Field Survey on the Indoor Environment of Elementary Schools for Planning of Environment Friendly School Facilities

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Abstract

The purpose of this study is to suggest a direction by which to develop environment-friendly school facilities. To achieve this, field measurements were conducted to evaluate indoor environmental conditions such as thermal, visual and indoor air quality in 15 schools. Additionally, environmental elements were also investigated and analyzed through teachers' questionnaires. According to the results of measurements, the thermal condition, minimum illuminance, CO, TBC and formaldehyde were satisfactory in most of the classrooms. However, CO_2, PM_{10} and TVOCs exceeded the standards. As it was found that the indoor classroom environment significantly influences the academic achievement of students, a plan should be made for indoor noise isolation, comfortable thermal environment maintenance, and uniform light distribution. The environment-friendly architectural design elements applicable to school facilities were found to be: environmental studio, vegetable gardening, school forest, and landscape architecture elements, in this order.

Keywords: school facilities; environmental friendly school; indoor environment condition; indoor air quality; thermal condition; environmental education; environment friendly design element; academic achievement

1. Introduction

School facilities have an important impact on students and their development since such facilities influence their environmental value system. School facilities provide not only a physical environment but also social environment that is a functional and complicated space where students, teachers, parents, education curriculum, local community, and other ecological factors interact (Hu *et al.* 2004). Since students who have a weak resistance to external stimuli spend a great number of hours in school, it is necessary to pay attention to maintaining a pleasant indoor environment in school facilities (Axelrad R. 2006). In the classroom, however, there are various teaching materials and audiovisual tools such as computers, projection televisions as well as air conditioning and heating systems that interact with synthetic resin products used for interiors. As a result, classrooms where physically weak students spend most of their time have become spaces with complex threat factors that include volatile organic compounds, common dust, noise, and poor lighting. In particular, such factors influence children's health, causing multiple chemical sensitivities, atopy and sick house syndrome among children. Therefore, it is urgent to take measures against these rising problems (Bearer C.F. 1995 and Tranter D. 2005).

The environment of school buildings has an influence on the health and well-being of students, their academic achievement and their behavior. It also has an important influence on teachers who spend a lot of time in school buildings (Daniel G. *et al.* 2005 and Curtis, P. 2002). In order to maximize the academic performance of students, the US has presented some guidelines to maintain an appropriate indoor air environment, to restrict the use of building materials, teaching tools and facility systems that may cause problems in indoor air quality, and to install equipment that can monitor the quality of the indoor air environment (Rod R. 2006, Deane E. 2005 and Don U. *et al.* 2000).

In addition, school facilities should be built in a way to help implement various education methods and contents efficiently, safely and pleasantly. In particular, school is very important since it is the place where environmental education is provided, thus influencing students' environmental value system. Currently, the environmental education in Korea centers on learning by using audiovisual materials, environmental education classes on campus, natural environment camps, and touring of environment-based facilities. In general, environmental education takes place in natural

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environments such as forests, oceans or rivers or by utilizing facilities such as waste or purification plants. Since these facilities are far from schools, it is not easy to visit them (Oh H.W. 2007). For more systematic and continuous environmental education, learning places should ideally be located near to schools. Thus, environmental education centered around the school (Environment protection authority, 1996).

Therefore, the purpose of this study is to suggest a planning direction for environment-friendly school facilities by conducting a field survey in elementary schools in order to evaluate the environmental performance of school facilities.

To this end, eco-friendly school facilities will be examined and a survey of their occupants will be conducted to collect data on the environmental impact on student performance.

2. Discussion on Environment-Friendly School Facilities

The environment-friendly school is synonymous with various terms such as eco-school, sustainable school, green school, and energy smart school.

Kim *et al.* (1999) had a two-way approach to the "environment-friendly school" the environmental and ecological aspect and the educational aspect. They stated that the environmental and ecological aspect included creating a school environment that coexisted with nature, energy and resource saving, and recycling while the educational aspect included creating a pleasant environment for study and creating a school environment as a resource for environmental education. Jo (2008) defined the "zero energy eco school" as the school facility of the future that applies the existing energy-saving technology, suitable for the regional characteristics and conditions of the school, to school facilities and realizes 100% energy independence and ecological area rate by using alternative energy. Energy smart school means a school facility in which students and teachers occupy a healthier building and save energy consumed by the building. Its intention is to help children acquire knowledge concerning energy and life style by using the energy-saving technique (DOE, 2003). The Education Department of Japan (1996) defined eco-schools as school facilities which are healthy thanks to environment-friendly design and construction, and can be used intelligently, and as a tool for environmental education.

