THERMAL EFFECT OF “BIOMIMETIC BUILDING” WITH PERSPIRABLE AND CHANGING CLOTHES FUNCTIONS

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1. Introduction

There has been a growing tendency to attain a desirable living environment in buildings by saving energy and low global emission with the use of natural energy resources and natural environment. Since we need both heating and cooling in Japan, it is necessary to investigate passive cooling in summer as well as passive heating in winter. From this viewpoint, the author has been investigating passive systems in buildings where the environment is controlled biomimetically and autonomously by simulating the physiological functions of animals and plants.

As an energy saving building in the next generation, the building called as an environment-harmonized “Biomimetic Building (BB)”, where the environment physiology mechanism of the humans as well as other creatures and human wisdom are applied to the environment symbiosis and control, has been developed. The human physiology mechanism such as perspiration, respiration, gooseflesh and shiver are simulated and the promising functions are applied to environment symbiosis and environment control in buildings. As one of the approaches, research and development of a “Perspirable Building” which simulates heat dissipation by perspiration as a thermo-control mechanism in the human body physiology, was introduced. (Ishikawa, 2006, 2008) Furthermore a “Changing Clothes Building” where the wall (roof and external wall) can autonomously vary thermal insulation performance and the window can autonomously vary the insolation shading performance, was introduced. (Ishikawa, 2007; Ishikawa et al., 2010)

This paper describes the thermal effectiveness estimated theoretically, of the “Biomimetic Building” with a complex of ‘Perspirable Function’ of roof and ‘Changing Clothes Function’ of wall.

2. Perspirable function

The “Perspirable Building (PB)” as a building with the ‘Perspirable Function’ was proposed by simulating the mechanism of concentration gradient, osmotic pressure, capillarity, mechanical energy and electric potential difference which controls perspirable action in a human body. The ‘Perspirable Function’ in the building manifests itself with the construction of perspirable roof and wall (window) using thermo-sensitive hydrogel as a new material. The thermo-sensitive hydrogel is absorption/desorption resin with thermal reversibility; water is absorbed below the specific sense temperature and water is desorbed over the temperature, like the perspiration in a human body. It is the evaporative cooling performed not by water sprinkling onto the roof and wall but by their autonomous perspirable function.

2.1. Perspirable roof

Three kinds of perspirable roof products were developed. Those are a mat type product and two kinds of precast products (a combined precast and a separated precast) made of rock wool as a base material to be improved to strengthen nonflammability. Fig.1(a) shows the mat type product which consists of two layers (32mm in thickness) and the arrangement is as follows; nonwoven fabric in the first layer (outside layer) for ultraviolet rays penetration prevention, and mat filled with thermo-sensitive hydrogel in the second layer. Fig.1(b),(c) show the combined precast product (10mm in thickness) and the separated precast product (5mm in thickness), respectively. The combined precasting consists of three layers; nonwoven fabric in the first layer for surface protection, rock wool and thermal bond fiber in the 2nd layer for ultraviolet rays penetration prevention, and thermo-sensitive hydrogel, rock wool and thermal bond fiber in the 3rd layer in three layer structure. On the other hand, the separated precasting assumes to be a double layered system, which consists of the 1st layer and the 3rd layer of the combined type, eliminating the 2nd layer. Both products were able to clear the fire test as a nonflammable material by the cone calorimeter examination.

2.2. Thermal effect of perspirable roof

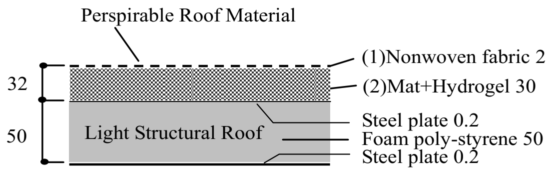
a. Performance observation of perspirable building

The perspirable roof (mat type product) was constructed on the south side of an existing office building, RC construction, B3F7P2, located in Tokyo (35.68°N, 139.77°E). Roof plan view, roof specifications and measuring items of the building are shown in Fig.2 and Fig.3. The thermal effect of the perspirable roof was evaluated by measuring temperature, heat flow and room thermal comfort under the perspirable roof in the summer season, compared to what were obtained from the roof unable to perspire. Measurement condition was as follows;

