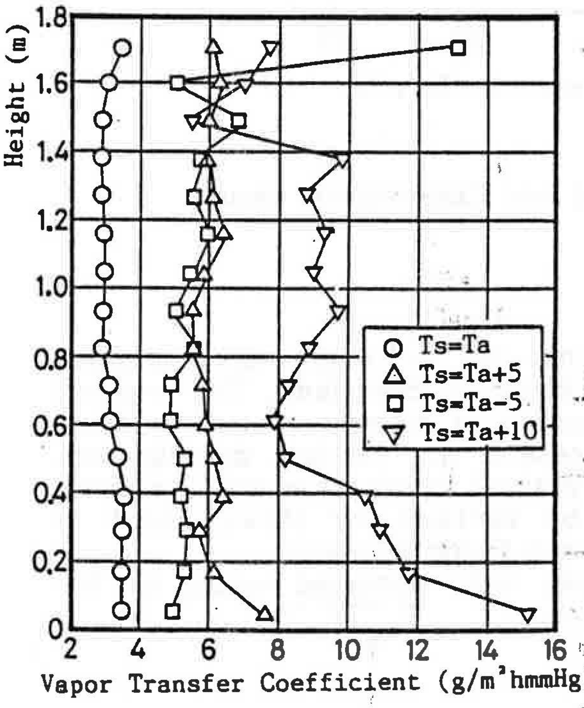


**FIGURE 6** Experimental Results

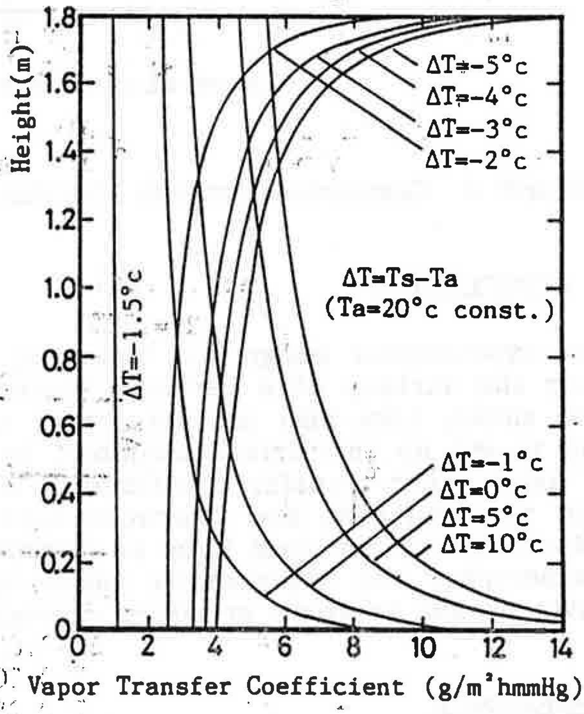


**FIGURE 7** Calculated Results

Figure 7 shows the profiles of vapor transfer coefficient calculated by the Navier-Stokes equations. It is clear that temperature difference between the wetted surface and its atmosphere affects the distribution of vapor transfer coefficient. At the temperature difference dT=-1.5 °C, the downward air flow by the thermal buoyancy counterbalances the upward flow by the humid buoyancy. This phenomenon suggests that the water vapor of the wetted surface is transferred to its atmosphere by diffusion only.

**Figure 8** shows the comparison of the average values with respect to the height between calculations and experiments. The agreement between calculated and experimental values within -5 to 5 °C is good. For the deviating experimental value at 10 °C, it appears that the result has the influence of the turbulent air flow nearby the surface of the model.

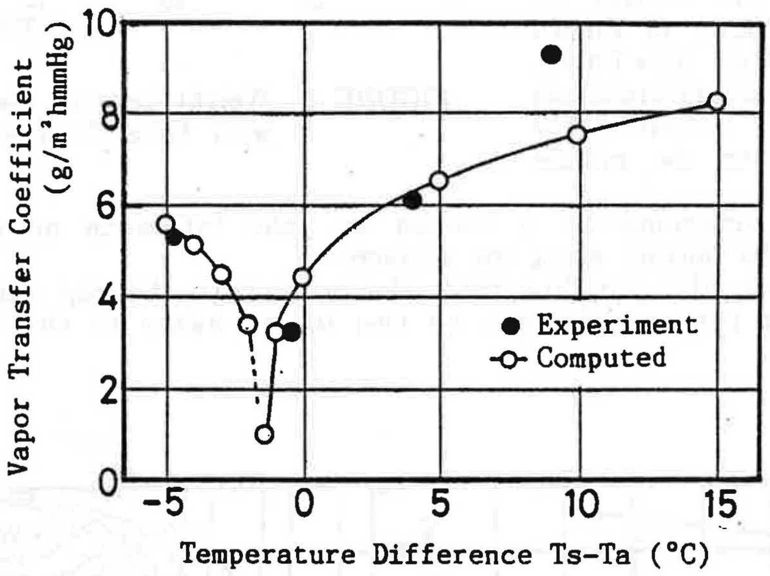


**FIGURE 8** Comparison between Calculated and Experimental Results

## 5. CONCLUSIONS

The experimental design for measuring the rate of water vapor transfer from the surface of a vertical wetted model is described. The original wall model, 1.8m high and 1m wide, consists of sixteen wetted surfaces and is set up in climate chamber. In result, the vertical distributions of local vapor transfer coefficients in natural convection are obtained. The distributions are characterized by surface air flows which is induced by the combined force of thermal and humid buoyancy.
Furthermore, the experimental values agree with computed values by the Navier-Stokes equations in natural convection.

## REFERENCE


(1)Lewis,W.K. The evaporation of a liquid into a gas, ASME trans., Vol.44, p.325-340, 1922.