Many countries have implemented assessment programs for environment-friendly buildings to expand construction of eco-friendly schools. In consideration of the characteristics of school facilities, European countries and the US suggest physical environment standards that can be reflected in the design stage. They also have guidelines for the maintenance of buildings after completion of construction. In addition, they emphasize the ripple effect that school education can have on environmental education through close connection between school facilities and curriculum. The well-known programs include the BREEAM for schools in the UK, the Eco-School program by the Foundation for Environmental Education (FEE) in Europe, the Green School program and Energy Smart School in the US, and the Eco-School program in cooperation between the Ministry of Education, Science and Culture and the Ministry of International Trade and Industry in Japan (Table 1.).

3. Methodology

In this study, measurements of the indoor environment by season were made in 15 schools located in Seoul and its surroundings with a view to creating a pleasant educational environment. Measurements in the winter season were conducted from November 2006 to February 2007 while measurements in the intermediate season were made from April to May 2007. Measurements were also made in two classrooms of the schools: general classroom and special classroom (science lab).

In this survey, as shown in Table 2., the measurements were taken for 11 variables based on the six characteristics such as temperature and humidity regulated in the School Health Act and the seven items regulated in the Indoor Air Quality Control in Public Use Facilities, etc. Act by the Ministry of Environment. Table 3. shows the standards for the measurement (Ministry of Education, Science and Technology, 2001 and Ministry of Environment, 2008).

Since the measurement methods were not regulated in the School Health Act, the measurements of temperature, humidity and illuminance were determined based on the process test method for the public use facilities sanitation standard by the Ministry of Health and Welfare while the measurement method of CO, CO_2, particulate matter (PM_{10}), total bioaerosol colonies, HCHO and TVOC was determined based on the indoor air quality process test method by the Ministry of Environment.

Table 1. Category and Features of Programs of School Facilities Certification and Assessment

Program	Site planning, transport	Energy, Environmental load	Ecology	Indoor Environment	Maintenance, Training	Eco-education
KGBCC (Korea)	○	○	○	○	△	×
BREEAM (UK)	○	○	○	○	○	◎
FEE (EU)	○	○	○	○	○	◎
Eco-School (Japan)	○	○	○	○	×	×
Green School (U.S.A)	○	○	○	○	△	◎

◎ Complete Adoption, ○ Adoption, △ Partial Adoption, × Non Adaption

Table 2. Measurement Items

The Code	Measurement Item
School Health Code (the Ministry of Education)	Temperature, Humidity, Ventilation rate, Daylight factor, Illuminance, Carbon dioxide,
Indoor Air Quality Code for Crowded Facilities (the Ministry of Environment)	Ventilation rate, Carbon monoxide/ dioxide, PM_{10}, Total Bioaerosol Colonies, Formaldehyde, Total Volatile Organic Compounds

Table 3. Standard of Measurement Items

Measurement Item	Standard
Temperature	18~28ºC
Humidity	30~80%
Ventilation rate	$21.6m^3$/h·person
Daylight factor	Above average 5%
Illumination	300lux
CO_2	1,000ppm
CO	10ppm
PM_{10},	$100\mu g/m^3$
TBC	800CFU/ m^3
HCHO	$100\mu g$ / m^3
TVOCs	$400\mu g$ / m^3

4. Result

4.1 Temperature and Humidity

The average temperature of the general classroom was 18~20ºC while that of the special classroom was 17~19ºC. At that time, the humidity was 40~45%. The temperature of the special classroom was lower by 1ºC than that of the general classroom because the special classroom was not used continuously so that its internal heat generated due to occupants was low. The humidity was satisfactory in most of the classrooms (Tables 4.~5.).

Table 4. Temperature Result of Classrooms (unit: ºC)

Season	Room	AVG	Median	Max.	Min.	STDEV
Winter	GC	18.9	19.0	24.5	14.7	3.3
	SC	17.0	17.0	21.4	13.8	2.2
Spring	GC	20.2	20.5	24.6	16.5	2.3
	SC	19.3	18.0	36.0	14.7	5.2

Table 5. Humidity Result of Classrooms (unit: %)

Season	Room	AVG	Median	Max.	Min.	STDEV
Winter	GC	44.4	46.0	55.0	31.0	6.7
	SC	40.0	38.0	61.0	25.0	9.0
Spring	GC	44.7	45.0	61.0	16.0	10.6
	SC	45.3	43.0	72.0	33.0	10.3

4.2 Daylight

Table 6. shows the daylight factors of the general classroom and the special classroom. The School Health Act regulates that the daylight factor should be higher than 5% on average and not less than 2%. According to the results of the measurement of the natural daylight factor, the schools that met the standard had a daylight factor of 13% for the general classroom and 20% for the special classroom in the winter season and 40% for the general classroom and 20% for the special classroom in the intermediate season. However, most of the schools had less than the minimum daylight factor of 2%. The ratio of the maximum illuminance to the minimum illuminance was more than 25:1, which indicates that occupants experience some visual discomfort (Fig.1.). The average illuminance (artificial lighting) was found to meet the standard of 300 Lux in all of the classrooms (Table 7.). However, the ratio of the maximum illuminance to the minimum illuminance was found to exceed the standard of 10:1.

