The effects of indoor temperature and outdoor air supply rate on learning performance of late-teen students

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ABSTRACT

In order to investigate the impact of IEQ on learning performance, intervention field experiments were carried out at two technical colleges in Japan. Indoor temperature and outdoor air supply rate were changed at 3 levels (22, 25, 28°C; 5, 10, 20 m^3/h/person), and 5 combinations of them were adopted as the experimental cases. The learning performance was evaluated with a 30-min examination after a 180-min video lecture. The examination score was found to be improved when PMV was close to zero, or outdoor air supply rate was increased. According to the comparisons with previous studies, it was considered that the learning performance of young people is more affected by the indoor temperature and outdoor air supply rate than that of older people.

INTRODUCTION

Indoor environmental quality (IEQ) has impact on occupants' productivity. A significant number of experimental and field studies have shown that poor IEQ can reduce the performance of simulated or actual office works. Recently, the impact of the IEQ on learning performance in classrooms is also getting noticed [1]. Classrooms often have insufficient function to control temperature and air quality, and the resulting low learning performance must cause great loss for the individuals and also for the society.

Learning performance can be distinguished from office work performance. Because learning performance is considered to be efficiency to acquire knowledge, but office work performance is more likely to be efficiency to utilize the acquired knowledge. In order to estimate the impact of IEQ on the learning performance, Murakami and Ito [2, 3, 4] carried out an intervention field experiment and a climate chamber experiment, and adopted an original experimental procedure with a video lecture and standardized examination. That procedure could provide a reproducible learning environment and allow cross-environmental evaluation. Twenty- to forty-year-old subjects were participated in those experiments, and their examination scores were found to be affected by the indoor temperature and ventilation rate.

In the present study, new intervention field experiments were conducted on late-teen subjects with the same procedure as the previous experiments. The aim of this study was to investigate the IEQ impact on the learning performance with younger people, and discuss if there are any differences from the previous experiments.

METHODS

The intervention field experiments were conducted at two national colleges of technology in Japan (colleges A and T). Those colleges provide five years professional education to students beginning as early as graduation from junior high school. At each college, the students who studied architecture or civil engineering were selected as subjects, and a classroom where they usually studied was used for the experiment.

There are air conditioning units and ventilation fans in the classrooms at both colleges. In order to evaluate the effects of indoor temperature and outdoor air supply rate, each of them were controlled at three levels and five combinations of them were adopted as the experimental cases as shown in Table 1. The five sessions under different experimental cases were carried out at both colleges and during the same hours in every week, between August to October 2008. The experimental cases were applied to the sessions in random order, and the subjects were supposed to participate in all sessions.

Table 1 Experimental cases

	Outdoor air supply rate [m^3/h/person]	Indoor temperature [°C]
Case 1		28
Case 2	20	22
Case 3		
Case 4	10	25
Case 5	5	

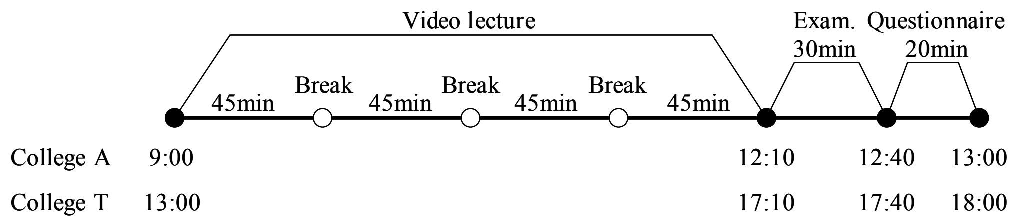


Figure 1 Experimental procedure and time table

An experimental procedure, which is the same with previous studies [2, 3, 4], was applied to every session. This procedure consisted of a video lecture, examination and questionnaire (Figure 1). The video lecture and examination, which we adopted, were developed by a nationwide private school for people aiming to be authorized architects. Issues treated in the lecture and examination were changed at every session so that the subjects would not take the same lecture. The examination scores got in the present experiments could standardized based on the average scores derived from approx. 6000 data of actual students in all parts of Japan. The average score represent only the difficulty of each set of the lecture and examination, because there is no difference in the teaching condition between the experiment and actual school due to the video lecture. Thus, the standardized examination scores can be compared even though the contents of the lectures and examinations were different among the sessions. Every examination consisted of twenty questions. An example of the question is shown in Table 2.

