Study on the Productivity in Classroom (Part 1)
Field Survey on Effects of Air Quality/Thermal Environment on Learning Performance

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Summary: *Many research papers have been published on the potential effects of indoor environmental quality of in classrooms and offices on productivity. This paper (Part 1) gives an outline of the series of this study and reports the results of field measurements focusing on the effect of the air quality and thermal environments on learning efficiency, with differences in ventilation rate. It also evaluates the consistency between objective and subjective evaluations of learning efficiency.*

Keywords: *Productivity, Learning Performance, Field intervention Survey*

1. Introduction

A series of these studies evaluate the effects of changes in the air quality and thermal environments on learning performance in classroom. These studies involve field intervention surveys in actual classrooms with students, and realistic simulation experiments in climate chamber using student subjects very closely simulating the same conditions as in the actual classroom. In this study, we attempted to evaluate the consistency of the field measurements and climate chamber experiments, which were difficult to compare precisely, using the same learning performance evaluation methods. This paper (Part 1) reports the results of field intervention survay and the next paper (Part 2) report on the results of realistic simulation experiments in climate chamber.

2. Summary of Study on Improving Learning Performance

A series of studies, including (Part 1) and (Part 2), evaluated the effects of the indoor environmental quality on learning performance from various perspectives, using as the subject a college that provides lectures nationwide to prepare students to take certification examinations of 1st class authorized architect. The college provides a uniform teaching environment nationwide by using DVD-based video image lectures. They also conduct standardized examinations (quiz) to measure the level of understanding after each lecture.

Generally, the teaching level of lecturer has a significant effect on learning performance. Since lectures are held in different classrooms and by different lecturers, it is very difficult to compare the effects of the indoor environmental quality on learning performance. The college chosen for this study provides standardized lectures nationwide, using the same DVD-based contents, and checks learning achievements by conducting standardized quizzes (test). This provides a reproducible learning environment and allows cross-environmental evaluation of the field measurements. Also, the use of DVD-based lectures allows the classroom environment used in the field measurements to be precisely replicated in the laboratory.

Based on the above characteristics, we evaluated the effect of the indoor environmental quality on learning performance, using the approaches of field intervention surveys and laboratory experiments. We adopted standardized quizzes used in the actual classroom to evaluate learning performance objectively. This allowed us to use a method standardized for all college buildings and classrooms in evaluating learning performance in the field measurements and to compare learning performance among classrooms with different indoor environments. Use of a standardized method of evaluating learning performance based on standardized quizzes in the field measurements and laboratory experiments allowed us to evaluate the effect of the indoor environment on learning performance from various perspectives.

2.1 Field Intervention Surveys

Before carrying out the field intervention survey on learning performance, the ventilation rate, and background levels of illumination and sound were measured to clarify of the indoor environmental quality, particularly the physical environmental parameters of the classroom to be surveyed. After preliminary measurement of the indoor environmental quality, the learning performance was measured for students in two classrooms with different indoor environments. Since field intervention surveys reflect the subjects' psychology, they have the advantage that the Hawthorne effect does not easily appear. In this paper (Part 1), the results of these field intervention surveys are reported.

2.2 Realistic Simulation Experiments in the Laboratory

Laboratory experiments in the climate chamber were conducted, simulating the classroom environment and lecture system of the college chosen for the field intervention surveys. The details and results of experiments in the laboratory will be reported in the subsequent paper (Part 2).

3. Methods of Field Intervention Surveys on Learning Performance

Field intervention surveys were conducted to evaluate the effect of changes in the air quality and thermal environments on learning performance, using classrooms at the college. Two evaluations methods – an objective evaluation based on quiz scores and a subjective evaluation based on a questionnaire on psychological factors – were used, and their consistency was evaluated as well. Figure 1 shows an appearance of the classroom where the field surveys were being carried out.

Field intervention surveys were carried out from January to April 2005 at the Ikebukuro campus of Nikken Gakuin College in Japan. An Air Handling Units are installed for temperature control in the ceiling of each classroom. Outdoor air is introduced in through the air intakes around the edge of the floor, and is delivered through the hallway into each classroom through the under-cut of the door. Each room has a ventilating fan, which, when operating, creates a negative pressure in the room and introduces outdoor air into the classroom through the hallway. The outdoor air flow rate introduced into each classroom is controlled by turning on or off the ventilating fan in each classroom.

