Study on Energy Saving Strategies for Public High Schools in Tokyo Considering Installation of Cooling Systems

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ABSTRACT: This study proposes several improvements for public high schools in Tokyo. The energy consumption and thermal performance of 191 schools were researched and 23 schools were selected on the basis of building age and plan, and their thermal environmental building specifications were researched. From the results, the effects of energy saving methods were assessed using the Building Energy Simulation Tool (BEST).

This study clarified the following matters: 1) Energy consumption increases 10% per year, and 20% during the summer term, by the installation of a cooling system. 2) Schools built before 1980 are not insulated. The thermal insulation performance of buildings constructed since 1980 has gradually improved up to the present, although most schools lack appropriately prepared eaves. 3) Simulated cooling loads comprise a high proportion of the total load. Collectively, these results highlight the importance of effective solar-shading techniques.

We conclude that the thermal performance of public high school buildings in Tokyo requires urgent improvement.
Keywords: school building, energy consumption, energy saving

INTRODUCTION

Air conditioning (cooling) systems were installed in the classrooms of all Tokyo public high schools in 2007–2008. However, because the thermal performance of the school buildings has not improved, energy consumption has increased regardless. According to the G8, a 50% reduction in greenhouse gas emissions by 2050 is mandatory. In Tokyo, the authorities aim for 25% reduction of greenhouse emissions by 2020.

To efficiently reduce the cooling and heating loads of high schools, we must understand the sources of energy consumption and develop methods of effectively conserving energy.

This study proposes appropriate methods for reducing energy consumption by public high schools in Tokyo. The sources of energy consumption were researched and the thermal performances of the schools were evaluated. The results are used to simulate the impact of energy-saving strategies. (Fig. 1) Our research can contribute to reaching the 25% reduction in greenhouse gases targeted for 2020.

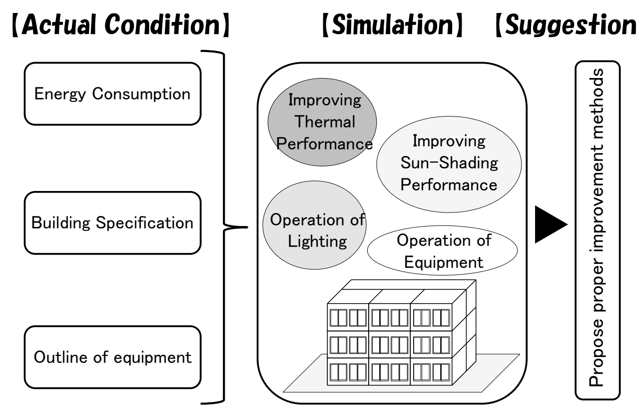


Figure 1: Flow of this study.

Table 1: Survey items.

Building outline	Building name, structure, Location, Number of stories,classes and students, Total floor area, Completion date
Building services outline	Heat source, air-conditioning system, manufacturer name, model number, installation date,type and site
Energy Consumption	monthly electricity, gas and oil consumption

Table 2: Primary energy equivalent value.

Electricity	9.97MJ/kWh	Gas	41.1MJ/m³	Oil	50.8MJ/m³

CONDITIONS OF ENERGY CONSUMPTION

This study includes all of the 191 public high schools in Tokyo in 2011. The survey items are listed in Table 1. Data on monthly electricity, gas, and oil consumption over seven years (from 2006 to 2012) of all schools in Tokyo were provided by Tokyo Metropolitan Government. The consumption of each source was converted to primary energy using its equivalent primary energy value, listed in Table 2.

Figure 2 shows the energy consumption of each heat source and energy consumption per unit area. Energy consumption increases 10% per year, and 20% during the summer term, by the installation of a cooling system. In 2012, following the Great East Japan Earthquake, the average energy consumed by air conditioned schools decreased by about 15%.

Figure 3 plots the monthly reduction rate of energy consumption, computed from the average energy consumed by each heat source in 2010, 2011, and 2012.

Although the reduction was small in January and thereafter, the climate conditions were normal, indicating that power saving was consciously implemented by school staff and students. The reduction rate during mid-term (April, May, October, December), when air conditioning is used only occasionally, is similar to that during summer. If energy reduction methods (such as switching off lights) could be implemented mid-term each year, remarkable energy savings should become possible.

