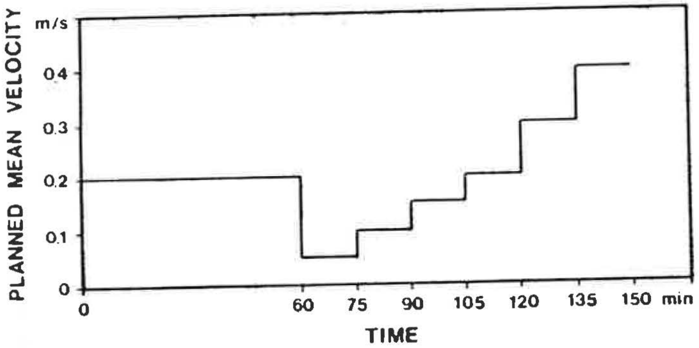
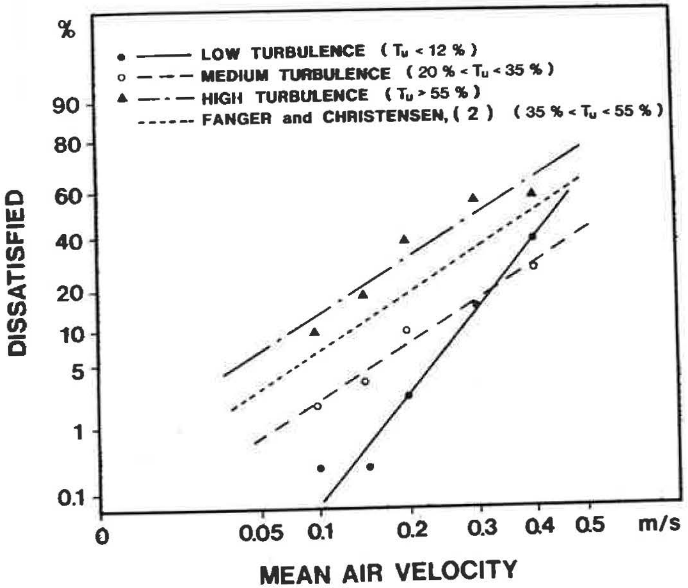
Figure 1. Planned mean velocity during each experiment.

Figure 2. The percentage of dissatisfied subjects, i.e. those feeling a draught at the head region as a function of the air velocity at the three levels of turbulence intensity. The points with 0% dissatisfied have been plotted at 0.2%.






# ESTIMATION OF THERMAL ENVIRONMENT IN A NATURALLY VENTILATED ROOM WITH WINDOWS OPENED BY USING DATA FROM FULL-SCALE MEASUREMENTS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## Abstract

The questionnaire inquiry conducted shows that cross-ventilation is used in 70-80% of apartment houses in the daytime of summer. We also carried out the simultaneous measurements of indoor climate in the two dwellings, one with windows opened and another with windows closed. Comparison of PMV of the two makes clear thermal effect of cross-ventilation. Nomogram for estimating indoor PMV from any outdoor climatic conditions can be made up by using relations between outdoor and indoor meteorological factors.


## Introduction

Cross-ventilation with windows fully opened is one of the most popular and traditional cooling means used in houses against the hot humid summer of Japan. Preference of people for cross-ventilation might be attributed mainly to that fluctuating air flow caused by natural wind makes them feel refreshing, different from steady air flow in air-conditioned rooms.

Considerable works on energy conservation effect, another meaning of cross-ventilation, have recently been done in America and Europe(Refs.1, 2,3,5,6). However there have been few reports on its effect on indoor thermal environment. This paper describes thermal effect of cross-ventilation in terms of PMV(Predicted Mean Vote in Ref.4), using data from the climatic measurements in the two dwellings, one with windows opened and another with windows closed, on the sixth floor of the 12-storied apartment house locating about 7km away from the coast line to the south.

## Background of utilization of cross-ventilaion

Fig.1 shows utilization of cooling means in apartments in Fukuoka city based on the questinnaire inquiry. In the daytime cross-ventilation is used in about 80% dwellings in residential and semi-industrial areas, though decreasing to 40% or so at night when wind becomes weaker. In commercial areas, however, utilization of cross-ventilation is less than half.

