4.4

EFFECT ON CO_2 EMISSIONS OF BUILDING-URBAN AREA BY INTRODUCING SOLAR REFLECTIVE PAINT

Tomohiko Ihara *, Yutaka Genchi
National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan

Masako Matsuo, Yoshikuni Yoshida, Ryuji Matsuhashi
University of Tokyo, Tokyo, Japan

1. INTRODUCTION

1.1 *Background*

The alterations in the global environment have recently become a serious issue, and it is urgent to develop technologies to reduce CO_2 emissions.

In Japan, the CO_2 emissions from commercial and residential sectors that reached one fourth of the total are still increasing, although ones from industrial sector or transportation sector stay almost the same. In commercial and residential sectors, energy demand for air-conditioning amounted to 30% of the total energy demand, and thus it is pivotal to introduce CO_2 reducing technologies into buildings.

In addition, heat island phenomenon that is caused by energy consumption in commercial and residential sectors is currently a serious problem, and it is of particular importance to develop heat island mitigation measures.

1.2 *Solar reflective paint (SRP)*

It has long been claimed that the use of heat insulation material is the most effective for reducing CO_2 emissions from buildings. Its introduction into existing buildings, however, poses very high cost, whereas the material can be readily introduced into newly-built ones.

On the other hand, a solar reflective paint (SRP) (also called light reflective paint or heat shield paint) (Kondo 2000) is effective simply by painting, and it is very easy to apply to existing buildings.

With introducing SRP, outer surfaces of buildings reflect solar radiation to a greater extent, and reduce the radiation absorption and the heat transfer to interiors. Thus its introduction could reduce cooling demands and CO_2 emissions. An additional impact is that, because its introduction results in high degree reflection of solar radiation, it can reduce sensible heat flux to atmosphere and artificial exhaust heat caused by cooling demands. A large-scale introduction of SRP is expected to reduce more CO_2 emissions and cooling demands, because outside temperature should decrease.

Thus, introduction of SRP would be highly desirable not only to reduce CO_2 emissions but also to mitigate heat island phenomenon.

1.3 *Objectives and the outline*

The extents of CO_2 reduction by introduction of SRP should be evaluated, taking into account the interaction between building environment and urban environment, for a large area and throughout the year.

However, previous studies reported on the effects throughout the year of only buildings or simulations about building-urban environment only during summer. Furthermore, the thermal properties of SRP used have never been investigated.

Here we measured thermal properties of SRP. Using our building heat load simulation model compounded with a mesoscale meteorological simulation model, we evaluated environmental impacts brought about by a large-scale introduction of SRP throughout the year.

2. BUILDING HEAT LOAD SIMULATION

2.1 *Building heat load simulation model*

On a dynamic heat load simulation model, which was developed to evaluate the impacts of SRP on a building surface, a building was divided into many small blocks, and simultaneous heat balance equations for each representative point of small block (thermal calculating point) were solved by difference method (Ihara 2003) (Fig. 1).

This model was designed to reduce computing loads by using the skyline method and the divide and conquer method (Oguni 1991), and is able to compute stored heat in each block at any time. Moreover, in order to estimate impacts to urban thermal environment, a sub model was developed to calculate the amount of exhaust heat by each energy use per hour, from stored heat in each block per hour.

* *Corresponding author address:* Tomohiko Ihara, National Institute of Advanced Industrial Science and Technology, Research Center for Life Cycle Assessment, 16-1 Onogawa, Tsukuba, Ibaraki, Japan, 305-8569; e-mail: ihara-t@aist.go.jp

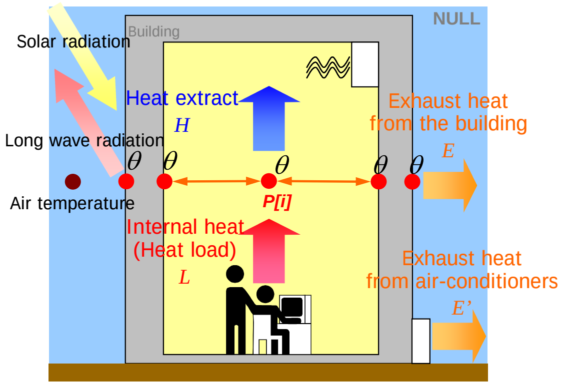


Fig. 1: Building heat load simulation model

2.2 *Exposure experiment about SRP*

To learn about the thermal properties of SRP, we set up at a rooftop of Engineering Bldg. 4th of Univ. of Tokyo, a cubic object made of stainless plates coated with SRP (Fig. 2).