CONDITIONS OF SCHOOL PLAN

Outline of research

Before proposing an energy-saving method, the conditions related to the environmental performance of high schools, such as building specifications and equipment, must be understood. To this end, we selected 23 schools of different ages and building plans. We referenced their drawings of building specifications and the apparatus table offered by Tokyo Metropolitan Government. The equipment used in the schools was identified by field survey.

Conditions related to environmental performance

Figures 4 and 5 plot the changes in the thermal resistance of each building component (floor, roof, external wall) and the length of the eaves, respectively, as functions of age. Schools built before 1980 are not insulated. The thermal performance of buildings constructed since 1980 has gradually improved up to the present. However, few schools are constructed with appropriately prepared eaves.

Figure 6 shows the number of schools adopting different types of glass for their classroom windows. Most of the schools use float glass, four schools use tempered glass, while no school uses double-glazed glass.

EQUIPMENT SPECIFICATION, OPERATION

Cooling or heating capacity of the indoor unit

To obtain the cooling/heating capacity of a single unit, the value provided in the apparatus table is divided by the number of indoor units corresponding to one outdoor unit capacity in newly air-conditioned schools.

The apparatus table reveals that age and building plan do not impact the cooling/heating capacity. As shown in Fig. 7, the typical cooling capacity is 7–9 kW, while the heating capacity is 8–10 kW. However, when these values are divided by the number of indoor units corresponding to one outdoor unit capacity, the results vary significantly.

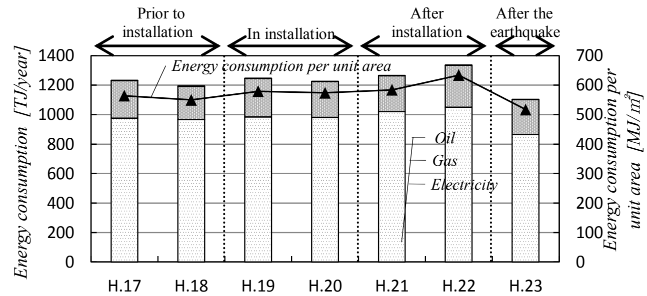


Figure 2: Energy consumption of each heat source and energy consumption per unit area.

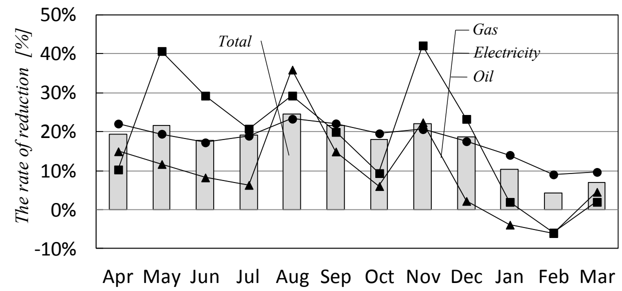


Figure 3: Rate of reduction in energy consumption.

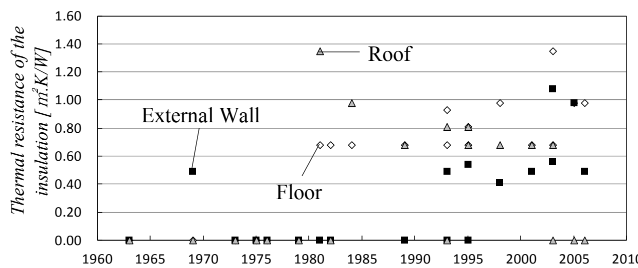
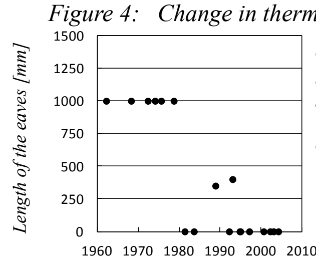


Figure 4: Change in thermal resistance of each component.



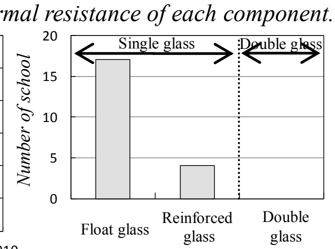


Figure 5: Change the length of the eaves.