Field intervention surveys were made by changing particularly the ventilation rate, focusing on the effect of indoor air quality (IAQ) on learning performance. The ventilating fan was turned off completely for low ventilation rate and was turned on constantly for high ventilation rate. The subjects of the lectures were roughly divided into two: a Theoretical Subject (in the field of building structure) and Memorization Subjects (in the fields of architectural planning and building construction). Learning performance was evaluated for each of the Theoretical and Memorization Subjects and compared under indoor environments with the case of high and low ventilation rate.

Measurements were made using lectures that were given on the same day and that were of the same duration to take into account the circadian rhythm of the subject students.

Field intervention survey began at 9 AM when the lecture began, according to the normal lecture procedure. After the 180-minute lecture ended (12 noon), the subjects took a 30-minute quiz, and then filled out the self-assessment form (Questionnaire). Three five-minute breaks were provided during the 180-minute lecture.

The trial subjects were students taking a course for the qualifying examination for first-class architects. Those students were highly motivated because nearly all of them were to take a qualifying examination slated for June. The total number of subjects

S= 141.7 m^2 (10.7×13.3m)
h= 2.4 m
ventilating fan; 4 places in classroom
Undercut of door; 4 places in classroom (0.2×0.6m)

Figure 1 Appearance of the Classroom

Table 1 Classroom Environmental Conditions

Vent. Rate (outdoor air)	Lecture contents	Number of Subjects	Temp.&Rh
High (3.5 h^{-1})	Theoretical Subjects	41	24.2(°C),22(%)
Low (0.4 h^{-1})		41	27.1(°C),35(%)
Low (0.4 h^{-1})	Memorization Subjects I	50	27.3(°C),44(%)
High (3.5 h^{-1})		50	25.2(°C),43(%)
High (3.5 h^{-1})	Memorization Subjects II	57	24.5(°C),42(%)
Low (0.4 h^{-1})		57	28.1(°C),63(%)

was about 70, most of whom were workers in their twenties to forties. Since the students need to attend all of the lectures, based on the curriculum provided by the college, the subject groups in individual measurement cases were almost the same. Table 1 shows classroom environmental conditions and measurement cases.

3.1 Measurement of the Physical Environmental Factors in the Classroom

Carbon dioxide concentrations and dust concentrations were monitored continuously during the measurement. A photoacoustic multi-gas monitor (INNOVA) was used to measure the carbon dioxide concentration, and a light- scattering digital dust monitor to measure the dust concentration.

The air change rate, chemical pollutants concentration (VOCs and carbonyl compounds), and fungus concentration (airborne fungi and settling fungi) were measured when students were not present. SF6 was used as a tracer gas for step-down method to measure the air change rate, and a multi-gas monitor was used to measure concentrations. The air conditioner was operated at 25°C during the measurements. VOCs were collected by active sampling on a Tenax TA, and were analyzed by GC/MS after thermal desorption. Carbonyl compounds were collected by active sampling on a SepPak-DNPH, and were analyzed by HPLC after solvent desorption. Settling fungi were collected by passive sampling on a 90-mm sterilized Petri dish with a PDA culture medium placed in the middle of the floor. Airborne fungi were collected by active sampling on the PDA medium. Both settling and airborne fungi were cultured in the incubator at 28°C after sampling. Fungus growth (number of colonies, CFU) on the surface of the PDA medium on the seventh day was monitored.

Air temperature, air velocity, relative humidity and mean radiant temperature were measured during the period of the field intervention survey. Air tempera-

Table 2 Questions of Standardized Quizzes for the Objective Evaluation (in the fields of architectural planning)

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 Self-Assessment Form for the Subjective Evaluation

Question 5; **Air Environment** (Contamination and smell of air)

(1) Are you satisfied with a current air environment? [ ].
1.) Desatisfied 2.) Slightly Desatisfied 3.) Medium 4.) Slightly Satisfied 5.) Satisfied

(2) What influence does today's air environment give to the level of the lecture contents understanding? [ ].
1.) Disimproved 2.) Slightly Disimproved 3.) No Influence 4.) Slightly Improved 5.) Improved

Question 8; **Understanding level** of lecture contents

(5) Convert at the time (in minutes) lost due to factors in various indoor environment in the classroom today.
[ ].min

ture and humidity were continuously measured by a digital temperature/humidity meter, and the mean radiant temperature was continuously measured by a globe thermometer. Air velocity was measured by an anemometer. All data was stored once every minute. For sound and illumination levels, indoor equivalent sound levels were measured with a noise meter, and desktop illumination levels were measured with a digital illuminometer.