As a result, it was found that the artificial lighting and the natural light caused visual discomfort. Therefore, a design plan concerning uniform illuminance distribution is required when making a plan for environment-friendly school facilities.

Table 6. Average of Daylight Factor (unit: %)

Season	Room	AVG	Median	Max.	Min.	STDEV
Winter	GC	3.1	2.6	8.5	0.5	2.4
	SC	3.0	2.2	6.3	0.2	2.2
Spring	GC	4.5	2.9	19.0	0.2	4.8
	SC	3.6	3.6	12.2	0.1	3.4

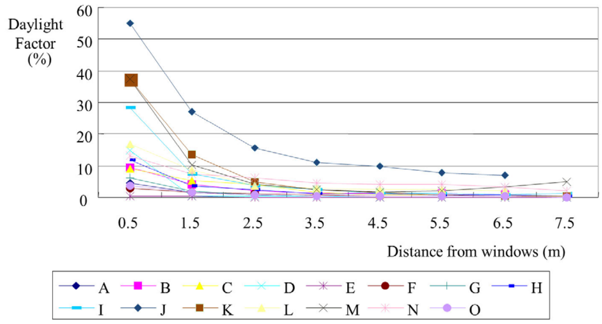

Fig.1. Daylight Factor of General Classrooms (Spring)

Table 7. Average of Illumination (unit: Lux)

Season	Room	AVG	Median	Max.	Min.	STDEV
Winter	GC	995	748	3,596	47	956
	SC	748	574	2,679	21	733
Spring	GC	740	687	1,245	390	288
	SC	892	570	3,837	63	979

4.3 Indoor Air Quality

Table 8. and Table 9. show the results of the measurement of indoor air quality concerning carbon dioxide, carbon monoxide, total bioaerosol colonies, particulate matter, formaldehyde, and volatile organic compounds.

The carbon dioxide concentration in the general classroom exceeded the standards both in the intermediate season and the winter season. The minimum value was measured at 1,040ppm while the maximum value was 3,254ppm. Particularly, in the winter season, the carbon dioxide concentration was high because the classrooms were not ventilated well. As the special classrooms were not frequently used by students, only 20% of them exceeded the standard of 1,000ppm in the winter and intermediate seasons. The carbon monoxide concentration did not surpass the standard in both of the seasons.

In regard to total bioaerosol colonies, 87% of the schools satisfied the standards in the winter and intermediate seasons. Measurements in the general

Table 8. The Result of Winter Season

	Item	AVG	Median	Max.	Min.	STDEV
GC	CO_2 (ppm)	2,083	2,139	3,254	1,040	793
	CO (ppm)	0	0	0	0	0
	TBC (CFU/m^3)	201.0	221.4	507.7	21.2	163.7
	PM_{10} (μg/m^3)	197.5	180.6	423.6	62.5	107.9
	HCHO (μg/m^3)	26.8	24.3	59.1	11.5	13.1
	TVOC (μg/m^3)	418.7	355.3	1,177.3	179.5	267.9
SC	CO_2 (ppm)	1,060	869	1,873	646	413
	CO (ppm)	0.7	0	7.2	0	2.3
	TBC (CFU/m^3)	101.2	47.4	269.1	4.7	95.1
	HCHO (μg/m^3)	28.0	26.2	56.5	6.8	13.2
	TVOC (μg/m^3)	267.9	248.4	437.3	134.2	103.3

Table 9. The Result of Spring Season

	Item	AVG	Median	Max.	Min.	STDEV
GC	CO_2 (ppm)	1798	1755	3081	831	552
	CO (ppm)	0.1	0.0	0.6	0.0	0.2
	TBC (CFU/m^3)	166.4	33.1	1,570.2	0.0	456.8
	PM_{10} (μg/m^3)	113.3	129.6	236.9	18.5	73.8
	HCHO (μg/m^3)	45.7	41.0	157.2	16.0	34.9
	TVOC (μg/m^3)	600.3	478.7	1,759.1	201.3	412.9
SC	CO_2 (ppm)	1,188	1,755	3,081	476	715
	CO (ppm)	0.3	0.0	1.1	0.0	0.4
	TBC (CFU/m^3)	35.3	11.8	307.9	0.0	94.1
	HCHO (μg/m^3)	37.6	41.0	78.2	16.3	21.2
	TVOC (μg/m^3)	272.3	216.3	673.7	116.8	148.6