Figure 6: Types of glass for their classroom windows.

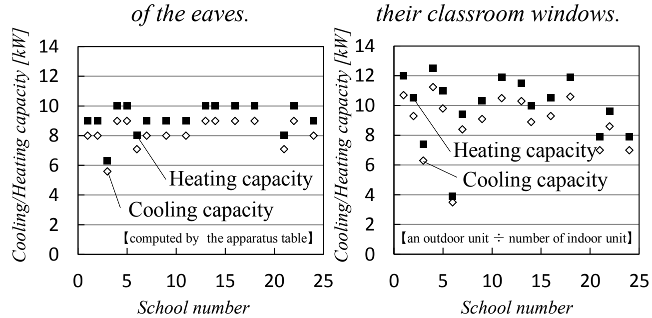


Figure 7: Cooling or heating capacity of the indoor unit.

Therefore, when deciding the capacity of an outdoor unit, the rate of concurrent heat load must be considered to ensure a non-superfluous design.

Installation conditions of outdoor unit air conditioning

Figure 8 shows the locations of the newly installed air conditioning in 120 schools. The air conditioning systems are installed in the roofs of about 10% of schools; in the remainder, the systems are installed on the ground, or on the outsides of school buildings.

Outdoor units are susceptible to damage from playground activities; for instance, by balls striking the units. In addition, exhaust air from outdoor units can invade classrooms. For these reasons, roof installation is desirable.

However, roof installation is precluded in many schools because their buildings cannot support the weight of outdoor units. Therefore, some schools have covered the upper part of the exhaust fans and erected fences around the outdoor units (Figs. 9, 10).

COP for individual room use and its age dependence

Figure 11 shows the coefficient of performance (COP) of air conditioning by room use. Leasing contract applies to air conditioning newly installed in classrooms, while in other rooms, air conditioning is a permanent fixture. In special classrooms where air conditioning was already installed (such as music and audio–visual rooms), the performance tended to be lower than that in other rooms.

Figure 12 shows the performance of GHP-EHP in fixed air-conditioning systems of different ages. The EHP performance has not appreciably improved in newer systems, while that of GHP has improved by 1.2 times in 15 years. Therefore, upgrading the GHP currently installed in special classrooms is an effective energy-saving strategy.

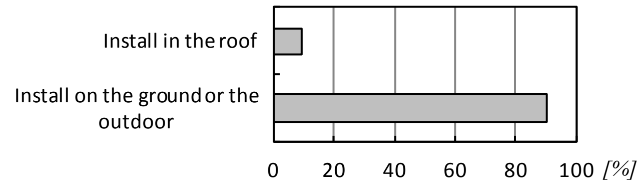


Figure 8: Locations of the newly installed air conditioning.

Figure 9: Problems of outdoor unit due to location.

Figure 10: Strategy of how to cope with problems.

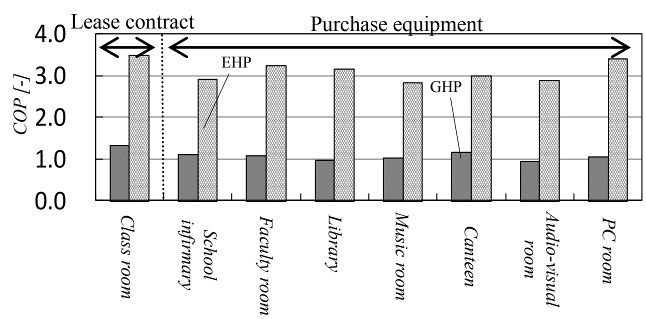


Figure 11: COP of the air conditioning by room use.

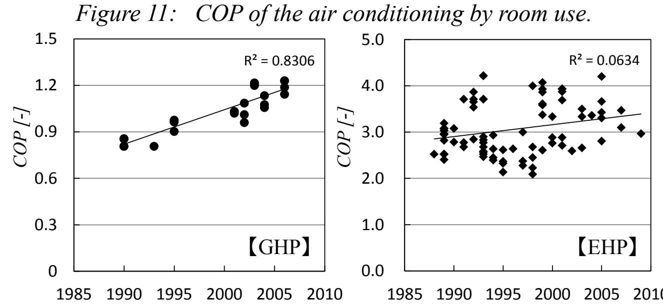


Figure 12: Performance of GHP-EHP in fixed air-conditioning systems of different ages.

