# Effect of External Ground Surface Materials on Indoor Thermal Comfort

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ABSTRACT: External ground surface materials produce enormous heat output and thus raise outdoor temperature, as well as reflecting solar radiation and creating long wave radiation that enters indoor areas via windows and increases indoor temperature, and thus influence occupant comfort. Using a field experiment and questionnaire study, this study examined the influence of external ground surface materials on indoor thermal comfort. Experimental results indicate that the subjective and objective thermal comfort evaluation of classrooms with greenery outside is better than that of those with concrete outside. External ground surface material thus physiologically and psychologically influences indoor thermal environment.

Keywords: external ground surface materials, thermal comfort

## 1. INTRODUCTION

When buildings are surrounded by artificial or impermeable pavements, the external ground surface material produces enormous heat output which increases outdoor temperature and subsequently increases indoor air temperature indirectly. The phenomena raise indoor air temperature and mean radiant temperature and thus influence occupant thermal comfort.

Numerous studies on thermal comfort have examined naturally ventilated spaces. Regarding classrooms, Kwok studied the thermal comfort of classrooms in Hawaii [1], while Wong performed a similar study in Singapore [2], and Hwang conducted field experiments on thermal comfort covering 1294 students in 14 naturally ventilated and 26 air-conditioned classrooms in Taiwan [3]. These studies discussed subjective and objective indices such as Thermal Sensation Vote (TSV) [4], Predict Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD) [5, 6], Standard Effective Temperature (SET*) [7], neutral temperature, preferred temperature, acceptable ranges of thermal comfort, and thermal adaptation.

This investigation performs field experiments examining the influence of external ground surface material on indoor thermal comfort. It focuses on two adjacent classrooms sharing the same space form and characteristics. The two classrooms only differ in external ground surface material. This study conducts field experiments focused on thermal environment and as well as a questionnaire focused on thermal comfort of indoor occupants, exactly how the two classrooms differ in terms of indoor thermal comfort is also discussed.

## 2. METHOD

2.1 Measurement and Instrumentation

This work used micro-meteorological instruments to measure two classrooms to analyze thermal comfort in subtropical Taiwan. To compare thermal comfort between the classrooms, measurements were conducted simultaneously at six indoor and outdoor points. The field experiment approach was applied to simultaneously record air temperature, globe temperature, surface temperature, relative humidity, wind velocity, and global radiation at each point. The instruments were fixed on a tripod at different heights, and the instrumentation specifications complied with the ASHRAE standard [4, 8].

2.2 Thermal Comfort Questionnaire and Thermal Indices

The questionnaire used an ASHRAE seven scale to assess respondent perceptions of Thermal Sensation Vote (TSV). The value of TSV form -3 to +3 means cold, cool, slightly cool, neutral, slightly warm, warm and hot, respectively. In the same time Humidity Sensation Vote (HSV), Wind Sensation Vote (WSV), Solar Sensation Vote (SSV) are also surveyed. Respondents also provided their thermal comfort acceptance (TCA). Meanwhile, the Percentage Mean Vote (PMV) and Standard Effective Temperature (SET*) were also calculated to provide objective thermal indices. SET* was calculated depend on the air temperature, mean radiant temperature, relative humidity, wind speed, clothing and activities of subjects The software used for this study was the same as that in the article of Fountain and Huizenga [9].

2.3 Investigation Area and Questionnaire Subjects

This study focused on two adjacent and identical classrooms, as shown on Fig. 1. Classrooms L and R shared similar area, scale, orientation, material and function. The classrooms only differed in that classroom L had concrete as the external ground surface material, while classroom R had grass outside. Two interior measuring points and one outdoor point were used for each classroom.

The experiment was conducted on Aug 8, 2005, which was a sunny day. The data were gathered at one-minute intervals from 8:00 to 17:30 for six points. Furthermore, the questionnaire investigation was performed at 8:00, 9:00, 10:00, 11:00, 13:00, and 14:00 for the four indoor points with the respondents being students. A total of 450 effective questionnaires were obtained.