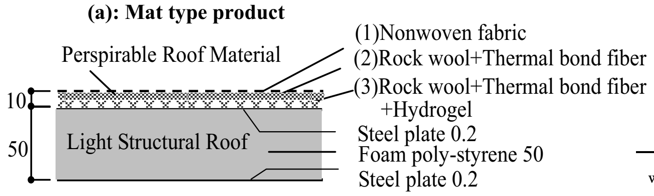
•Measurement period: August 20- September 2, 2003, •The 1st period: August 20-August 26: East half of the south side of the roof was able to perspire. West half of the south side was unable to perspire. •The 2nd period: August 28 16:00-September 2: All the south side of the roof was able to perspire. •The setting of water supply rate: 7l/(m^{2}day) • Hydrogel: 294g/m^2 (mat thickness:30mm) •Water absorption magnification of hydrogel: 25-50 times (i.e. water supply rate for 1 to 2 days) •Blend ratio of hydrogel: the specific sense temperature 20:25:30:35 ºC → 1:3:5:4 (ratio in weight)

b. Results and consideration of measurement

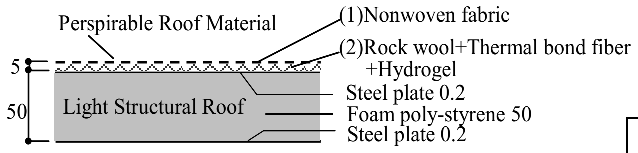
During the 1st period, the difference of the roof temperature, heat gain and the improvement in room thermal comfort between the roof perspirable and non perspirable, is shown in Table 1. They were the maximum values in the period. The thermal effect of the perspirable roof was as follows; roof outer surface temperature (37.7ºC decrease), ceiling surface temperature (3.8ºC decrease), ceiling heat gain (77% decrease), room temperature (FL+1500) (3.1ºC decrease), PMV (0.88 decrease; improvement) and PPD (29.4% decrease). In the 2nd period after the construction of the perspirable roof on the west half, the values between room A and B were mostly the same, showing that there were also good evaporative cooling effects in room B under the perspirable roof. The thermal effect of the perspirable roof was great.



(a): Mat type product



(b): Combined precast product



(c): Separated precast product

Fig.1: Perspirable roof

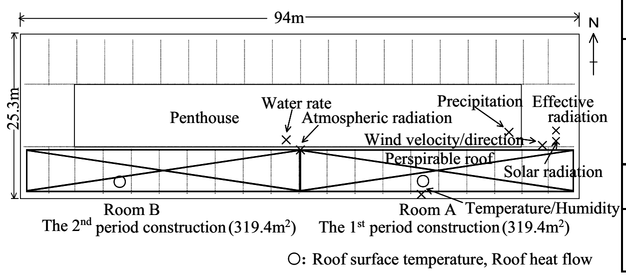


Fig. 2: Roof plan view and measurement points

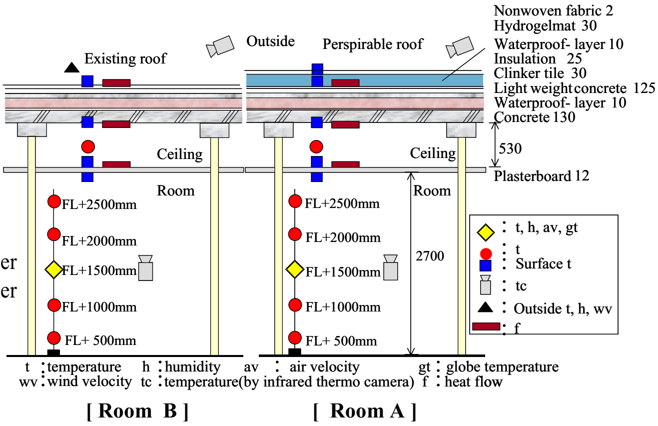


Fig. 3: Roof specifications and measurement item

Tab.1: Comparison of measured values between perspirable roof and non perspirable roof