CLASSROOM ENVIRONMENTS

Outline of research

To understand how air conditioning influences the indoor environment, indoor environmental reports containing data on temperature, humidity, air flow, and carbon dioxide levels, measured in classrooms twice annually (from June to September and from December to February), were analyzed for each school.

In the analysis, the data of four measurement periods were totaled, covering 2007 (before installation) and 2009 (after installation). The data in the first and second halves of 2007 were 41 and 73, respectively, while in 2009, the respective data were 58 and 78.

Ratio of Discomfort Index

Figure 13 shows how the discomfort index ranges during summer and winter. In the summer, the rate of feeling hot is decreasing.

Therefore, the indoor thermal environment has been improved by installing air conditioning systems.

However, in the winter, the rate of feeling cold is increasing.

Ratio of classroom carbon dioxide levels

Figure 14 shows a graph of the ratio of carbon dioxide levels in classrooms during summer and winter.

In the summer, air conditioning raises the carbon dioxide concentration to over 1500 ppm, the limit recommended by the school environmental plumbing law. The cause is believed to be closed windows during air-conditioning operation.

Also in winter, carbon dioxide levels exceeded the standard in 40% or more of the schools, indicating that the ventilation capacity is insufficient or a suitable equipment method has not been established. Many schools were not using ventilating facilities so few teachers understood the capability of total heat exchangers.

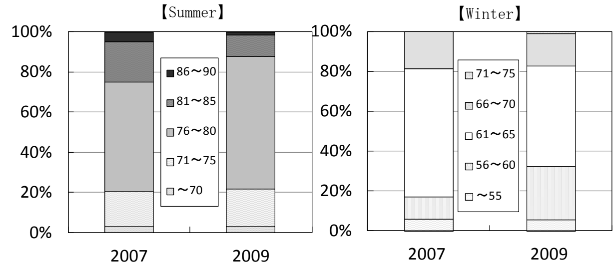


Figure 13: Ratio of Discomfort Index in summer and winter.

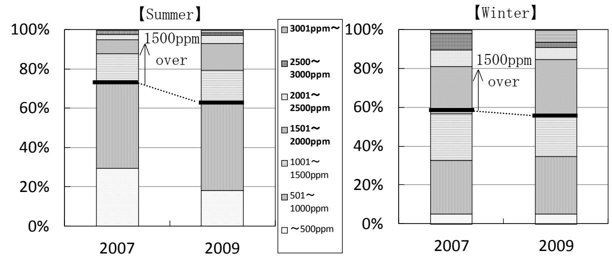


Figure 14: Ratio of the carbon dioxide levels in classroom during summer and winter.

SIMULATION METHODOLOGY

Purpose of simulation

The above investigations revealed that schools built before 1980 are not insulated and that the eaves of most school buildings are improperly prepared.

Therefore, to improve energy-saving and environmental comfort, it is important to revisit school design. The simulation study examined design criteria aimed at energy saving, with emphasis on the outer skin performance of buildings.

Calculation conditions

In this study, the effect of energy saving and comfort for different skin performances was investigated using the Building Energy Simulation Tool (BEST). The specifications and parameters of the simulation are listed in Table 3 and Tables 4–5, respectively.

The cooling period lasts from June to September, while the heating period runs from December to March. During mid-term (April, May, October, November) air conditioning is used scarcely, if at all. The schedules of heat generation and heat generation rate were determined from previous studies [3] [4], and altered as appropriate. The simulated building model is a south-facing side corridor of three stories (Figs. 15,16). Six classrooms (three on the middle floor, three on the top floor) were analyzed. All classrooms are of length 9 m, width 7.5 m, and height 3 m. The windows cover one-fifth of the 13.5 m^2 floor area.

Table 6 tabulates the composition of the simulated building model, obtained by researching materials related to environmental performance.