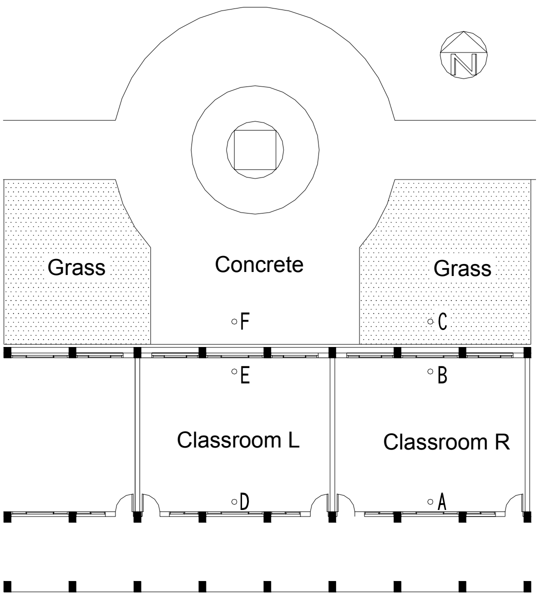


**Figure 1:** Floor plan and measurement point of the classrooms.

## 3. RESULTS

3.1 Air Temperature and MRTs Variation

Figure 2 illustrates the variation of air temperature for each indoor point. The figure shows that points B and E, located closest to the outdoors have higher variation of air temperature than points A,D, located near the corridor. However, the difference is not significant. Figure 3 shows the variation of mean radiant temperature (MRT), and reveals significantly higher variation of MRT for B,E points than for points A and D. Points B and E clearly have higher values of solar radiation owing to their proximity to the windows. Notably, the MRT of point E, where concrete is the external ground material is 1ºC higher than that of point B, where the external ground material is grass.

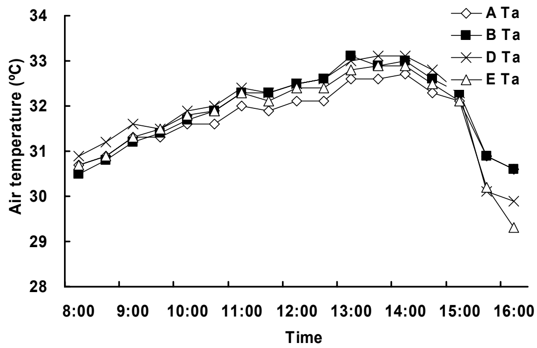


**Figure 2:** Variation of Air temperature for each point.

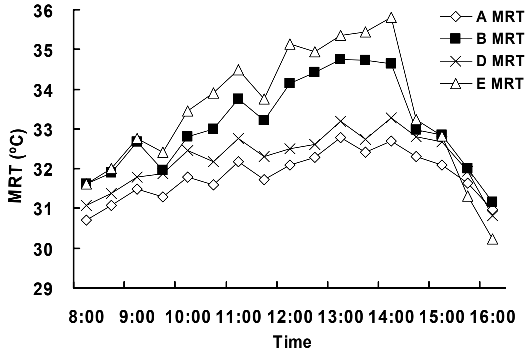


**Figure 3:** Variation of MRT for each point.

3.2 Thermal Comfort Indices

Figure 4 and 5 shows the thermal indices, including SET* and PMV. Both the PMV and SET* of points B and E exceed those of points A and D, and the value of E is also higher than that of point B. Consequently, in terms of measured thermal comfort performance the survey points have the ranking A, D, B, and finally E.