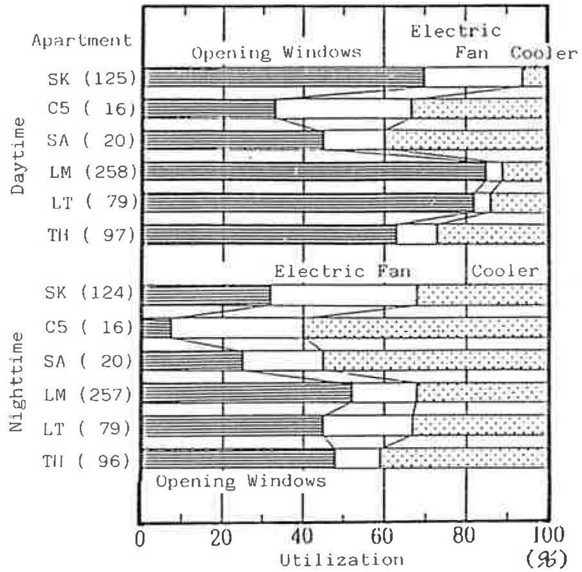


Fig. 1.

Utilization of cross-ventilation for cooling in apartment houses in Fukuoka city.

Numericals in parenthesis are sampling number.

SK, LM, LT : Residential Area

C5, SA : Commertial Area

TH : Semi-Industrial Area

Fig.2 compares wind-roses of the day and the night during the measurements done. It should be noted that northern wind or sea breeze dominantly blows in the day and south wind or land breeze at night over this city.

Variations of air temperature with wind vectors in the morning are dipicted in Fig.3. Comparison of wind direction change from the southern to the northern and air temperature variation makes clear the alleviation effect of sea breeze on air temperature rising. This implies that we can expect to get cooling effect of cross - ventilation to large extent, if we design buildings in consideration of the orientation so as to well accept sea breeze. As seen in Fig.1, cross-ventilation is not so much used in Apartment C5 as in the others, which is a side-corridor type facing to east, that is, which has windows on the east and the west side.

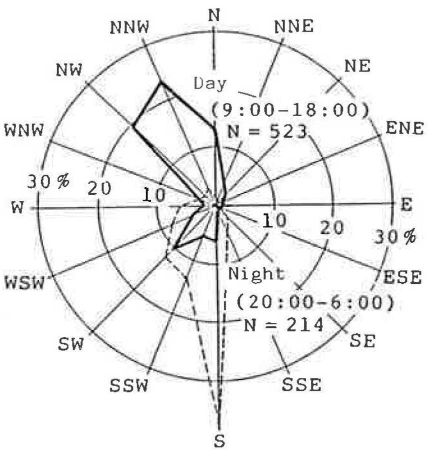


Fig. 2.

Comparison of wind-rose between day and night during the measurements.



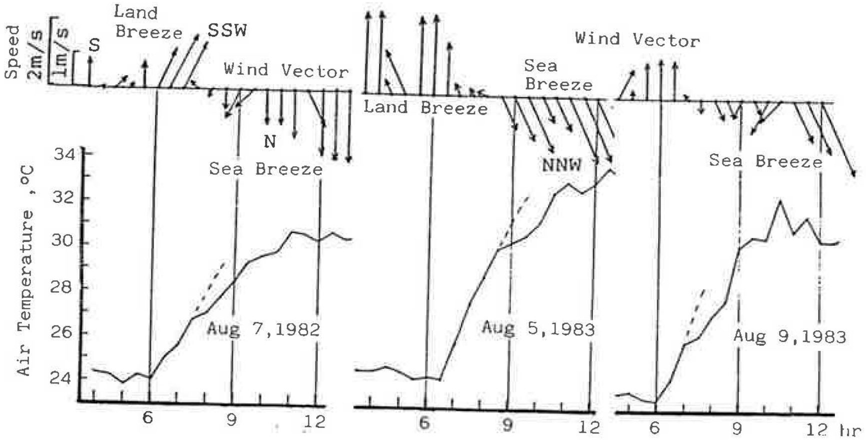


Fig. 3. Alleviation of air temperature rising by sea breeze. Air temperature is supposed to rise as shown by a broken line if it had not blown.