Review method of the simulation

The environmental performance of classrooms built at different times under different conditions is divided into three classes, as shown in Table 7. The parameters for *Environmental Performances 1*, *2*, and *3* are 72, 67, and 33, respectively.

Table 8 summarizes and classifies various approaches for improving the thermal performance, with respect to energy saving and comfort. Three proposed improvement methods are analyzed: controlling cooling and heating load by insulating the external walls and roofs, adopting double-glazed windows, and installing eaves.

The external walls and roofs are comprised of rigid polyvinyl chloride firing board and rigid urethane foam firing board, respectively (with respective thermal

Table 3: Outline of simulation

Region	Tokyo (Region Ⅳ)	
Calculation period	2006/1/1～2006/12/31	
Calculation interval	Every hour and Every month	
Structure	Reinforced Concrete	
Use time on weekdays	Class room	8:00～15:30
	Staff room	8:00～20:00
Usage of holiday	Not open the region	
Long vacation period	Summer vacation	7/20～8/31
	Winter vacation	12/24～1/8

Table 4: Calculation condition of air-conditioning

	summer	winter
Air conditioning period	6/1～9/30	12/1～2/28
Preset temperature	26～28℃	18～20℃

Table 5: Calculation condition

Lighting load	FLR (20W/㎡)	Hf (15W/㎡)
Human load	0.5人/㎡	
Equipment load	10W/㎡	
amount of metabolism	1.2met	
amount of clothing	0.55clo(sum), 1.0clo(win), 0.8clo(mid)	

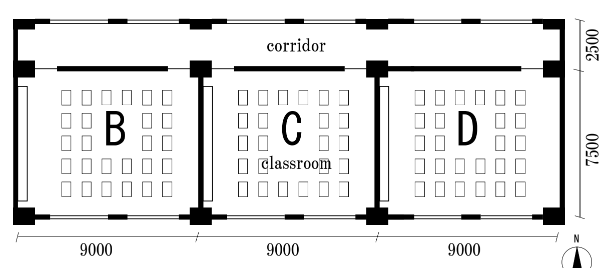


Figure 15: Simulation model (plan).

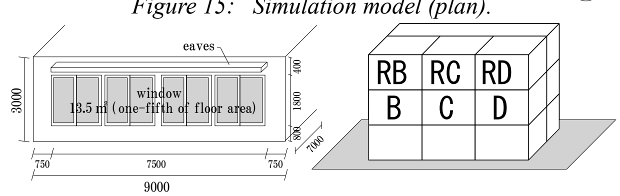


Figure 16: Simulation model (façade & perspective).

conductivities λ= 0.036 W/mK and λ = 0.028 W/mK).

TYPE5 was considered as the thermal environment performance demanded of the “energy saving and re-energy Tokyo specification” [5] in 2011.

SIMULATION RESULTS

Energy-saving effects by improved thermal-performance

The graphs in Fig. 17 show the cooling/heating loads under improved thermal performance.

No TYPE4 improvement was implemented in *Environmental Performance 1* because the eaves of 1000 mm length already exist in this class. Under TYPE5 improvement, *Environmental Performances 1*, *2*, and *3* are reduced by 22.5%, 19.4%, and 12.3%, respectively, relative to TYPE0.

Comparing TYPE3 with TYPE4 improvement, eaves will increase the heating load by 6.6%, but will reduce the cooling loads by 5.8%, with a potential 2.2% reduction each year. The annual cooling/heating load depends little on whether TYPE3, TYPE4, or TYPE5 improvement is implemented.

Study on lighting energy savings

Lighting makes a large contribution to energy consumption in school buildings.

Figure 18 illustrates the reduction in cooling/heating load attainable by reducing the lighting load.

Approximately 26% reduction can be expected by replacing FLR lighting with Hf lighting in present-day Tokyo high schools.

The actual condition of the electric amount of energy consumption of a school is investigated, since 80% or more of energy consumption is for lighting, it is effective to use daylight from the viewpoint of energy saving. Even when satisfied, the illumination criterion is securable only by using daylight, but despite this, the lighting is always turned on in almost all classrooms.