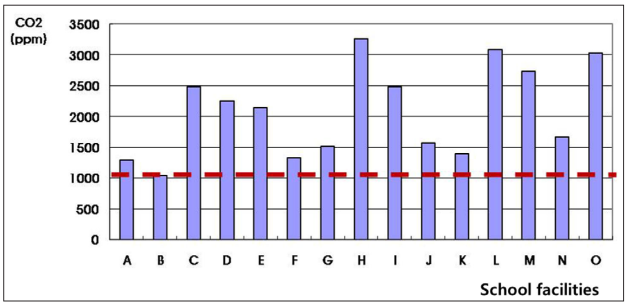

Fig.2. Carbon Dioxide Result of General Classrooms (Winter)

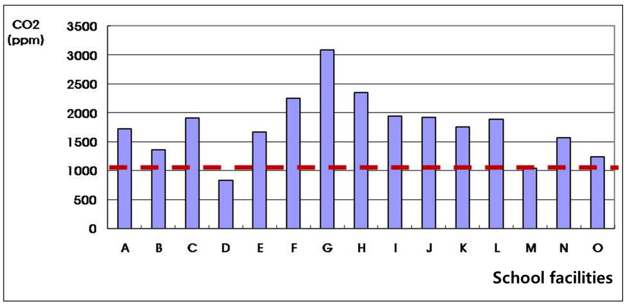

Fig.3. Carbon Dioxide Result of General Classrooms (Spring)

classrooms showed that the values were higher in the winter season. This is probably because the classrooms are kept closed for a longer time with less time for ventilation leading to increased temperature and humidity due to heating resulting in bacteria propagation. In addition, the results of measurements in the special classrooms showed that the concentration of total bioaerosol colonies was lower by half than that in the general classrooms since the temperature, humidity and time of occupants' staying in the special classrooms were lower compared with the general

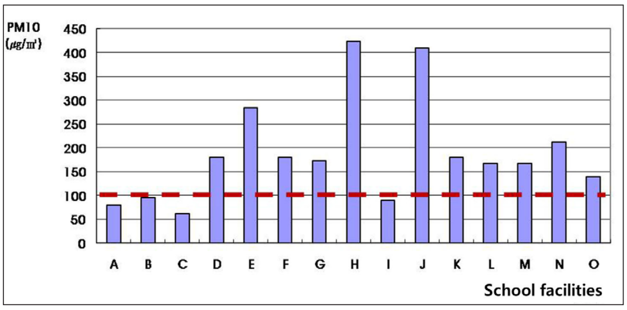

Fig.4. PM_{10} Result of General Classrooms (Winter)

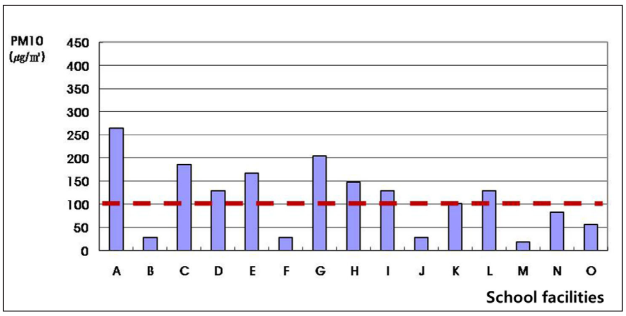

Fig.5. PM_{10} Result of General Classrooms (Spring)

classrooms.

In regard to particulate matter, the maintenance standard (100μg/m^3) was exceeded by 73% of the classrooms in the winter season and 67% of the classrooms in the intermediate season. In particular, the high value in the winter season seems to be attributable to insufficient ventilation.

In regard to HCHO, most of the schools were found to satisfy the maintenance standard. However, in terms of TVOCs concentration, it was found that the standard was surpassed by 40% of the schools where measurements were conducted in the winter season and 60% of the schools in the intermediate season. This means that pollutants have flowed in and emitted continuously due to remodeling of the school buildings such as floor replacement, painting and furniture replacement, even though a considerable time has passed since the completion of school building construction. In addition, the high number of schools that exceeded the standard in the intermediate season seems to be attributable to the fact that as the temperature of a structure itself increased, the emission of pollutants increased in intensity, which led to the increase in the TVOCs concentration. Consequently, continued ventilation is required for reduction of pollutants in the classroom.