3.2 Evaluation of Learning Performance

1) Evaluation of Objective Learning Performance

Objective learning Performance was evaluated according to scores in standardized quizzes to measure the level of understanding of lectures. The purpose of the lectures was to prepare students to take the qualifying examination for first-class authorized architects. Each standardized quizzes consisted of 20 questions, each of which was answered by choosing one out of five options. Table 2 shows questions in a typical standardized quiz. To compare scores in quizzes on different lecture content, a correction was analyzed to the scores based on data on the average scores in the examinations conducted by Nikken Gakuin College in 2004FY, and the difficulty levels of all examinations were standardized.

2) Evaluation of Subjective Learning Performance

In addition to the objective evaluation using quiz scores, a subjective evaluation of learning performance was carried out using a questionnaire as self-assessment form. The items to answer on the form were: (1) the effect of the classroom environment on the level of understanding of the lecture content (5-point scale); (2) time (in minutes) lost due to factors in the indoor environment; (3) factors limiting the understanding of the lecture content (choosing top three out of eight factors: 1. thermal environment; 2. air environment; 3. illumination levels; 4. sound levels; 5. spatial environment; 6. human relationships; 7. lecture content; 8. motivation), and (4) improvement rate (%) in the level of understanding of lecture contents with improvements in the above environmental factors (=1 to 5 in (3)). Table 3 shows part of the self-assessment form for the subjective evaluation.

The significance level was set at 5% and a corresponding t-test was used to compare quiz results with varying environmental conditions. The Wilcoxon matched-pairs signed rank test was used as a corresponding rank scale in comparing the results of self-assessment with varying environmental conditions.

4. Results

4.1 Physical Environment

Figure 2 shows the results of ventilation rate per person. The outdoor air flow rate was 1190 [m^3/h] (= 3.5 at air change rate [h^{-1}]) in the high ventilation case and 136 [m^3/h] (=0.4 [h^{-1}]) in the low ventilation case. Dust concentrations did not change when the ventilation rate was changed. The carbon dioxide concentration became constant at around 1000 [ppm] in the high ventilation case. In the low ventilation case, the indoor CO2 concentration gradually increased due to respiratory CO2 emissions and eventually exceeded 5000 [ppm].

Measurement of VOC concentrations show a formaldehyde concentration of below 10 [μg/m^3] and an acetaldehyde concentration of below 12 [μg/m^3], thus meeting the guideline values for indoor concentrations set by WHO. Airborne and settled fungi levels were 10.0 [cfu/m^3] and 1.6 [cfu/m^2], respectively. Almost no indoor fungi were observed because it was the winter season.

Figure 2 also shows the results of PMV calculations. PMV was calculated based on a metabolic rate of

1.0 [met] and the amount of clothing typical for the classroom of 1.0 [clo], which was determined based on monitoring. PMV was about 0.8 [-] and PPD was about 17 [%] for low ventilation rate case, while they were about -0.1 and about 5[%] for high ventilation rate case.

Since the air-conditioning system in the classrooms was a constant flow rate type, the thermal condition changed with the change in the ventilation rate (outdoor air flow rate), resulting in different thermal environments for high and low ventilation rate case.

The desktop illumination level was 817 [lx], and the equivalent noise level was 46.9 [dB].

4.2 Evaluation of Learning Performance

Figure 3 shows the results of evaluating the objective learning performance based on the standardized quizzes. For the Theoretical Subject in the field of building structure, a significant improvement of 4.7 points ($p<0.03$) resulted with the change in environmental conditions from low to high ventilation. This is a 5.4[%] improvement in learning performance when expressed as a percentage of the score for low ventilation. For Memorization Subject I in the fields of planning and construction, a significant improvement of 6.4 points ($p<0.002$) resulted with the change in environmental conditions from low to high ventilation. This is an 8.7[%] improvement in learning performance. For Memorization Subject II in the field of planning, a significant improvement of 4.6 points ($p<0.0007$) resulted with the change in environmental conditions from low to high ventilation. This is a 5.8[%] improvement in learning performance.