Switching FLR sources off during lunch break would reduce energy consumption by about 8%. Moreover, if the row of lights nearest a window were turned off during daylight hours, energy consumption could be reduced by a further 2.8% per hour.

If lights adjacent to the window were switched off during lunch break and lesson time (6h), the lighting load would be reduced by about 25%.

By implementing both improvements (replacing FLR lighting with Hf and strategic use of lighting), the lighting load could be reduced by 40% or more.

Effect of relaxation preset temperature

Figure 19 shows the effect of relaxing the preset temperature on cooling/heating loads and time of feeling comfortable in an air-conditioned classroom reinforced by improved insulation and attached eaves (*Environmental Performance 1* is improved by TYPE3, while *Performances 2* and *3* are improved by TYPE4).

Time of comfort defines the time during which temperature lies within

Table 6: Composition of the building model.

Element	Composition	Element	Composition
External wall	Sprayed tile t=20 Rigid polyvinyl chloride t=0,50 Air Concrete t=150	Roof	Concrete t=80 Rigid urethane foam t=0,60 Asphalt t=10 Concrete t=150
Door	Steel t=1 Rigid urethane foam t=15 Steel t=1	Partition wall	Plaster board t=12 Air Plaster board t=12
Ceiling	Concrete t=150 Plaster board t=12	Floor	Carpet t=7 Concrete t=150
Window	Single glass U = 4.6W/㎡.K η = 0.490 Double-glazed Low-E glass U = 2.3W/㎡.K η = 0.404		
Eaves	Length = 0 , 1000mm		

Table 7: Classified into Environmental Performance.

Environmental Performance 1	In the school built before 1980, not insulate with the eaves length of the 1000mm
Environmental Performance 2	In the school built from 1981 to 1993, insulate floor and roof without the eaves
Environmental Performance 3	In the school built after 1994, insulate floor, roof and external wall without the eaves

Table 8: Type by improved the thermal performance.

TYPE0	Standard [Environmental Performance 1, 2, 3]
TYPE1	Insulation of the external wall t=50mm
TYPE2	Insulation of the external wall t=50mm + Change to the double glazing
TYPE3	Insulation of the external wall t=50mm + Change to the double glazing + Insulation of the roof t=60
TYPE4	Insulation of the external wall t=50mm + Change to the double glazing + Insulation of the roof t=60 + Eaves L=1000
TYPE5	Insulation of the external wall t=50mm + Change to the double glazing + Insulation of the roof t=75 + Eaves L=500 (energy saving and re-energy Tokyo specification)

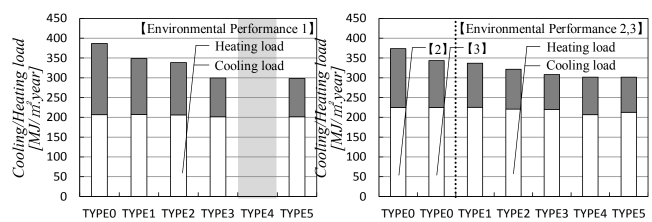


Figure 17: Cooling/heating loads under improved thermal performance.

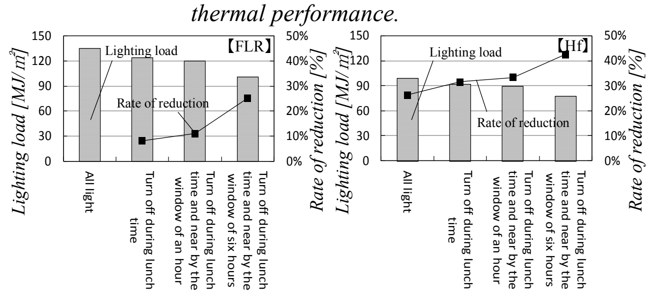


Figure 18: Study of energy-saving of lighting.

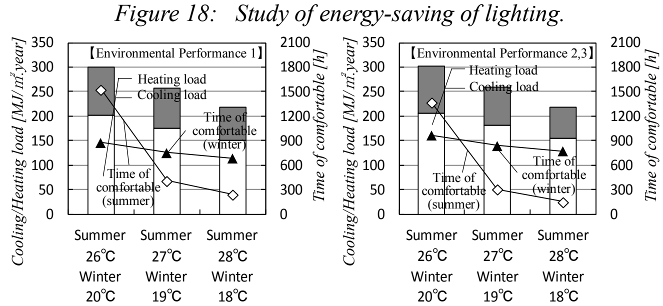


Figure 19: Effect of a preset relaxation temperature on cooling/heating loads and time of feeling comfortable.