4.4 Airtightness

When the pressure difference was 1Pa between the indoors and the outdoors, the ventilation rate was measured at 3.6ACH on average while the infiltration amount was 659.7m^3/h. The ventilation rate by each school was 0.12~5.23ACH, showing a significant difference among the schools according to the year of construction and construction status. The School Health Act regulates that the ventilation rate per a person

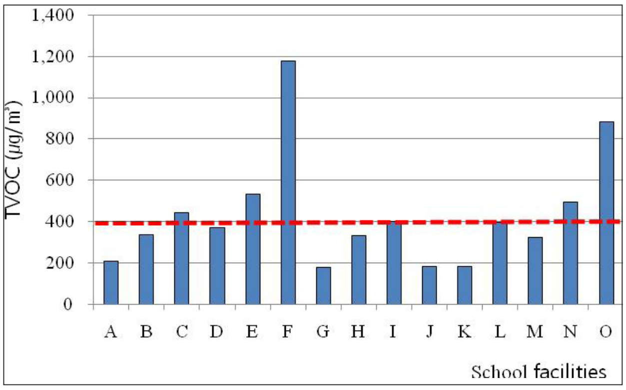

Fig.6. TVOCs Result of General Classrooms (Winter)

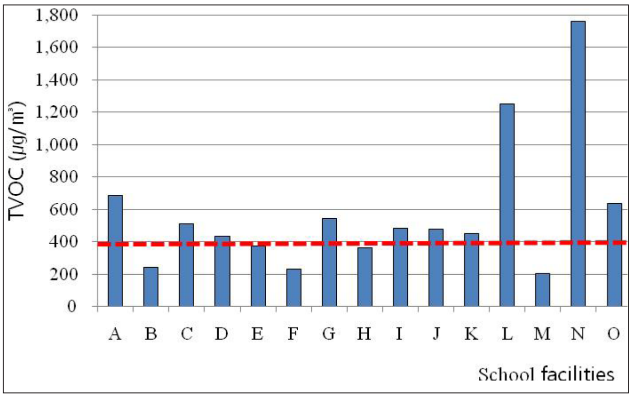

Fig.7. TVOCs Result of General Classrooms (Spring)

should be 21.6m^3/h. Therefore, school buildings should satisfy the ventilation rate of 777.6m^3/h or higher if it is assumed that one class consists of approximately 35 students along with a teacher (36 persons in total). If a classroom is not well-ventilated, it may cause problems related to CO_2 concentration, odor, and others. As a result, schools that fail to meet the standard should devise additional measures to maximize ventilation in addition to natural ventilation.

4.5 Questionnaires on Indoor Environment

(1) Classroom Amenity

The survey on indoor classroom amenity was conducted based on the 5-point Likert scale. Table 11. shows the satisfaction concerning indoor environment factors with the results of calculation of the average scores for each survey item when 5 points means

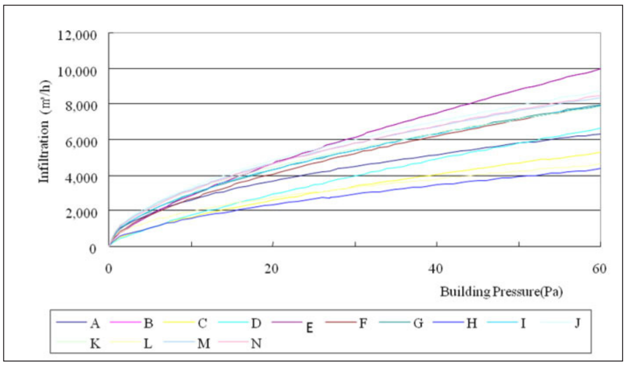

Fig.8. Airtightness Evaluation

Table 10. Result of Infiltration and Air Change Rate

School	Infiltration (m^3/h)	Air Change Rate (ACH)
A	837.4	5.01
B	21.3	0.12
C	372.6	2.02
D	311.5	2.26
E	574.6	2.98
F	661.1	3.99
G	798.3	4.60
H	430.9	2.30
I	834.9	4.53
J	957.0	4.96
K	952.6	4.63
L	658.0	3.12
M	944.4	4.99
N	881.4	5.23
O	N/A	N/A

Table 11. Satisfaction and Correlation of Indoor Environment

Elements	Satis-faction	A	B	C	D	E	F
A. Indoor Environment	2.9	1	.678	.641	.700	.393	.360
B. Thermal Comfort (Summer)	2.3		1	.879	.636	.441	.404
C. Thermal Comfort (Winter)	2.3			1	.629	.424	.365
D. Air Quality	2.8				1	.422	.303
E. Daylight	3.0					1	.136
F. Indoor Acoustics	2.5						1

"very pleasant." The correlation between variables is expressed in the Pearson Correlation Coefficient.