The questionnaire asked subject's perception of IEQ, total time of doze, percentage of previously known issues, and self-evaluation of learning performance (i.e. loss of learning time due to IEQ, and percentage of expected improvement in learning performance by improving IEQ). Part of the questionnaire is shown in Table 3. As physical parameters, air and globe temperatures, humidity, air velocity and CO2 concentration were measured during experiments. Back ground noise and illumination level were measured before each sessions, and confirmed to be almost identical in all sessions.

Table 2 Example of questions in examinations

Question 10; Which is the **most improper** one among the following descriptions concerning various wiring methods used for the office construction?
(1) The free-access floor wiring method makes the floor a double floor, and it is a method of using between those as wiring space, and there is an effect of reducing the design load of the floor.
(2) The floor on the standard floor was made to the free-access floor of 6cm in height, and to correspond to the change in the layout of the office, considered in the office building.
(3) Under the carpet wiring method is a method to construct a thin cable directly in the above the floor level, and special floor finish is needed. However, it is possible to correspond to the change easily.
(4) It wires a necessary place, and the bus baton wiring method is large the maximum, permissible current, and in the method to accommodate and to protect the conductor in this, is suitable for a mass power supply.
(5) In general, the conductor used for the bus baton wiring method is copper or, aluminum.

Table 3 Part of the questionnaire

Thermal Environment
・ Which is your thermal sensation? [.] 1. Very cold 2. Cold 3. Slightly cold 4. Neutral 5. Slightly hot 6. Hot 7. Very hot
・ Are you satisfied with a current thermal environment? [.] 1. Dissatisfied 2. Slightly Dissatisfied 3. Medium 4. Slightly Satisfied 5. Satisfied
Learning Performance
・ If the current indoor quality is improved, how do you think of the percentage of improvement in learning performance? [.]%

RESULTS

Physical measurements and subjects

Tables 4 and 5 show summary of physical measurements and characteristics of the subjects at the colleges A and T. Because of insufficient capacity of air condition units, air temperatures in some experimental sessions were slightly higher than the setting points. In every sessions, MRT was almost the same as air temperature and air velocity was lower than 0.2 m/s. Clothing value was estimated by experimenters. It was found to be adjusted due to temperatures, and average values among the sessions were different between 0.48 to 0.62 clo. With assuming that the metabolic rate was 1.0 met, PMV was calculated as shown in the tables. Outdoor air supply rate per person was determined based on the air change rate measured before experiments, and all of the subjects did not necessarily participate in every session. Thus, it varied with the number of attended subjects. The subjects at college A were tend to be two years older than the subjects at college T.

Subjective measurements on IEQ and total time of doze

Figure 2 shows observed thermal sensation and PMV in each case. Change of the thermal sensation well corresponded to that of the PMV. However, the subjects at both colleges tended to feel colder than expected. It was found that the thermal sensation in cases of PMV=0 was lower than neutral, and almost neutral even in Case 1 where the temperature was 28°C. This trend was more obvious at college A than at college T. Figure 3 shows subjects' satisfaction with thermal environment. It was well related to the thermal sensation. The subjects at colleges A and T were most satisfied in Case 1 and Case 3, respectively. Figure 4 shows satisfaction with indoor air quality. It was found that the subjects at each college were most satisfied in the case with the highest outdoor air supply rate. However, the differences were very small, and the subjects of both colleges were satisfied with indoor air quality of all cases. Total time of doze, which was self-assessment by the subjects, was shown in Figure 5. The subjects slept for 10-50 min during each session. The time of doze had no obvious relationship with thermal environment or indoor air quality in the present experiments.

Table 4 Physical measurements and subjects at college A

Date	Case	Contents of Lecture	Air temp. [°C]	Humidity [%]	PMV [−]	Outdoor air supply rate [m^3/h/p]	CO2 [ppm]	Num. of attended subjects / mean age / male:female
Aug. 8	Case 1	A	28.0±0.3	59±3	0.8	19.3	1414± 84	16 / 19.7 / 12:4
Aug. 28	Case 5	B	25.1±0.1	59±2	0.0	7.1	2236±490	22 / 19.8 / 13:9
Sep. 4	Case 3	C	25.0±0.1	54±1	-0.1	18.2	1130± 80	17 / 19.8 / 11:6
Sep. 11	Case 4	D	26.0±0.4	59±3	0.2	9.8	1817±258	19 / 19.8 / 12:7
Sep. 18	Case 2	E	23.7±0.3	59±3	-0.4	15.1	1331± 94	21 / 19.9 / 13:8