Figure 4(1) shows the results of self-assessment of the “time lost due to the indoor environment.” For the Theoretical Subject, a significant decrease of 6.0 minutes ($p<0.004$) in “time lost due to the indoor environment” resulted with the change in environmental conditions from low to high ventilation. The effective lecture time which was defined to express the change in learning performance as a percentage was calculated by subtracting the “time lost due to the indoor environment” in the self-assessment form from the overall lecture time (180 minutes). The improvement is a 4.0[%] in learning efficiency (converted to time) when expressed as a percentage of the effective lecture time for low ventilation. For Memorization Subject I, a significant decrease of 3.8 minutes ($p<0.04$) in the “time lost due to the indoor environment” resulted with the change in environmental conditions from low to high ventilation. This is a 2.2[%] improvement in the effective lecture time. For Memorization Subject II, a significant decrease of 4.7 minutes ($p<0.02$) in the “time lost” resulted with the change in environmental conditions from low to high ventilation. This is a 2.8[%] improvement in the effective lecture time.

Figure 4(2) shows the results of self-assessment of

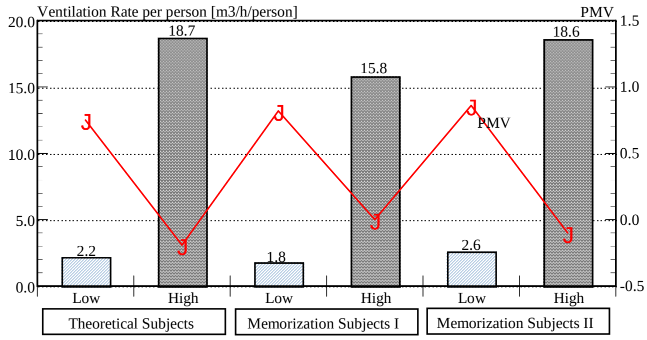


Figure 2 Ventilation rate and PMV

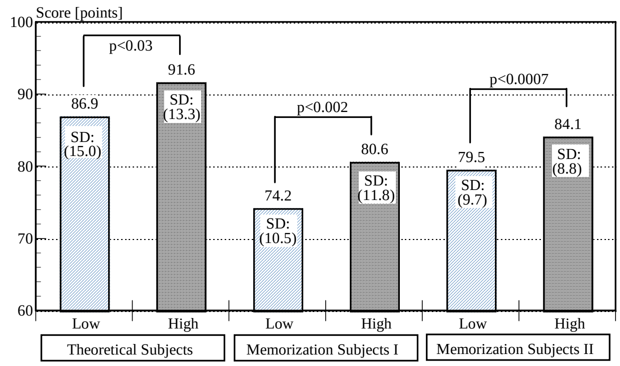
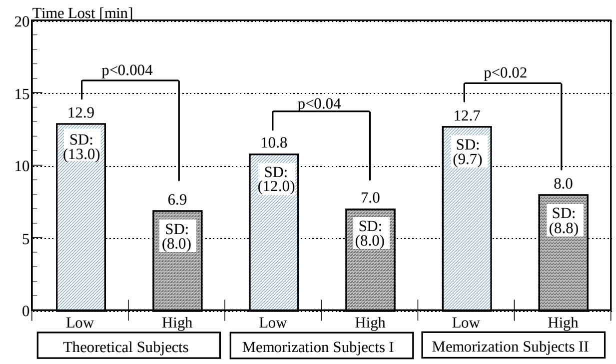
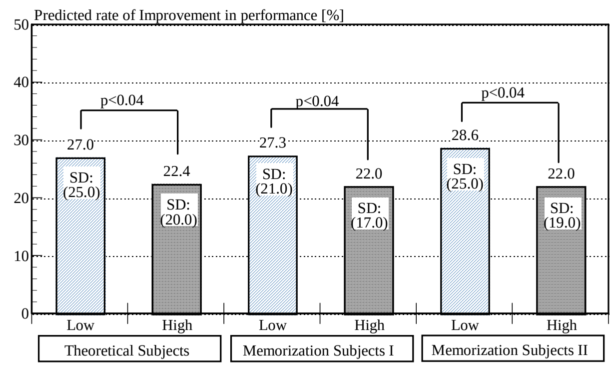


Figure 3 Results of Objective Evaluation



(1) “Time lost due to the indoor environment.”



(2) “Predicted rate of improvement in learning performance with an improvement in the environment.”

Figure 4 Results of Subjective Evaluation

the “predicted rate of improvement in learning performance with an improvement in the environment.” The subjects were requested to report the learning performance improvement rates that they expected if the indoor environment was improved.