Item	Section	Perspirable roof (Room A)	Non perspirable roof (Room B)	Decrease (Room B - Room A)
Surface Temperature	Roof outer	30.2(°C)	67.9(°C)	37.7(°C)
	Roof inner	27.5(°C)	30.2(°C)	2.7(°C)
	Ceiling	25.3(°C)	29.1(°C)	3.8(°C)
Heat gain Decrease rate =(Decrease /Existing roof)	Roof	-14.78(W/m^2)	3.09(W/m^2)	17.88(W/m^2) 17.88/3.09=5.78
	Ceiling	1.48(W/m^2)	6.37(W/m^2)	4.89(W/m^2) 4.89/6.37=0.77
Room temperature	FL+1500	25.3	28.4	3.1
Thermal comfort	PMV	0.36	1.24	0.88(improved)
	PPD	7.65(%)	37.0(%)	29.4(%)

(The time when the maximum values occurred in the 1st period was different in each item and section.)

3. Changing clothes function

The “Changing Clothes Building (CCB)” was proposed as a building with ‘Changing Clothes Function’, which can vary the thermal properties of the building surface autonomously; they become low solar absorptivity with high emissivity (selective emission surface) in summer and become opposite (selective absorption surface) in winter. According to the building surface temperature, this function is fulfilled by two ways shown in Fig.4. One is to transform the ‘thermo sense transformation material’ or ‘bimetal’ with different thermal properties on both sides of the fin plates, one side of which is a selective emission surface and the other selective absorption, set to the building. The other is to use the torque of the ‘shape-memory alloy (SMA)’ to rotate the fin plates with different thermal properties on both sides or the cylinder with different thermal properties on each half of the circumference, set to building.

3.1. Changing clothes wall (Experimental model)

Five kinds of south-facing experiment wall models were constructed for the building concrete wall; one ‘normal wall model’ with fixed surface thermal properties throughout the year, and four ‘changing clothes wall models’ the changing clothes unit installed onto. The size of each wall model was assumed to almost 1/5 scale of the exterior wall, 3 m in height, 6 m in width and 0.15 m in thickness. A concrete wall of 0.15 m thickness was substituted with the plywood in thickness 3 mm which makes almost the heat conductance equivalent to the concrete wall. To remove the thermal influences from the edges and the backside of the wall models, thermal insulation of 0.1 m thickness was installed at the edges and the backside of the models. The surfaces of those insulators were covered with aluminium foil to prevent them from absorbing solar radiation. Fig.5 shows the experiment wall models and Table 2 shows the measurement results of surface thermal properties of the models.

a. Normal wall model

A ‘normal wall model’ designed for a normal existing concrete wall was painted gray twice by zinc spray on the surface of the plywood.

b. Changing clothes wall model

1) ‘Horizontal rotation pipe’ (Fig.5(a))

The changing clothes unit consisted of the pipes of 20 mm diameter arranged horizontally, set onto the ‘normal wall model’. Each pipe was painted with selective emission on a half of circumference and with selective absorption on the other half.

2) ‘Vertical rotation pipe’ (Fig.5(b))

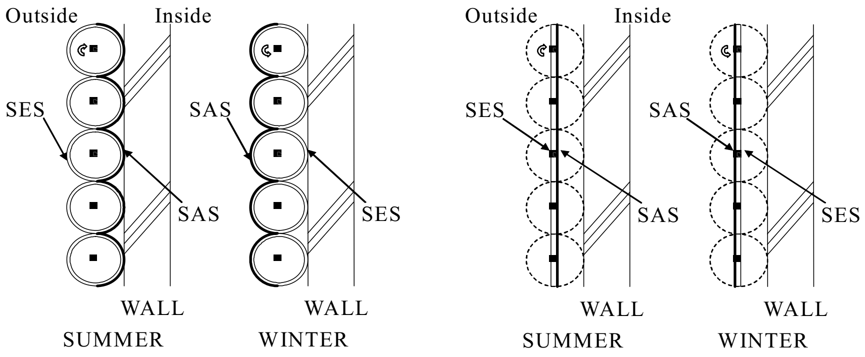
It was similar to the ‘horizontal rotation pipe’ except the pipes were arranged vertically. Surface thermal properties varied in the same way as the ‘horizontal rotation pipe’.