Table 5 Physical measurements and subjects at college T

Date	Case	Contents of lecture	Air temp. [°C]	Humidity [%]	PMV [−]	Outdoor air supply rate [m^3/h/p]	CO2 [ppm]	Num. of attended subjects / mean age / male:female
Sep. 6	Case 3	A	26.1±0.6	38±1	0.0	29.2	826± 29	11 / 17.7 / 9:2
Sep. 13	Case 1	B	28.0±0.1	51±2	0.7	16.5	1156± 26	21 / 17.6 / 17:4
Sep. 20	Case 5	C	25.1±0.2	41±1	-0.4	6.7	2319±277	20 / 17.8 / 13:7
Sep. 27	Case 2	D	22.5±0.3	40±1	-1.0	17.2	1082± 19	20 / 17.7 / 13:7
Oct. 4	Case 4	E	25.0±0.3	50±4	-0.2	11.0	1533± 83	24 / 17.7 / 16:8

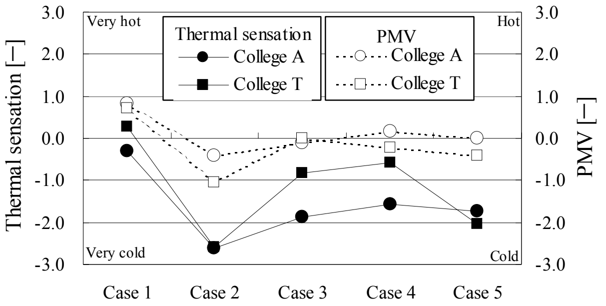


Figure 2 Thermal sensation and PMV

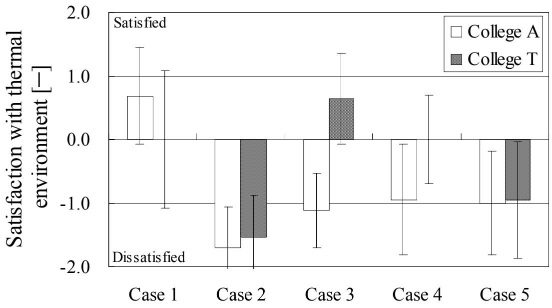


Figure 3 Satisfaction with thermal environment

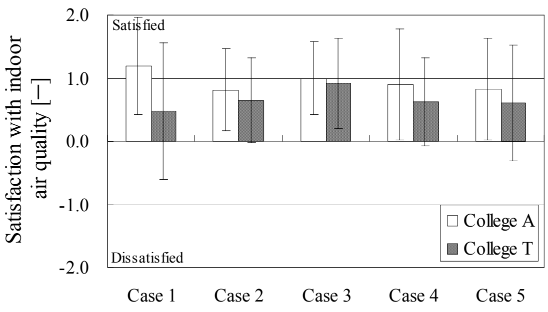


Figure 4 Satisfaction with indoor air quality

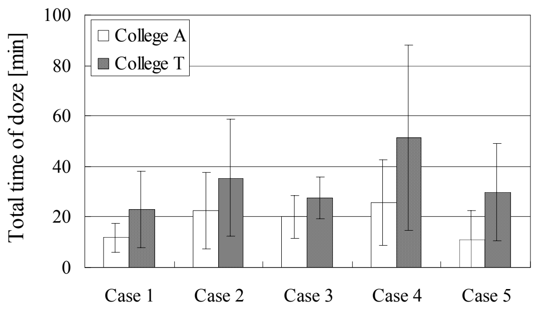


Figure 5 Total time of doze

Examination scores

Standardized examination scores were shown in Figure 6. T-tests were conducted to compare the scores between the experimental cases, and the results were shown in Tables 6 and 7. Cases 1, 2 and 3 correspond to high, low and middle indoor temperature cases, respectively.