The overall satisfaction concerning the indoor environment of a classroom was calculated at 2.9 points on average. All of the environmental factors excluding the luminous environment were evaluated to be below the average, which means that they are not pleasant. In addition, the analysis showed that satisfaction with each environmental factor had a high correlation with "satisfaction concerning air environment (.700)," "satisfaction concerning thermal environment in the summer (.678)," and "satisfaction concerning thermal environment in the winter (.641)." In other words, it can be said that the amenity of the indoor environment of a classroom on the part of occupants is affected mainly by the air and thermal environments.

Fig.9. shows the results of analysis of multiple answers concerning the reason why the indoor environment of a classroom was not pleasant. In this case, the major issues with the indoor environment

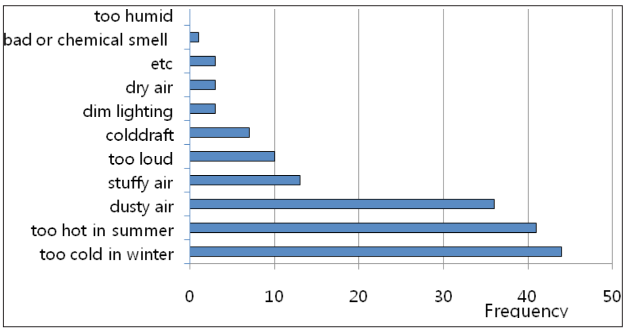

Fig.9. The Reason Why a Classroom is Uncomfortable

were found to be indoor temperature in the winter season, indoor temperature in the summer season and dust generation in this order. As a result, it will be necessary to make a plan for the thermal and air environments in order to ensure a pleasant classroom environment.

(2) Classroom Environment and Academic Achievement

On the question of how much indoor environment factors influence the academic achievement of students, 38% of the teachers answered "very important" (Fig.10.) with the importance of 4.4 on average out of 5 points. In particular, the factors that affected academic achievement the most among the indoor environment factors were noise, temperature, air quality, illuminance, and humidity in this order as shown in Fig.11. These results seem to be attributable to the fact that the luminous environment and the thermal environment were improved significantly thanks to the project for school facilities improvement, but the 7th curriculum, representative of the open education, was implemented with relatively insufficient measures for noise control.

As shown in the survey results concerning satisfaction with the indoor environment of classrooms, the satisfaction with the thermal environment was the lowest among the indoor environment factors and had a great influence on academic achievement. However, most of the school facilities were built without consideration of the air-conditioning and heating systems because the schools have vacations during the fierce cold and hot seasons. Even when the air-conditioning and heating systems are updated, it is only done for some part of the special classroom and

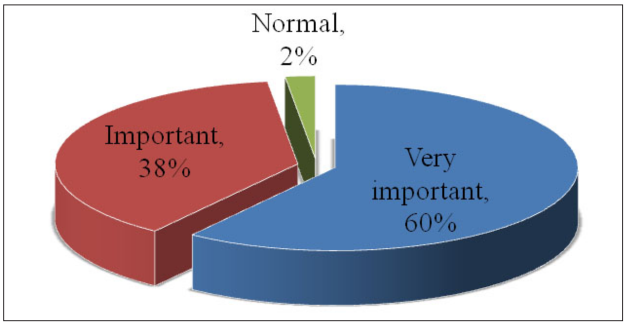

Fig.10. Relation between Indoor Environment and Academic Achievement of Students

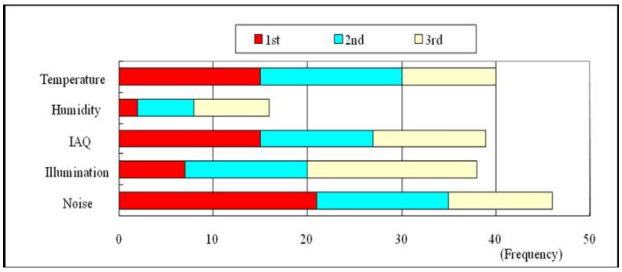

Fig.11. Priority Order of the Factors that Affected Academic Achievement Significantly among the Indoor Environment Factors

the teacher's room. In addition, as education methods are diversified, multimedia devices and microphones are increasingly used for teaching purposes. However, no measures are taken for soundproofing between adjacent classrooms.