−0.5 to +0.5 (comfort zone) of PMV in this study.

By imposing a relaxation of the preset temperature of 1°C in summer, the cooling load could be reduced by 12%, but the time of comfort is considerably reduced.

By comparison, in winter, the relaxation of the preset temperature exerts little effect on comfort time.

In summer and winter, by implementing relaxation of the preset temperatures from 26°C to 28°C and from 20°C to 18°C, respectively, the cooling load could be reduced by 25%, heating load could be reduced by 32%, and the annual load could be reduced by 27%.

Imposition of a relaxation of the preset temperature of air-conditioning can be performed comparatively easily. In winter, after improving the environmental performance, it is effective to preset the air-conditioning temperature.

Effect of improved performance and operation

The effect of comprehensive energy saving is summarized in Table 9 and Fig. 20.

Under TYPE A improvements, *Environmental Performances 1*, *2*, and *3* are enhanced by 22%, 19.8%, and 15.1%, respectively.

In addition, by imposing a relaxation of the preset temperature and strategic lighting operation, respective improvements in *Environmental Performances 1*, *2*, and *3* are 40.6%, 38.9%, and 35.3%, respectively.

To reach Tokyo's emission reduction target, it is critical to improve the environmental performance and limit the use of energy-consuming apparatus in schools.

CONCLUSION

In this study, the actual conditions of the building specification, equipment employment and energy consumption by public high schools in Tokyo have been grasped by data-analysis and a field survey.

Based on this research, we performed simulations to examine the energy-saving effects and comfort by improving the thermal performance.

From this study, we drew the following conclusions:

i) Energy consumption decreased by about 15% following the Great East Japan Earthquake, when electricity-saving strategies were imposed. If these energy reduction methods, such as switching off lights, could be implemented mid-term each year, remarkable energy savings could be achieved.

ii) Schools built before 1980 are not insulated and the majority of schools lack appropriately prepared eaves. Therefore, improving the building properties of these schools is important for energy saving and user comfort.

iii) Suitable improvements to buildings and strategies for reducing energy consumption were identified and compared by simulation.

Table 9: Verification type by comprehensive energy-saving.

TYPE A	Energy consumption of standard [Environmental Performance 1, 2, 3]
TYPE B	Energy consumption by improved thermal performance [Environmental Performance 1 is TYPE3, Environmental Performance 2,3 is TYPE4]
TYPE C	Energy consumption by improved thermal and lighting performance [TYPE B + Change from FLR type to Hf type]
TYPE D	Energy consumption by improved thermal, lighting performance and operation [TYPE C + Air−Conditioning : relaxation preset temperature to 28℃ in summer, to 18℃ in winter Lighting : turning out lights by the window is performed in a lunch break and school hours (6 hours)]

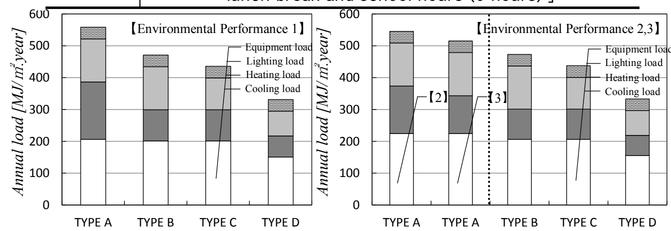


Fig. 20 Effect of energy-saving by improving performance and operation

To accomplish the CO_2 reduction target set by Tokyo Metropolitan Government, both the improvement of building environmental performance and the proper control of building services, especially lighting and air-conditioning, are required.

ACKNOWLEDGEMENTS

This study is part of a leading project "Construction Technology of City Construction Stock That Contributes to Environmental Impact Reduction," conducted in Tokyo.

We are grateful to the Regional Finance Bureaus and the Education Bureaus in Tokyo, who supplied their data for analysis.

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