At college T, the score in Case 3 was significantly higher than those in Cases 1 and 2, and the score in Case 1 was significantly higher than that is Case 2 (Case 3 > Case 1 > Case 2). At college A, the sore in Case 1 was the highest, but its difference with Case 3 was not significant. The score in Case 2 was significantly lower than those in Cases 1 and 3 (Case 1, Case 3 > Case2). On the other hand, Cases 3, 4 and 5 correspond to high, middle, low outdoor supply rate cases, respectively. At college A, the score in Case 3 was the significantly higher than those in Cases 4 and 5, and the score in Case 5 was significantly higher than that in Case 4 (Case 3 > Case 5 > Case 4). At college T, the scores in Cases 3 and 5 were significantly higher than that in Case 4, but there was no significant difference between Cases 3 and 5 (Case 3, Case 5 > Case 4).

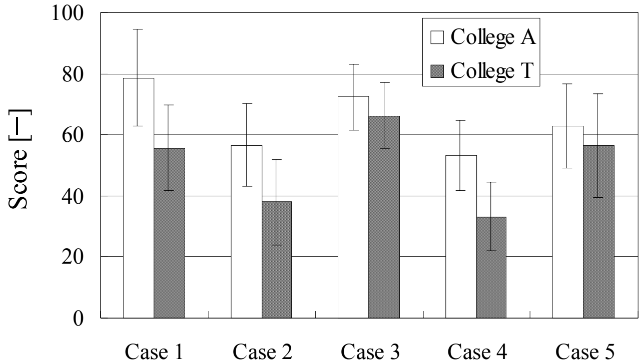


Figure 6 Examination scores

Table 6 Comparisons of examination scores at college A (t-test)

	Case 2	Case 3	Case 4	Case 5
Case 1	p<1.0E-4	n.s.	p<1.0E-5	p<0.01
Case 2		p<0.001	n.s.	n.s.
Case 3			p<1.0E-4	p<0.03
Case 4				p<0.03

Table 7 Comparisons of examination scores at college T (t-test)

	Case 2	Case 3	Case 4	Case 5
Case 1	p<0.001	p<0.05	p<1.0E-6	n.s.
Case 2		p<1.0E-5	n.s.	p<0.01
Case 3			p<1.0E-8	n.s.
Case 4				p<1.0E-4

Self-evaluation of learning performance

Figures 7 and 8 show subjects' estimation of loss of learning time due to IEQ, and percentage of expected improvement in learning performance by improving the IEQ. The loss of learning time was obviously affected by the low indoor temperature (Case 2), but not affected by the high temperature (Case 1). There was little influence of the outdoor supply rate on the loss of learning time. The percentage of expected improvement also seemed to be affected by the low temperature, and little affected by the other factors. Both kinds of self-evaluation were not clearly consistent with the examination score.

Percentage of previously known issues

In each session, the subjects were asked to answer a percentage of issues which they had known before the lecture. The results are shown in Figure 9. The percentages of Cases 1 and 3 at college A were obviously higher than those of the other cases. In addition, the subjects at college A tended to answer higher percentage than those at college T. As comparing to the examination scores in Figure 6, theses facts seemed to be reflected in the scores.

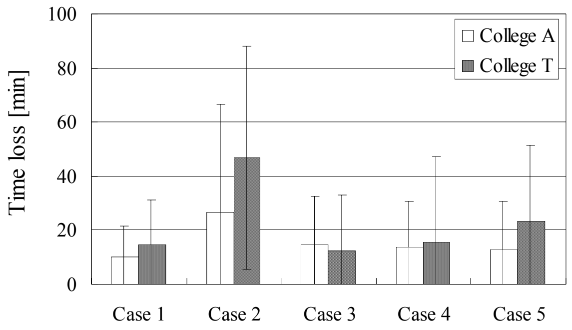


Figure 7 Loss of learning time due to IEQ

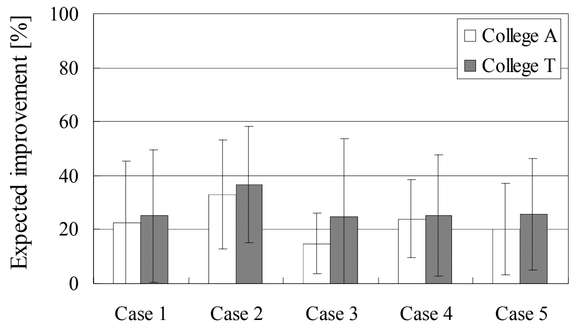


Figure 8 Percentage of expected improvement in learning performance by improving IEQ