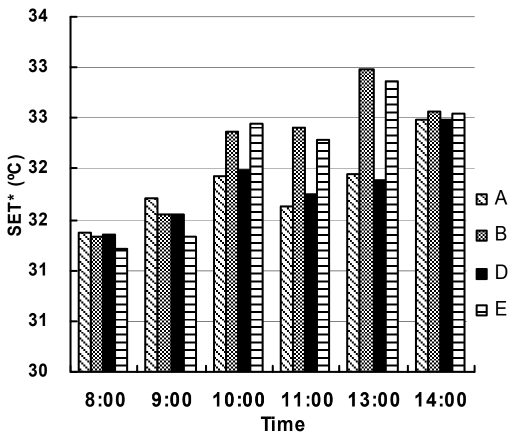


**Figure 4:** SET* for each location in different time period.

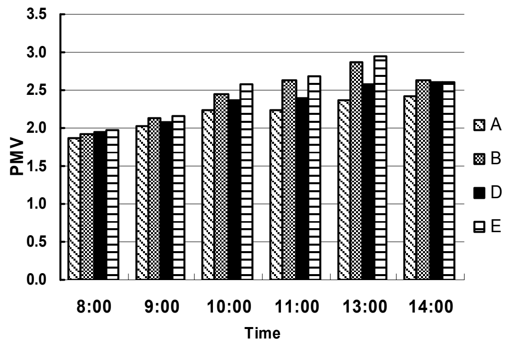


**Figure 5:** PMV for each location in different time period.

3.3 Thermal Comfort Questionnaires

Occupant thermal comfort is also evaluated using a subjective thermal comfort questionnaire investigation to clarify whether occupant thermal comfort is correlates with the objective thermal indices. Figure 6 displays the TSV percentage for each point. The figure reveals that most occupants of points A and B feel neutral to slightly warm, while most occupants of points D and E feel warm to hot. Students thus feel most comfortable at points A and B. This analytical result differs slightly from the mean MRT of Fig. 3. For example, subjects at point B should feel hotter than those at point D because point B have higher MRT, SET* and PMV values than D. However, Fig. 6 shows the opposite, namely that respondents feel more comfortable at point B than at D. This unexpected finding may result from a combination of both physiological and psychological factors affecting the thermal preferences of occupants. The mean TSV during each time period, shown in Fig. 7, also reveals the same situation as Fig 6, namely that points D and E have higher values as TSV=1.2 in 10:00, 13:00 and 14:00. Locations with grass outside may make people feel more comfortable in terms of the thermal environment than locations with artificial pavement outside, even when both locations share identical thermal indices.

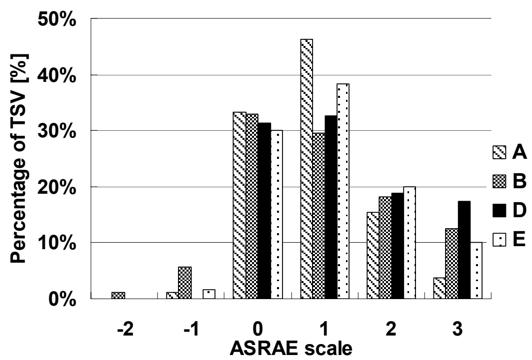


**Figure 6:** TSV percentage for each point.

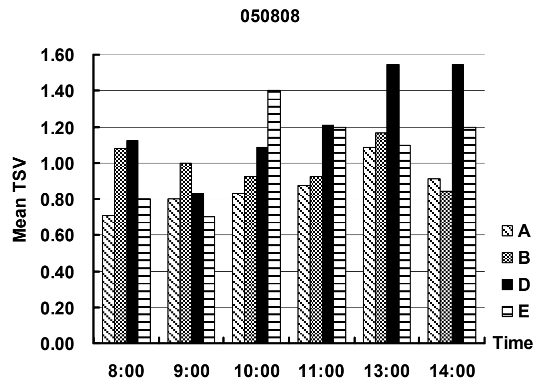


**Figure 7:** Mean TSV in each time period for each point.

3.4 Correlation Analysis

Table 1 shows the correlation between measured items and thermal indices. The measured items and thermal indices are closely correlated since the indices are calculated using the measured values. The globe temperature exhibits the best fit to each index. Meanwhile, Table 2 lists the correlation between the subjective questionnaire and objective thermal indices. The table reveals that the correlation of the TSV value and thermal indices is significant but not strong. It showed that the actual thermal condition does not reflect on subjects' thermal sensation.