In this measurement, for the Theoretical Subject, a significant decrease of 4.6[%] ($p<0.04$) in the expected improvement rate resulted with the change in environmental conditions from low to high ventilation. This means that the learning performance improved by 4.6[%] ($p<0.04$) on changing the environmental conditions. Similarly, for Memorization Subject I, a significant decrease of 5.3[%]($p<0.04$) in the expected improvement rate resulted with the change in environmental conditions from low to high ventilation. In other words, the learning efficiency increased by 5.3[%] ($p<0.04$). For Memorization Subject II, a significant decrease of 6.6[%] ($p<0.04$) in the expected improvement rate resulted with the change in environmental conditions from low to high ventilation. In other words, the learning efficiency improved by 6.6[%] ($p<0.04$).
Table 4 shows the results of a self-assessment of the percentage of dissatisfied of indoor environment. For the Theoretical Subject and Memorization Subject II, a significant improvement in the percentage of dissatisfied of thermal environment resulted with the change in environmental conditions from low to high ventilation.

4.3 Evaluation of Consistency between the Objective and Subjective Evaluation of Learning Performance

Figure 5 shows learning performance improvement rates [%] (from low to high ventilation rate) for the quiz-based objective evaluation and self- assessment form-based subjective evaluation for the Theoretical Subject and Memorization Subjects I and II. The measurements show that the subjective evaluation tends to underestimate the learning performance compared to the objective evaluation. A comparison between the evaluation based on the “expected improvement rate” and the evaluation based on the “effective lecture time” shows that the evaluation based on the expected improvement rate agrees more closely with the objective evaluation.

5. Evaluation of the Learning Performance by Score

The subjects were put into two groups: a higher score group and a lower score group to analyze the effect of air and thermal conditions and motivation on learning performance. Subjects in the higher score and lower score groups were defined as those with above-average and below-average scores in the quiz for low ventilation case, respectively.
Figure 6(1) shows the results for the objective learning performance (based on the standardized quiz) by score for Theoretical Subject. For the higher score group, no significant difference in the quiz results was identified with changes in the environmental conditions. For the lower score group, a significant improvement of 11.2 points (17.9[%]) resulted with a change in the air environment from low to high ventilation ($p<0.009$).

Table 4 Percentage of Dissatisfied

	Air env. Dissatisfied [%]		Thermal env. Dissatisfied [%]	
Ventilation	Low	High	Low	High
Theoretical Subjects	7.9%	11.3%	50.0%	29.6%
	n.s.		p<0.003	
Memorization Subjects I	18.1%	8.0%	44.6%	33.0%
	n.s.		n.s.	
Memorization Subjects II	11.3%	9.3%	59.7%	34.9%
	n.s.		p<0.0005	

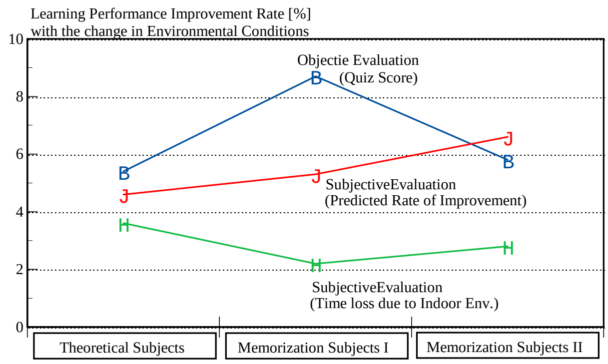
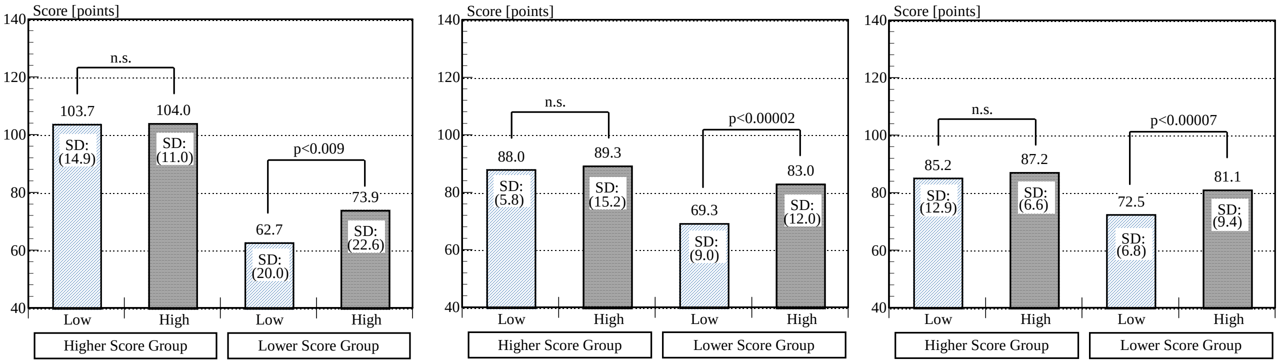