Fig. 2: An aspect of the exposed cubic object

We measured the object's solar reflectance, it's inside temperatures and weather conditions long time from November 2002 to October 2003, to accurately assess averaged solar reflectance.

When the influence of solar position is removed from the measured data (Fig. 3) by ray-tracing method, mean solar reflectance of SRP was assessed to be 0.75, if the life of SRP is assumed to be five years. This value approximately agreed with Nikaido's measured data (Nikaido1999).

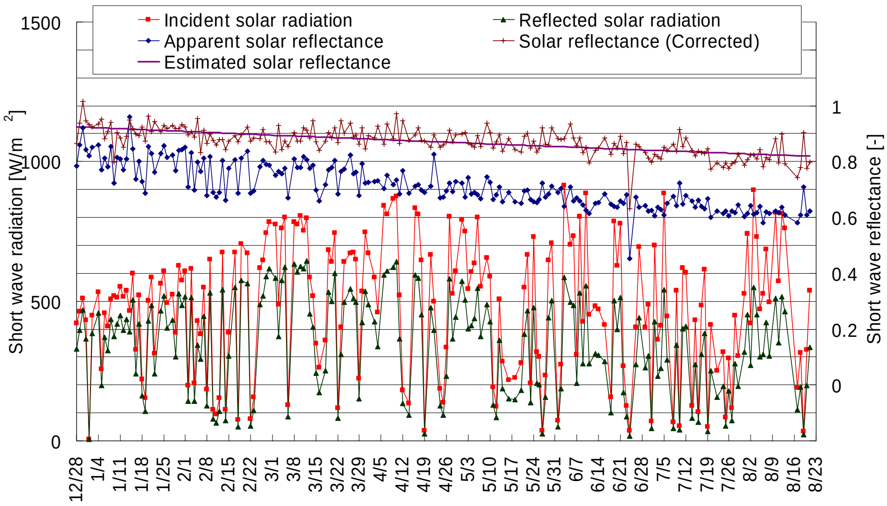


Fig. 3: Measured data about the object's solar reflectance

2.3 *Simulation conditions*

By use of building heat load simulation model and measured solar reflectance of SRP (Tab. 1), air-conditioning load reduction effect in buildings by SRP and exhaust heat from buildings per hour (exhaust heat curve) were calculated. For calculating target buildings, one is one of typical office buildings, and another is one of typical houses.

Tab. 1: Postulated solar absorptance and thermal emittance

Outer surface	Solar absorptance [-]	Thermal emittance [-]
Default	0.80	0.90
SRP	**0.25**	0.90

Simulation conditions are following.

- A calculating target office building (including air-conditioners, Tab. 2) and schedules follows "Model Building (Newly built, Medium-scale)" (CRIEPI 1985) which CRIEPI made. This is a reinforced concrete building which consists of one-story basement, ten stories and tower. Its floor and total floor areas are 954.72[m^2] and 10,089[m^2], respectively. The air-conditioning setting room temperature ranges from 22 to 26[deg C].
- A target house is "Standard problem for house" (Udagawa 1985) (wooden house) which AIJ proposed. Refer to "Life Schedule and Energy Consumption in Houses" (SHASEJ 2000) which

SHASEJ planned, for each of the schedules. The setting room temperature ranges from 20 to 27[deg C].

- Use AIJ's "Expanded AMeDAS Weather Data" (EA Weather Data) (AIJ 2000), Tokyo, typical meteorological year.
- Solar position is calculated using the equations of Yamazaki (AIJ 2000).
- Direct and diffuse solar radiations are calculated from horizontal global radiation using an Erbs model (Erbs 1982). A global radiation on tilted surfaces is calculated from direct and diffuse radiation using a Perez model (Perez 1992).
- Temperature below the ground surface is calculated using a Hayashi model (AIJ 2000).