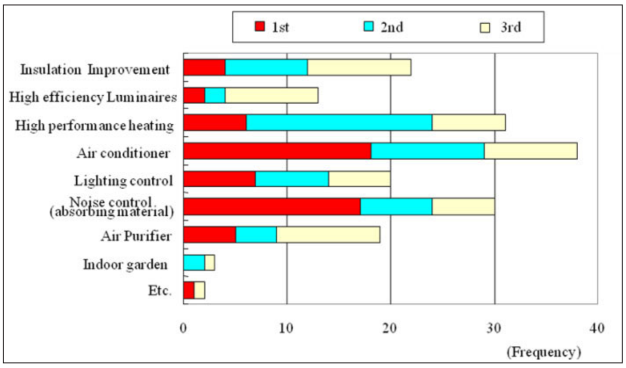

Fig.12. Priority Order of the Factors Required for Improvement of Indoor Environment and Academic Achievement

Fig.12. shows the results of multiple answers concerning the three items according to the priority order of the factors that are required for improvement of the indoor environment and academic achievement. In this case, the most important factors for improvement of the indoor environment and academic achievement included air conditioner, heater and noise control. Particularly, the demand for noise control was found to take first priority.

5. Survey on Environment-Friendly School Facilities

The survey was conducted among 200 teachers in 50 elementary schools to examine whether or not environment-friendly facilities available for environmental education are installed and utilized.

According to the results of examining the possibility of utilizing a nature-friendly design space developed in school, the environmental studio showed the highest rate of 52.2% along with the vegetable garden (33.7%), school forest, and landscape architecture elements (42%) in this order.

Fig.13. shows the results of frequency analysis for environment-friendly design elements installed in schools based on multiple answers from the survey.

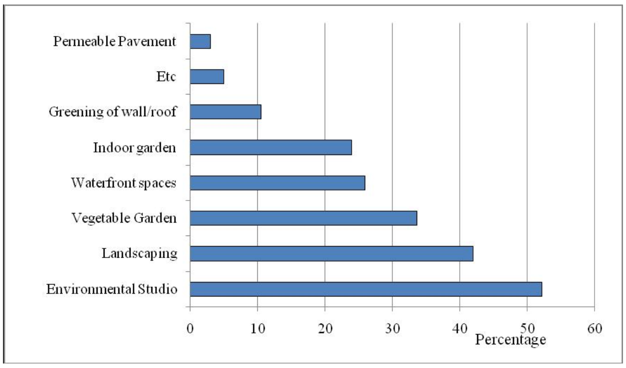

Fig.13. Environmental-Friendly Element Developed in Schools

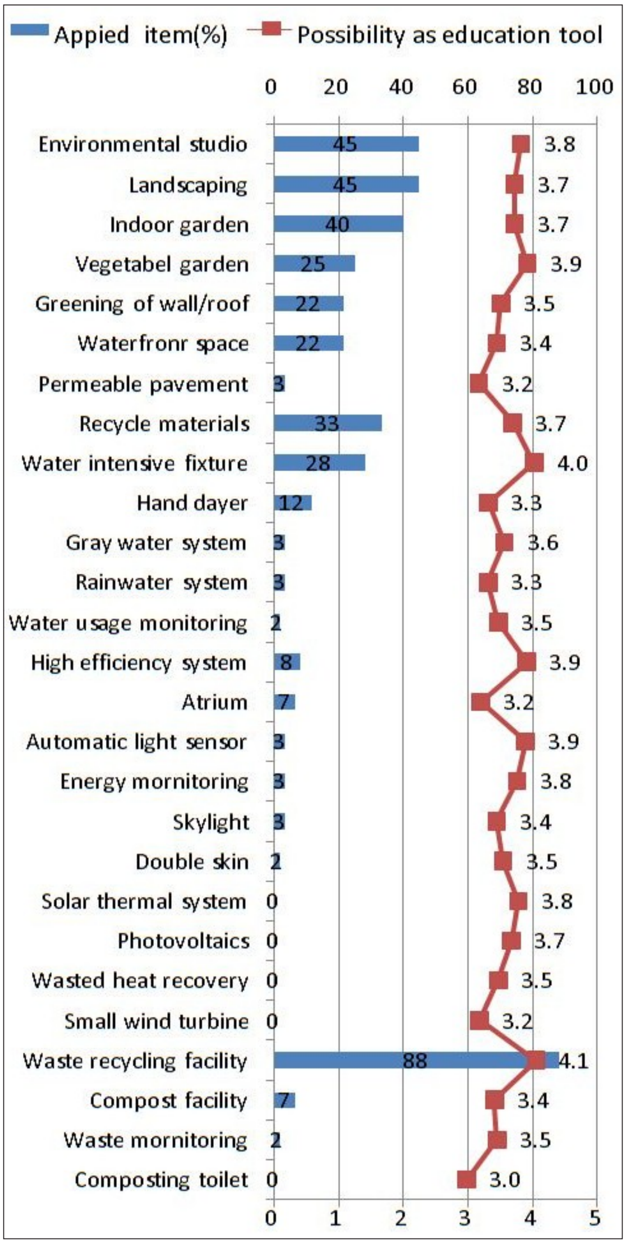

Fig.14. Applied Environment-Friendly Design Elements and Possibility of Utilizing Them as Education Tools