3) ‘Flat rotation plate type 1’ (Fig.5(c))

A unit consisted of long strips of aluminum fin plate, 1.2m in length × 0.02m in width × 2mm in thickness, arranged horizontally, painted with selective emission on the front surface and selective absorption on the back. The selective emission surface faced outside in summer, while the selective absorption surface in winter. In the experiment practice, one aluminum plate, 1.2m in length × 0.6m in width, painted with selective emission and selective absorption on each surface, was used, because the tightly arranged horizontal long strips of aluminum fin plate were equal in form to a piece of plate when seen vertically.

4) ‘Flat rotation plate type 2’ (Fig.5 (d))

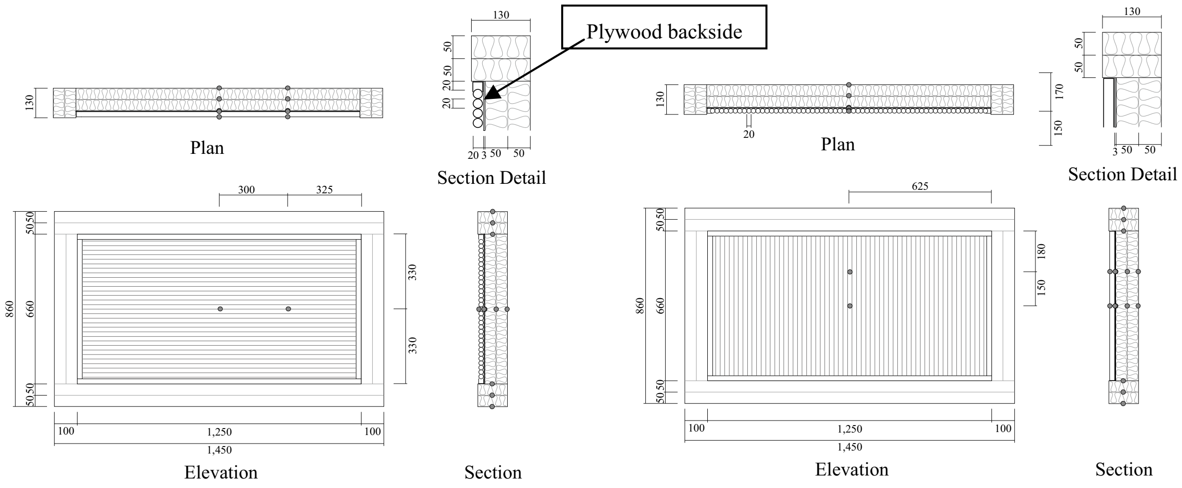
It was similar to the ‘flat rotation plate type 1’, though one side of the long aluminum plate was not coated with selective absorption paint. The selective emission surface of the plate faced outside in summer, while aluminum flat fin plates with selective emission surface on the upper side were arranged horizontally in winter. The selective absorption material for this type was so spread on the plywood surface that it could easily absorb the reflected solar radiation from the flat fin plates with selective emission in the daytime in winter.