Tab. 2: Settings of air-conditioners for office buildings

	No.	Type name	Fuel	COP	[%]
Cool-ing	1	BMPAC	Electricity	3.1	33.7
	2	C/H-WG	City gas	1.07	25.6
	3	CWC	Electricity	4.1	40.7
	-	Average	-	2.99	100.0
Heat-ing	1	BMPAC	Electricity	3.5	33.7
	2	C/H-WG	City gas	0.85	25.6
	3	Boiler	City gas	0.85	40.7
	-	Average	-	1.74	100.0

BMPAC : Building multi packaged air conditioner

C/H-WG : Cold and hot water generator

CWC : Centrifugal water chiller

* The combination of the air-conditioner with the same type number is considered as one air-conditioning system.

2.4 *Simulation results about heating and cooling loads*

The results of heating and cooling loads indicate that, when SRP is introduced to office buildings in which cooling load exceeds heating load, cooling load is reduced by 370[GJ] (19.4%), and heating load is increased by 260[GJ] (33.1%), and that the reduced amount of cooling load exceeds the increased amount of heating load (Fig. 4). On the other hand, when introduced to houses in which heating load amounts to two and a half times more than the cooling load, cooling load is reduced by 1.47[GJ] (21.4%), and heating load is increased by 2.30[GJ] (13.3%). Thus, SRP onto houses is able to increase energy consumption for air-conditioning (Fig. 5).

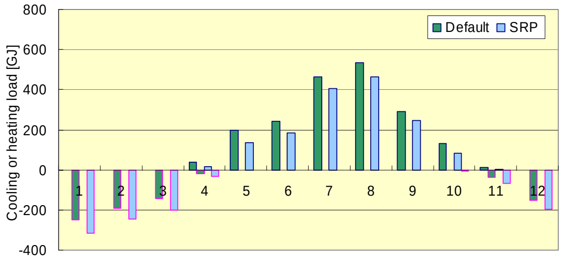


Fig. 4: Monthly cooling and heating load (Office building)

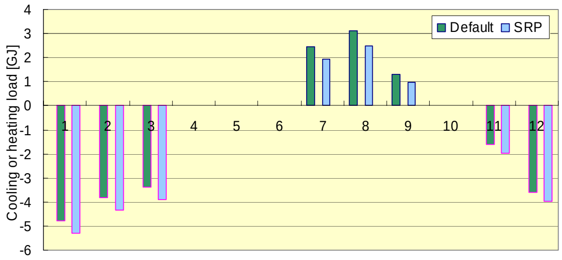
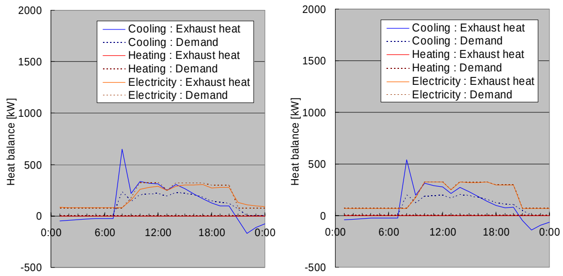


Fig. 5: Monthly cooling and heating load (House)

Moreover, exhaust heat from buildings immediately after starting air-conditioning is found to amount to more than twice the energy demand (Fig. 6).



(Default) (Introducing SRP)

Fig. 6: Exhaust heat curve (Weekday in August, Office building)

3. AIR TEMPERATURE DECREASE BY INTRODUCING SRP

3.1 *Mesoscale meteorological simulation model*

We used a mesoscale meteorological simulation model developed by Kondo et al. (Kondo 1989, Kikegawa 2001). This model is one of hydrostatic numerical models with Boussinesq approximation which is assimilated by Grid Point Value (GPV) provided by Japan Meteorological Agency (JMA).

3.2 *Simulation conditions*

Properly, it is desirable to simulate throughout the year, but it requires enormous calculation time. We categorize one year to six seasons by pressure patterns and air-conditioning types (Tab. 3). We extracted one representative day per one season and performed mesoscale meteorological simulation about only representative days.

Tab. 3: Representative days for mesoscale simulation

Representative day	Weather map (Pressure pattern)	Air-conditioning	Period applied calculation result
2003/02/01	Winter	Winter (Heating)	Jan, Feb, Dec
2003/03/21	Spring or autumn	Winter (Heating)	Mar, Nov
2003/04/18	Spring or autumn	Spring or autumn	Apr, May
2002/06/17	Rainy season	Spring or autumn	Jun, Oct
2002/08/09	Summer	Summer (Cooling)	Jul, Aug
2002/09/12	Rainy season	Summer (Cooling)	Sep

As ground surface conditions, we prepared now and when SRP is introduced to all office buildings as a commercial sector in the Tokyo area. Exhaust heat curve of commercial and residential sectors derived building heat load simulation results (Fig. 6). Ground surface albedo data are in Tab. 4. Based on assumption that commercial buildings occupy 30% of land for commercial sector, we assumed that albedo of land for commercial sector with SRP is 0.30.