Figure 5 Learning performance improvement rates [%]

Figure 6(2) shows the results for the objective learning efficiency (based on the standardized examination) by score for Memorization Subject I. For the higher score group, no significant difference in the experimental results was identified with changes in the environmental conditions. For the lower score group, a significant improvement of 13.7 points (19.8[%]) resulted with a change in the air environment from low to high ventilation ($p<0.00002$).
Figure 6(3) shows the results for the objective learning efficiency (based on the standardized examination) by score for Memorization Subject II. For the higher score group, no significant difference in the experimental results was identified with changes in the environmental conditions. For the lower score group, a significant improvement of 8.6 points (12.9[%]) resulted with a change in the air environment from low to high ventilation ($p<0.00007$).
As shown above, no significant difference in learning efficiency was identified between the set environments for the higher score group for any of the Theoretical Subject, Memorization Subject I or Memorization Subject II, and the learning efficiency improved significantly with the change in the air environment, i.e., an increase in ventilation, for the lower score group ($p<0.009$). Thus, the lower score group was more susceptible to changes in the indoor environment.

6. Discussion

Figure 7 shows the relationship between the results of objective evaluation (quiz score) and the air environmental factors. In this section, statistical analyses were carried out for the data of Memoriza-



(1) Theoretical Subject (2) Memorization Subject I (3) Memorization Subject II

Figure 6 Results for the objective learning performance by Score group

tion Subjects. The logarithmic relationship was observed between quiz score of objective evaluation and ventilation rate per person [m^3/h/person]. The linear relation was observed between quiz score of objective evaluation and percentage of dissatisfied of air environment of subjective evaluation.

7. Conclusions and Implications

(1) The change in environmental conditions from low to high ventilation significantly improved the objective learning efficiency by 4.7 points (5.4[%]) for the Theoretical Subject ($p<0.03$), by 6.4 points (8.7[%]) for Memorization Subject I ($p<0.002$), and by 4.6 points (5.8[%]) for Memorization Subject II ($p<0.0007$).

(2) The change in environmental conditions from low to high ventilation significantly improved the subjective learning efficiency.

(3) The subjectively reported “effective lecture time” significantly improved by 6.8 minutes (4.0%) for the Theoretical Subject ($p<0.004$), by 3.8 minutes (2.2[%]) for Memorization Subject I ($p<0.04$), and by 4.7 minutes (2.8[%]) for Memorization Subject II ($p<0.002$).

(4) The subjectively reported “expected improvement rate” improved by 4.6[%] for the Theoretical Subject ($p<0.01$), by 5.3% for Memorization Subject I ($p<0.05$), and by 6.6% for Memorization Subject II ($p<0.04$).

Notes

Pre-screening was conducted on the following factors that were expected to have a significant effect on learning performance, using self-assessment form data: (1) physical condition [%], (2) previous learning experience [%], and (3) level of interest in lecture (five-point scale). Only highly reliable subject data was selected. In the screening process, subject data that was not available for the environmental comparison between Theoretical Subject and Memorization Subjects I and II was also discarded.

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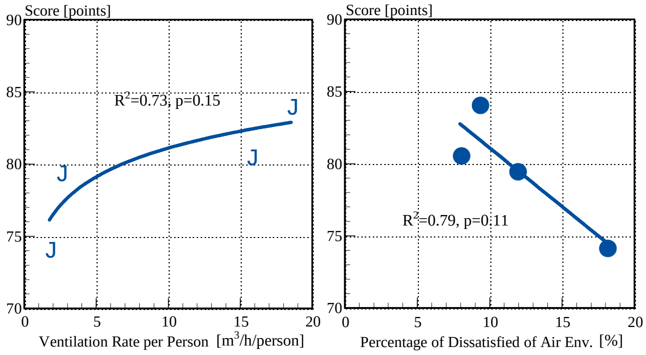

(1) Quiz score vs Vent. rate (2) Quiz score vs Dissatisfied

Figure 7 Objective Evaluation vs Air Environment