(a) Cylinder type

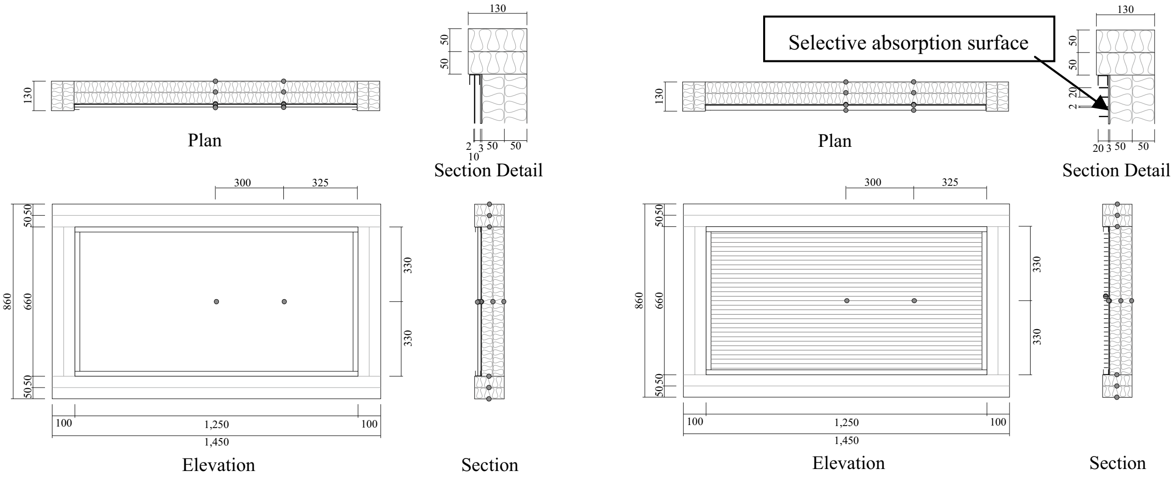
(b) Flat plate type

Fig. 4: System examples to fulfill 'Changing Clothes Function' of wall
[SAS:Selective Absorption Surface SES:Selective Emission Surface]



(a) 'Horizontal rotation pipe'

(b) 'Vertical rotation pipe'



(c) 'Flat rotation plate type 1'

(d) 'Flat rotation plate type 2': in winter

Fig. 5: Experiment wall models (• : Temperature measurement points)

Tab. 2: Measurement results of surface thermal properties

Experiment Wall Model (Material)	Absorptivity (Short wave-length)	Emissivity (Long wave-length)
Normal wall (plywood)	0.82	0.69
Selective absorption surface (plywood)	0.95	0.91
Aluminum plate	0.84	0.72
Selective emission surface (aluminum plate)	0.15	0.89
Selective absorption surface (aluminum plate)	0.94	0.53

3.2. Thermal effect of changing clothes wall

The experiment was carried out in Tsu city, Mie Prefecture, Japan, (34°44′N, 136°31′E) in summer and winter from July 2007 to February 2009. Table 3 shows the maximum temperature difference at the plywood backside of each wall model between the ‘changing clothes wall model’ and the ‘normal wall model’ in summer and winter. The maximum temperature decrease at the plywood backside through the surface selective emission was about 32-37 ºC in summer compared to the ‘normal wall model’, while the maximum temperature increase at the plywood backside through the surface selective absorption was about 3-29 ºC in winter. ‘Changing clothes walls’ were effective as a result and the thermal effect of the ‘flat rotation plate type 1’ was almost the best in both seasons. In winter the temperature at the plywood backside of the ‘flat rotation plate type 2’ was often lower than that of the ‘normal wall model’, because the outside surface of the plywood faced directly to the outside air, unlike the other ‘changing clothes wall models’ and there was no proof for selective absorption performance of the plywood surface from the measurement result of the surface thermal properties shown in Table 2.

Tab. 3: Maximum Temperature difference at the plywood backside (ºC)
(Increase in summer and decrease in winter)

Experiment Wall Model	Summer	Winter
Horizontal rotation pipe	32.6	20.2
Vertical rotation pipe	32.8	18.3
Flat rotation plate 1	34.4	28.4
Flat rotation plate 2	36.4	3.3

4. Complex thermal effect of ‘Perspirable function’ and ‘Changing clothes function’

A detached house with ‘Perspirable Function (PF)’ roofs and ‘Changing Clothes Function (CCF)’ walls was adopted as a simulation model of the “Biomimetic Building” and the annual heat loads and the room temperatures were theoretically predicted. The complex thermal effects were estimated by comparing them with those of common building which has neither ‘Perspiration Function’ nor ‘Changing Clothes Function’, that is, the evaporative cooling doesn’t occur nor does the thermal property of the wall surface vary.

4.1. Analysis method and algorithm

The method adopted was of calculating multi room temperature, heat load and ventilation rate, setting up simultaneous non linear equations of room heat balance, room air rate balance, and outer and inner wall surface heat balance, with room temperature, room pressure, and outer and inner wall surface temperatures for each room set as unknown quantities, which was shown in the literature. (Ishikawa, 1986a, 1986b) As for the heat conduction calculation of the wall, the finite difference method (implicit scheme) was used. The thermal properties of the outside wall surface were made variable by using each surface temperature obtained from the step just before in the calculation process.

4.2. Simulation model

A detached house was selected as a simulation model. The plan and elevation views are shown in Fig.6, the building material specifications in Fig.7, Table4 and Table5, and the schedules of various items in Fig.8.