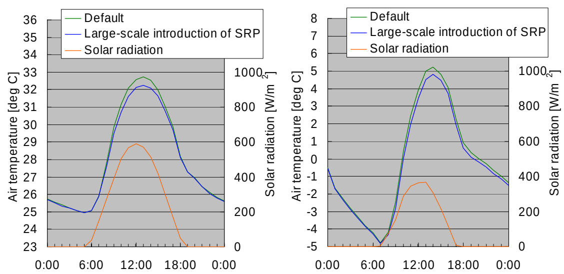
Tab. 4: Ground surface albedo

ID	Type of land use	Albedo [-]
7	Commercial sector	0.13
7'	Commercial sector with SRP	**0.30**
8	Residential sector	0.15

3.3 *Simulation results*

We assessed a change in the urban thermal environment by a large-scale introduction of SRP.

Calculation on each representative day in each season indicates that its introduction brings about a 0.5[K] decrease in air temperature in the daytime irrespective of season and also a maximum 0.2[K] reduction in the nighttime (Fig. 7).



(2002/08/09) (2003/02/01)

Fig. 7: Air temperature decrease by introducing SRP

3.4 *Air temperature decreasing effect by introducing SRP*

Using regression analysis for the extents of air temperature decrease and solar radiation, we constructed equations estimating air temperature decrease by introducing SRP in each season. A formula using this regression analysis is following.

$$(\Delta\theta)^K = \Delta_I I_G{}^K + \Delta_{(\Delta\theta)}(\Delta\theta)^{K-1}$$

K is time, $\Delta\theta$ is a decrease in air temperature, I_G is global solar radiation, Δ_I is a coefficient which describes how a reduction in solar radiation affects a decrease in air temperature and $\Delta_{(\Delta\theta)}$ is a coefficient which describes how a decrease in air temperature at previous time $(K-1)$ affects now decrease.

By applying these equations to the annual air temperature data of EA Weather Data, we calculated annual air temperature in case of a large-scale introduction of SRP.

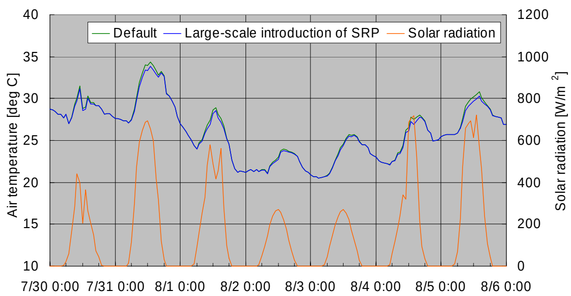


Fig. 8: Air temperature data in case of a large-scale introduction of SRP (part of annual data)

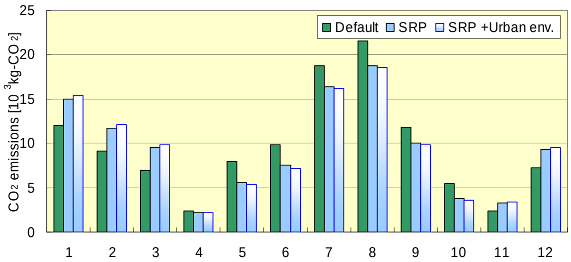
4. BUILDING HEAT LOAD SIMULATION CONSIDERING URBAN THERMAL ENVIRONMENT

4.1 *Environmental impacts*

Environmental impacts by introducing SRP consist of a direct impact by a reduction in absorbing solar radiation and an additional impact by a decrease in air temperature caused by changing the urban thermal environment.

4.2 *Simulation results about reduction in CO_2 emissions only including a direct impact*

As the direct impact, CO_2 emissions increase by 0.6% in office buildings (Fig. 9) and by 4.5% in houses (Fig. 10), although the extents of reduction in the cooling load exceed the extents of increase in the heating load in office buildings. This result is attributed to COP of air-conditioning in office buildings.