**Table 1**: Correlation of measured items and thermal indices.

| | SET* | ET* | PMV | PPD |
|---|---|---|---|---|
| Tg | 0.52* | 0.86* | 0.96* | 0.92* |
| Ts | 0.51* | 0.87* | 0.86* | 0.82* |
| Ta | 0.48* | 0.76* | 0.89* | 0.90* |
| RH | -0.38* | -0.55* | -0.81* | -0.83* |
| MRT | 0.49* | 0.84* | 0.90* | 0.83* |

(* p-value<0.05)

**Table 2**: Correlation between the subjective questionnaire and objective thermal indices.

| | SET* | ET* | PMV | PPD |
|---|---|---|---|---|
| TSV | **0.10*** | **0.15*** | **0.13*** | **0.12*** |
| HSV | 0.04 | 0.02 | 0.00 | 0.01 |
| WSV | -0.09* | -0.11* | -0.06 | -0.04 |
| SSV | -0.08 | -0.03 | -0.04 | -0.07 |
| TCA | 0.23* | 0.14* | 0.09* | 0.07 |

(* p-value<0.05)

Further analysis is performed for the correlation between TSV and SET* for each point, as illustrated in Fig. 8. The figure shows that the TSV increases with SET*, except for point B. Clearly, the subject thermal comfort assessments at point B are not easily influenced by the actual SET*.The same condition occurred for the relation between SET* and PMV (Fig. 9), meaning that the thermal comfort evaluation for point B is not entirely determined by PMV.

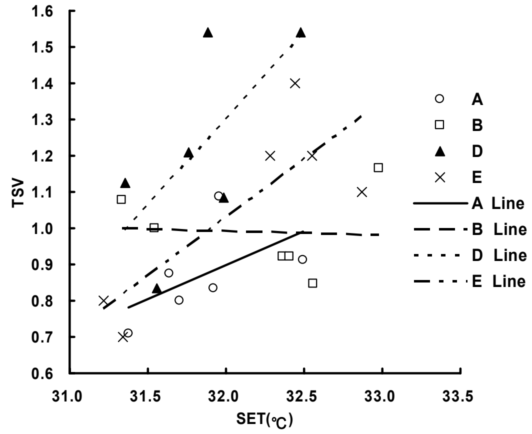


**Figure 8:** Correlation between TSV and SET*.

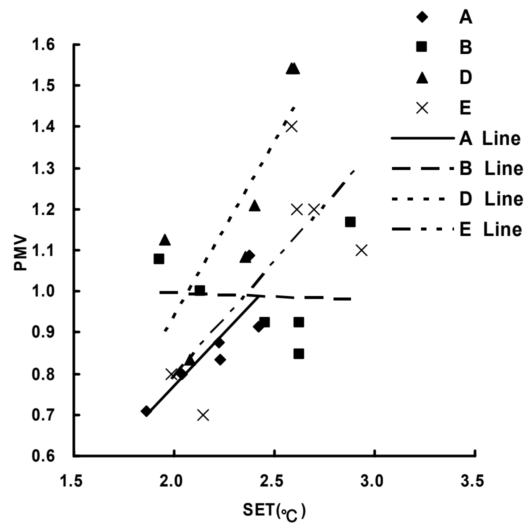


**Figure 9:** Correlation between PMV and SET*.

The analytical results demonstrate that external ground greenery around indoor spaces not only reduces indoor MRT but also improves subject assessments of thermal comfort, meaning subject assessments of thermal comfort are not easily influenced by actual temperature variation. Therefore, external ground greenery helps maintain stable physiological and psychological thermal comfort.

## 4. CONCLUSIONS

This work examined the thermal comfort of classrooms constructed using different external ground materials in Taiwan using field experiments together with a questionnaire survey. The following conclusions were reached:

1. Classrooms with greenery outside had higher indoor temperatures than those with grass outside.
2. The subjective thermal comfort evaluation revealed that the occupants felt more comfortable in classrooms with greenery outside than in those with concrete outside.
3. The material outside classrooms both physiologically and psychologically affects the indoor thermal environment, and classrooms with grass outside offer occupants a more stable and comfortable environment.

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