## Effect of cross-ventilation on indoor thermal environment

The apartment, where the measurements were conducted, has a corridor to the north side. Besides the extending area from the apartment to the coast is composed of the field and low-rised buildings. Thus the dwellings well accept the sea breeze in the day.

Fig.4 compares the variation of the thermal environmental factors measured and PMV calculated from them between the opened dwelling and the closed one. Indoor air flow velocity when closed is supposed to be 0.1m/s. Metabolic rate, M, and clothing insulation, I, are assumed to be equal to 58W/$m^2$(1met) and 0.3clo, respectively, for calculating PMV. PMV of the opened dwelling decreases soon after opening windows, remaining nearly 0, i.e., neutral, while that of the closed is about +2, i.e., warm.

Cumulative frequency distribution of PMV for three ranges of outdoor air temperature are compared between the opened dwelling and the closed one in Fig.5. The shaded zone of PMV from -0.5 to +0.5 corresponds to PPD(Predicted Percentage of Dissatisfied) less than 10% and is here considered as comfort zone. In the opened dwelling about 70% of the case is included in comfort zone for temperature range II and about a third for range III. In the closed, however, about 80% is greater than +1, i.e., slightly warm, even for range I.

Comparison of indoor and outdoor meteorological factors measured gives the following relations with correlation coefficients greater than 0.80.

For the opened dwelling

$ta = 11.3+0.61*Ta$

$tg = 3.0+0.92*ta$

$rh = 26.9+0.65*RH$

$v = 0.40*V$ for north

For the closed dwelling

$ta = 19.6+0.35*Ta$

$tg = -3.7+1.15*ta$

$rh = 53.8+0.22*RH$

where ta, tg, rh and v are indoor air temperature, globe temperature, relative humidity and air flow velocity, respectively, and those in capital letter are corresponding outdoor climatic factors.

Using these relations, we can calculate indoor PMV for any outdoor climatic conditions. Fig.6 is an example of nomogram for estimating PMV in a cross-ventilated room with parameters of outdoor air temperature, Ta, and wind speed, V, in combination with PPD. For north wind with speed of 4m/s, indoor air flow velocity of 1.6m/s is obtained, as relative velocity, v/V, is about 0.4 for this direction. In this case PMV remains within comfort zone even for Ta of 30 ºC. For Ta greater than 32ºC, however, cross-ventilation is less effective, as PMV exceeds +1, i.e., slightly warm, almost for any wind speed.

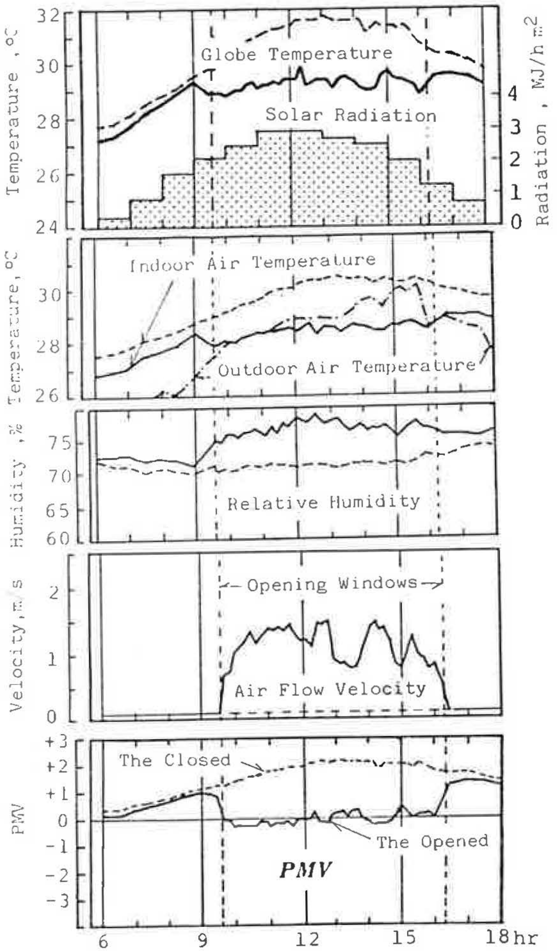


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Fig. 4.