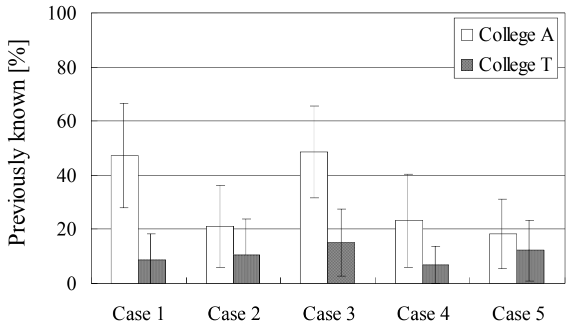


Figure 9 Percentage of previously known issues

DISCUSSIONS

In the present experiments, the examination score in Case 3, i.e. middle indoor temperature and high outdoor sir supply rate, were generally higher than those in the other cases. This result implies that the subjects' learning performance was affected by IEQ. However, the relations of the examination scores to the indoor temperature and outdoor air supply rate, which are shown in Figures 10 and 11, were not necessarily clear. As seen in the previous section, the examination score could be varied due to the subjects' background knowledge (i.e. percentage of previously known issues). Thus, it was considered that those relations were disturbed due to the differences in the background knowledge. In order to determine the cases which were significantly different from others regarding to this background knowledge, Games-Howell pairwise comparison test was performed. As shown in Table 8, it was found that Cases 1 and 3 at college A and Case 4 at college T were significantly different from other cases. Therefore, these cases could not be treated in the same way with the others. Without these cases, there were found to be clear relations in both Figures 10 and 11. The approximate curves of quadratic or logarithmic functions were depicted in the figures.

The subjects in the present study were from 16 to 22 years old, and mean age was approx. 18.7. Field and chamber experiments had been done with the same procedure but different age groups in previous studies [2, 3, 4]. The age of the subjects in the field experiment was mainly from late 20 to 40, and that in the chamber experiment were early 20. These results were compared in Figure 12. The curves of the present study were derived from the data without three cases mentioned above. The relative score in Figure 12(a) was defined as a ratio to the score observed at PMV=0 in each study. It means that the relative scores are 1 in the cases of PMV=0. On the other hand, that in Figure 12(b) was defined as a ratio to the score at 1.0 m^3/s/person of outdoor supply rate, which was estimated with a regression model determined in each study. As shown in Figure 12(a), the highest scores of all experiments generally appeared at PMV=0, although that in the previous field experiment was found at slightly lower temperature. Impact of the temperature change in the present study was similar to that in the previous chamber experiment, but much greater than that in the previous field experiment. On the other hand, the change of the outdoor supply rate had greater impact in the present study than the previous experiments. With both indoor temperature and outdoor supply rate, it was noticed that the relative score in the present study was greater than that in the field experiment where the subjects were from late 20s to 40s. From this fact, it is considered that the learning performance of young people is more affected by the IEQ than that of older people. It may be because young people are more sensitive to IEQ. Or else, young people have less knowledge and there is more information to get during the lecture. If there is no information to newly get, learning performance has no meaning and examination scores must be constant regardless of IEQ. Therefore, the difference in the learning performance between the age groups can be explained by the difference in the background knowledge as well as the physical sensitiveness to the IEQ.