"+Urban env." includes an additional impact. (See 4.3)
Fig. 9: Monthly CO_2 emissions from air-conditioning (Office building)

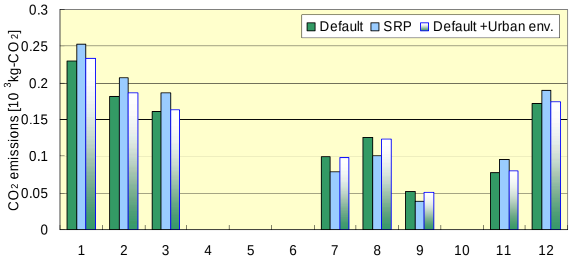


Fig. 10: Monthly CO_2 emissions from air-conditioning (House)

Then, according to simulation for each type of air-conditioning, introduction of SRP reduced 5.2% in CO_2 emissions in case of a building multi packaged air conditioner (BMPAC) that is one of new air-conditioning systems and 1.3% in case of a cold and hot water generator (C/H-WG) that is also new, but increased 6.7% in CO_2 emissions in case of a combination of centrifugal water chiller (CWC) and boiler that is an old system, irrespective of the same air-conditioning load (Fig. 11).

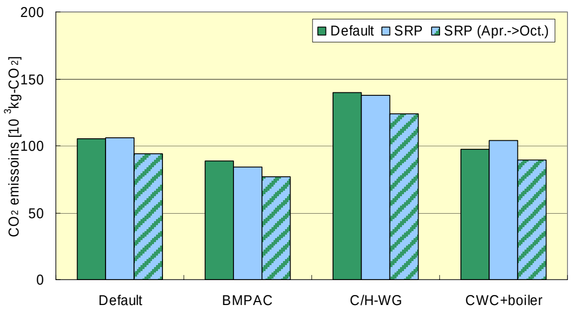


Fig. 11: Difference of CO_2 emissions by air-conditioning system (Office building)

Moreover, according to calculation of the effects changing by office automation, in case of the present super high-rise buildings its introduction reduce 6.7%, and in case of automation such as two personal computers per office worker, its introduction reduce 11.8% (Fig. 12).

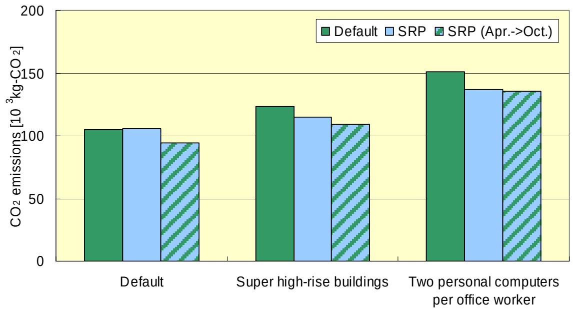


Fig. 12: Difference of CO_2 emissions by office automation (Office building)

If it is realized to introduce SRP April through October, it reduces CO_2 emissions 11.8% in office buildings and 5.4% in houses (Fig. 9 and Fig. 10).

4.3 *Simulation results about reduction in CO_2 emissions also including an additional impact*

To assess the additional environmental impact, we simulated a case of introducing SRP to all office buildings in the Tokyo area.

The result indicates that its introduction increases 0.6% in CO_2 emissions from office buildings, taking into account only reduction in absorbed solar radiation. When considering a decrease in urban air temperature, its introduction results in an increase of 0.8% in CO_2 emissions from office buildings and 0.9% from houses (Fig. 13 and Fig. 14).

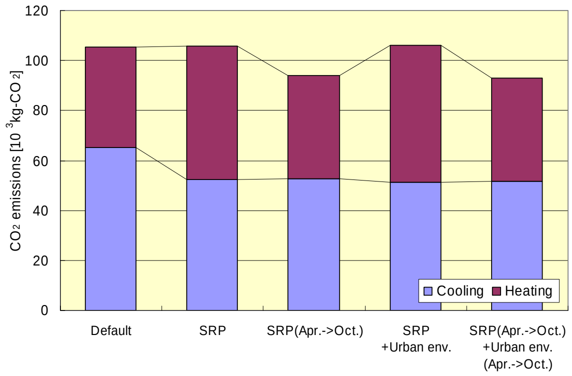


Fig. 13: CO_2 emissions (Office building)