4.3. Simulation condition

The areas selected were Sapporo(43°4′N, 141°21′E) as a cold weather region, Tokyo(35°39′N, 139°41′E) and Osaka(34°41′N, 135°30′E) as mild weather regions, and Naha(26°12′N, 127°41′E) as a hot weather region, and the Standard year of expanded AMeDAS weather data 1981-2000 for each area were used. Air-conditioning case according to the air-conditioning schedule shown in Fig.8 and non-air-conditioning (natural room temperature calculation) case were examined. A family of four (parents and two children) was assumed, and each schedule was assumed to be similar on the weekday, weekend and holiday. In the air-conditioning case, the room temperature and humidity were set at 27°C, 60%, respectively for cooling and 20°C, 40% for heating. As for the air-conditioning period for cooling, June - September were assumed for Sapporo, Tokyo, Osaka, and May - October for Naha, and moreover, for heating, November - April for Sapporo, December - March for Tokyo, Osaka, and December - February for Naha in thermal load calculation.

4.4. Simulation mode

The 'flat plate thermo sense transformation material' or some others set to the wall surface will express the change of surface thermal properties. In the simulation, eight changing modes (mode A-H) were set as shown in Fig.9. The 'Changing Clothes Function' manifests itself on the outside surfaces of all walls facing north, south, east, and west through the year. Mode A is 'Non Changing Clothes Mode (NCCM)', which means the thermal properties do not change through the year; solar absorptivity(a) is set at 0.89, emissivity(ε) at 0.84, considering the typical building material properties. The modes from B to H are 'Changing Clothes Mode (CCM)', where the thermal characteristics are assumed to vary linearly between two set temperatures high and low. The properties of materials considered, solar absorptivity(a) is set at 0.2-0.9, emissivity(ε) at 0.2-0.9. From mode B to D, the set high and low temperatures become higher gradually. Mode E has a wider range of set temperatures. The variation of the surface thermal properties can be fulfilled by rotating the cylinder and by changing a sunward surface ratio of selective emission to selective absorption (Fig.4(a)). The modes from F to H are also 'CCM', where the thermal properties are assumed to change at a certain temperature, fulfilled by rotating and turning over the flat plates with different properties between front and back surfaces (Fig.4(b)). From mode F to H, the set temperatures become gradually higher. As the 'Perspiration Function', evaporative cooling by perspiration on the roof was carried out in summer season and the sense temperature of the thermo-sensitive hydrogel was set at 25°C. The case only with the 'Perspiration Function' (without the 'Changing Clothes Function') in summer was called mode I ('Perspiration Mode (PM)'). Moreover, the complex function of the 'Perspiration' and the 'Changing Clothes' in summer was called 'Summer Complex