Comparison of diurnal variations of thermal environmental factors between the opened dwelling(solid lines) and the closed one (broken lines).



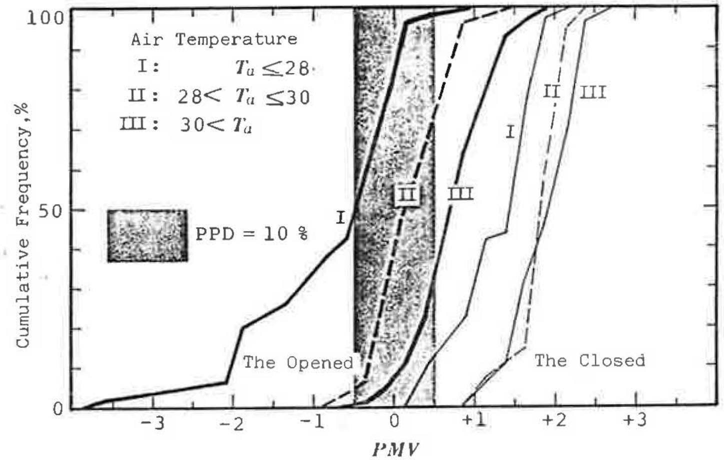


Fig. 5. Comparison of cumulative frequency distribution of PMV for three ranges of outdoor air temperature between the opened dwelling unit (bold lines) and the closed one(thin lines).

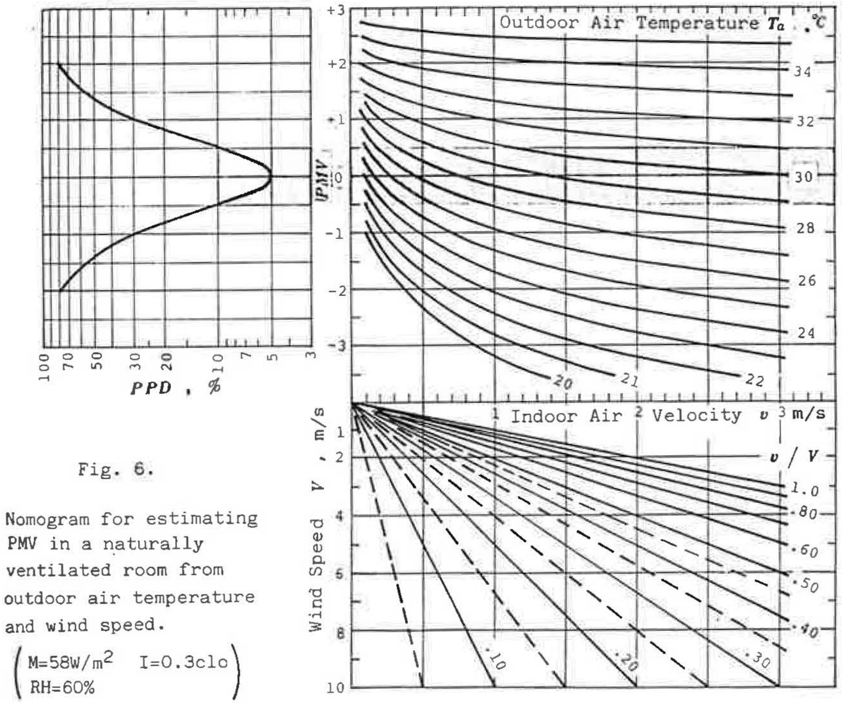


Fig. 6.

Nomogram for estimating PMV in a naturally ventilated room from outdoor air temperature and wind speed.

($M=58W/m^2$ I=0.3clo RH=60%)