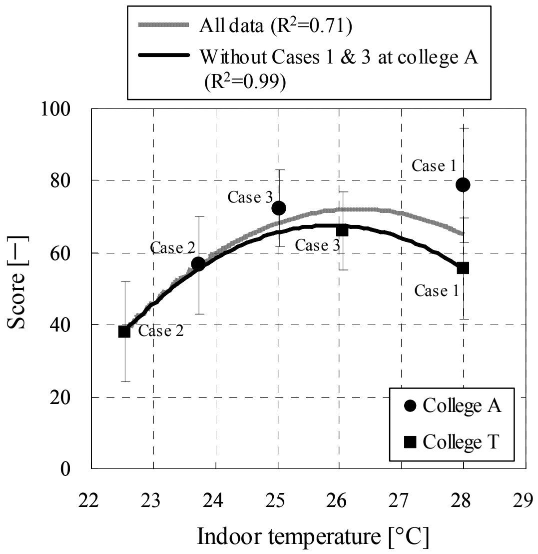


Figure 10 Examination score as a function of indoor temperature

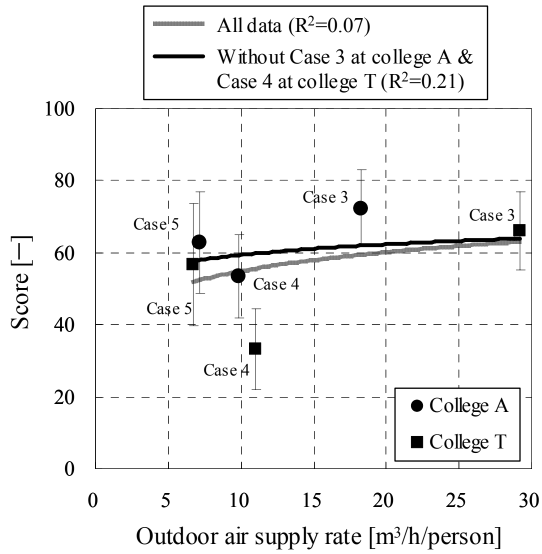
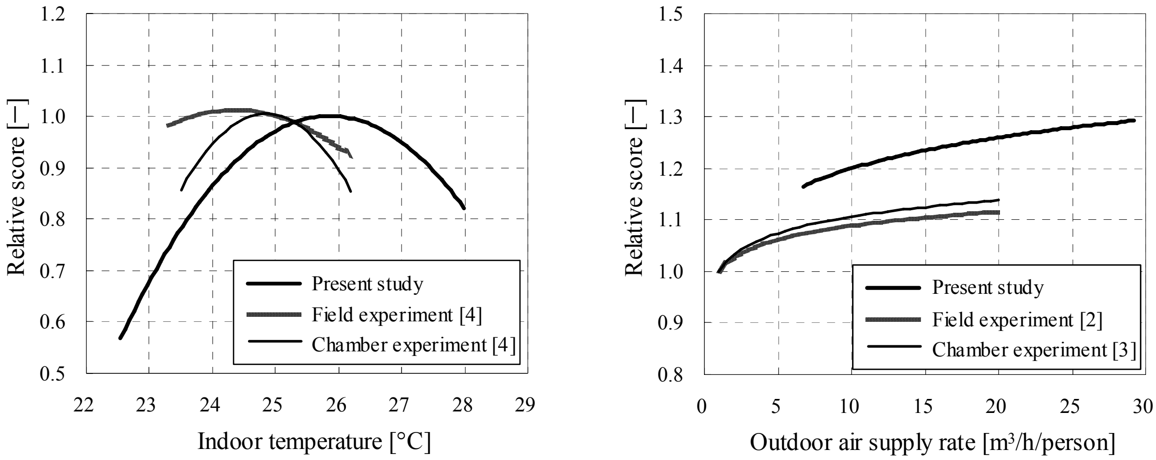


Figure 11 Examination score as a function of outdoor air supply rate

Table 8 Comparisons of percentage of previously known issues (Games-Howell pairwise comparison test)

	College	A	A	A	A	T	T	T	T	T
College	Case	2	3	4	5	1	2	3	4	5
A	1	p<0.01	n.s.	p<0.01	p<0.01	p<1.0E-4	p<1.0E-4	p<0.01	p<1.0E-4	p<1.0E-4
A	2		p<0.001	n.s.	n.s.	n.s.	n.s.	n.s.	p<0.02	n.s.
A	3			p<0.01	p<1.0E-4	p<1.0E-6	p<1.0E-5	p<0.001	p<1.0E-6	p<1.0E-5
A	4				n.s.	n.s.	n.s.	n.s.	p<0.03	n.s.
A	5					n.s.	n.s.	n.s.	p<0.03	n.s.
T	1						n.s.	n.s.	n.s.	n.s.
T	2							n.s.	n.s.	n.s.
T	3								n.s.	n.s.
T	4									n.s.



(a) Indoor temperature (b) Outdoor air supply rate

Figure 12 Comparisons of learning performance with previous experiments of different age groups

CONCLUSIONS

Intervention field experiments were conducted on late-teen subjects according to a procedure with a video lecture and examination. The examination score was found to be improved when PMV was close to zero, or outdoor air supply rate was increased. Based on the comparisons with previous studies, it was considered that the learning performance of young people is more affected by the indoor temperature and outdoor air supply rate than that of older people.

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