The figure also shows the average values after examining the possibility of utilizing the environment-friendly design elements as tools for environmental education based on the 5-point Likert scale. The design elements were classified by major environment issues: environmental-friendly element, material and resource saving element, energy saving-related element, and waste disposal-related element. The facilities that were expected to show the highest utilization were found to be waste recycling facilities, water saving devices, outdoor natural learning centers, high efficiency equipment, and automatic light sensors. As a result, planning is required to ensure that environmental education is linked to plans for an environment-friendly school.

Fig.15. shows the advantages that can be obtained when environment-friendly architectural planning elements are utilized for environmental education. As shown in the figure, the highest advantage was that practical education could be implemented in daily life.

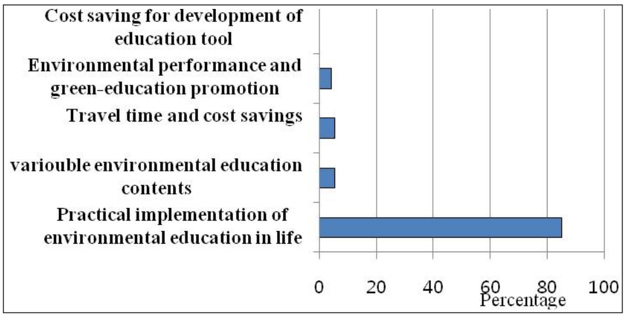

Fig.15. Advantage of Environmental Education by Utilizing the Architectural Elements of Schools

6. Conclusion

The purpose of this study was to suggest a direction in developing a model of education facilities for environment-friendly schools. The aim of this paper is to suggest a direction for improving the indoor environment and its effect on education by utilizing eco-friendly design elements when planning the construction of school buildings, and at the same time a direction for using environment-friendly facilities as effective tools for environmental education.

To achieve this, field measurements were conducted to evaluate indoor environmental conditions such as thermal, visual and indoor air quality in 15 schools and a survey on environment friendly school facilities was conducted in 50 schools. According to the results of measurements, thermal condition, minimum illuminance, CO, TBC and formaldehyde were satisfactory in most of the classrooms. However, CO_2, PM_{10} and TVOCs exceeded the standards. The main reason is insufficient ventilation because the classrooms are ventilated based on the subjects' own judgment even though classrooms have a high potential concerning natural ventilation. Especially, TBC, PM_{10} and TVOCs are wide variations this is due to types of finishing materials, maintenance condition and so on.

As it was found that the indoor environment of a classroom influences the academic achievement of students significantly, it is necessary to conduct an analysis of indoor environmental performance in order to design an eco-friendly and pleasant classroom environment. To plan an environmental friendly school facility, reference should be made to the following recommendations.

Visual amenity should be improved by planning for uniform light distribution to make full use of natural lighting. In addition, energy-saving facilities should be installed and utilized as education tools. Furthermore, in order to maintain a healthy indoor environment, environment-friendly materials should be used for construction to reduce the concentration of indoor air pollutants such as formaldehyde and volatile organic compounds. Also, a plan should be made to maintain good indoor air quality based on the ventilation plan specific to each classroom.

The impact factors in relation to classroom environment factors and academic achievement turned out to be noise, temperature, air quality, illuminance, and humidity in this order. The factors requiring the greatest improvement regarding the education environment and academic achievement were suggested to be the installation of air-conditioning and heating systems, and noise control and insulation improvement.

The environment-friendly architectural design elements applicable to school facilities were found to be environmental studio, vegetable garden, school forest, and landscape architecture elements in this order. The factors that had high potential for utilization as models for environmental education turned out to be waste recycling facilities, water saving devices, fields attached to the school, and farms for hands-on experience, high efficiency equipment, and automatic light sensors. In particular, the energy saving factor was highly evaluated as it had the possibility of being utilized as a model for environmental education.

The results of this study are expected to be used as basic materials for improving academic achievement and creating a pleasant indoor environment when planning to construct environment-friendly school facilities. In addition, it is expected that the study results will be used very frequently as a basic study for standardizing environment-friendly school facilities to implement environmental education by using school facilities as the demand on activity-oriented environmental education in daily life is an increasing trend. Therefore, further study would provide a standard model as a specific design plan based on this study for environment friendly school facilities.

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