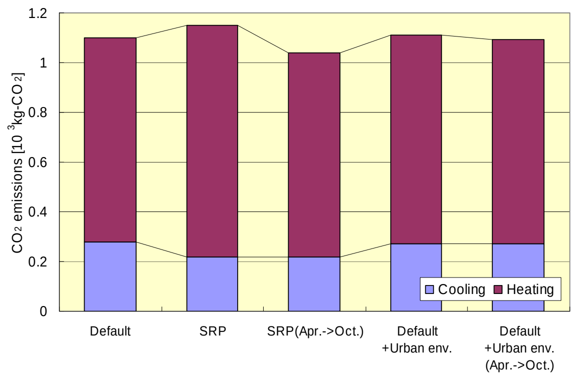


Fig. 14: CO_2 emissions (House)

5. CONCLUSION

Introduction of the solar reflective paint (SRP) is effective for reducing cooling demand in existing buildings and mitigating heat island phenomenon in summer, but simultaneously increases heating demand in winter. Therefore, the introduction is expected to increase in CO_2 emissions in standard buildings, and uniform large-scale introduction could bring about a greater increase in CO_2 emissions. On the other hand, the introduction of SRP to buildings which has new air-conditioning system or advanced automation effectively reduces CO_2 emissions.

Considering these properties of SRP, we conclude that its introduction to the areas in which buildings are equipped with new air-conditioning system and/or advanced automation, is one of the effective CO_2 reduction measures. However, it should be noted that there are not only the direct impact in office buildings introduced, but also the additional impact in their surroundings.

REFERENCES

Kondo, Y., Nagasawa, Y., Irimajiri, M., 2000: Reduction of Solar Heat Gain of Building, Urban Area and Vending Machines by High Reflective Paint, *Research Reports of Society of Heating, Air-conditioning and Sanitary Engineers of Japan*, **78**, 15-24. (in Japanese)

Ihara, T., Handa, T., Matsuhashi, R., Yoshida, Y., Ishitani, T., 2003: Proposal of a Novel Method to Calculate Room Temperature in Multi-Room Building by an Improved Matrix Computing and its Application to Evaluate CO_2 Reduction Utilizing High Light-Reflective and High Heat-Emissive Paint, *IEEJ Transactions on Electronics, Information and Systems*, **123**-8, 1493-1501. (in Japanese)

Oguni, C., Murata, K., Miyoshi, T., Dongarra, J. J., Hasegawa, H., 1991: Matrix Computing Software, Maruzen. (in Japanese)

Nikaido, M., Terauchi, S., 1999: High light-reflective and high heat-emissive paint which decreases temperature of built structures, *Annual report of Kajima Construction Technical Research Institute*, 47, 153-158. (in Japanese)

Central Research Institute of Electric Power Industry (CRIEPI), 1985: Energy-saving of Office Building -Evaluation of Potential Amount and Required Cost in Tokyo-", Research report of CRIEPI. (in Japanese)

Udagawa, M., 1985: Proposal of Standard problem -standard problem for house-, *The 15th Heat Symposium*, The Architectural Institute of Japan, 23-33. (in Japanese)

Society of Heating, Air-conditioning and Sanitary Engineers of Japan (SHASEJ), 2000: Life Schedule and Energy Consumption in Houses, SHASHJ Symposium, 23-33. (in Japanese)

The Architectural Institute of Japan (AIJ), 2000: Expanded AMeDAS Weather Data, Maruzen. (in Japanese)

Erbs, D.G., Klein, S.K. Duffie, J.A., 1982: Estimation of the diffuse radiation fraction for hourly, daily and monthly-average global radiation, *Solar Energy*, 293-302.

Perez, R.R., Ineichen, P., Maxwell, E.L., Seals, R.D., Zelenka, A., 1992: Dynamic Global to Direct Conversion Models, *ASHRAE Transactions Research Series*, 154-168.

Kondo, H., 1989: Description of NRIPR mesoscale model, Report of the National Research Institute for Pollution and Resources (NRIPR), **44**.

Kikegawa, Y., 2001: Evaluation of Heat Island Countermeasures considering Interaction of Thermal Environment with Air-conditioning Energy Demand, Univ. of Tokyo Doctorial Thesis. (in Japanese)