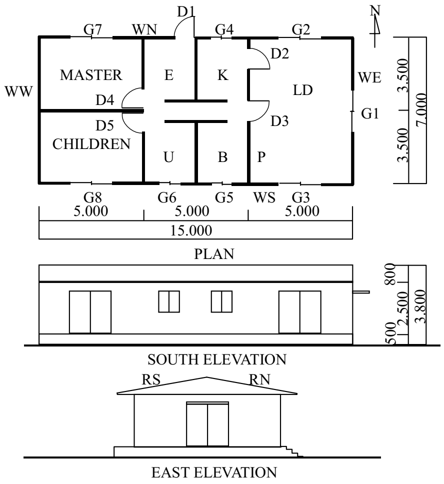


Fig. 6: Plan and elevation views of detached house

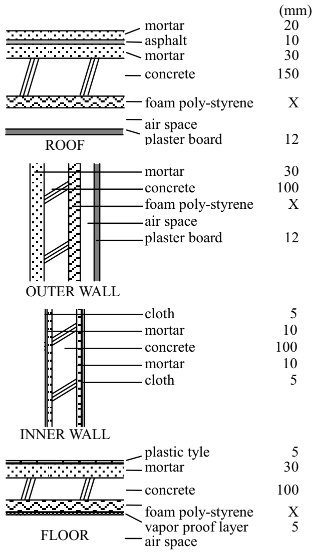


Fig. 7: Building material

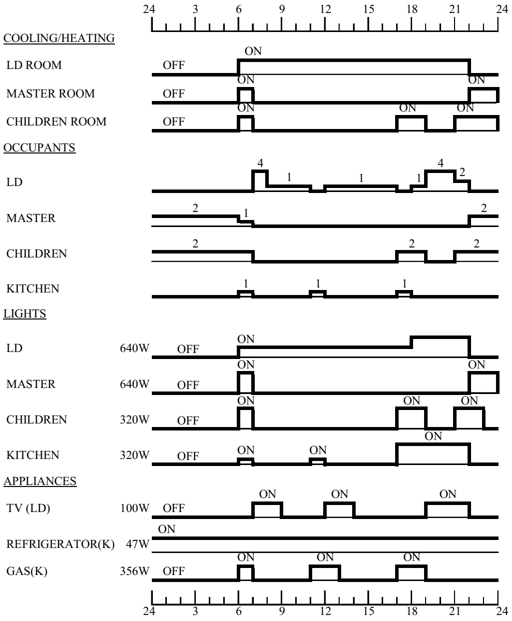


Fig. 8: Schedule of various items

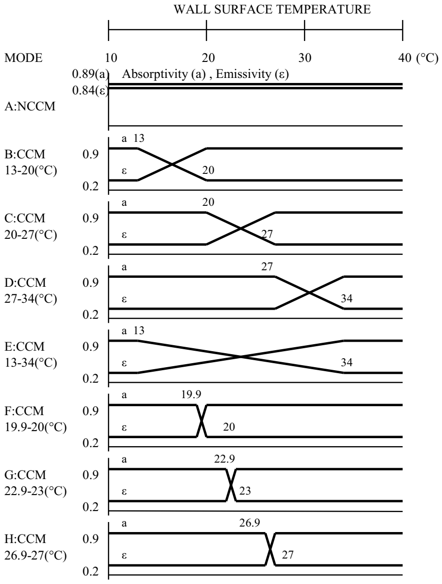


Fig. 9 : Variation of surface thermal properties

Tab. 4: Thickness(X) of wall insulation for each area (mm)

	Outer wall	Roof	Floor
Sapporo	50	50	50
Tokyo, Osaka	25	25	25
Naha	0	25	0

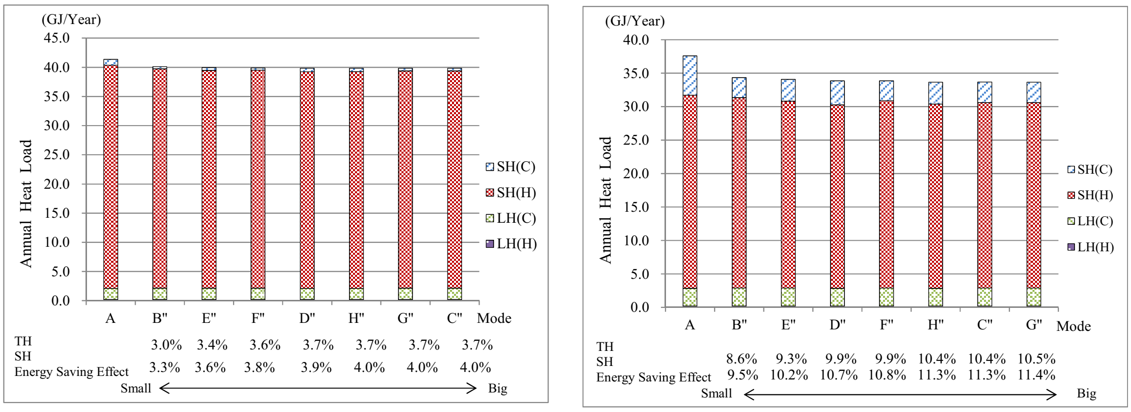
Tab. 5: Window specification for each area

	Window Type	Reflectivity	Transmissivity	Absorptivity	Heat Transfer Coefficient (W/㎡/K)
Sapporo	Sheet glass (Double)	0.120	0.653	0.228	3.5
Tokyo, Osaka	Sheet glass (Single)	0.072	0.802	0.126	6.3
Naha	IR reflecting glass	0.216	0.630	0.154	6.3

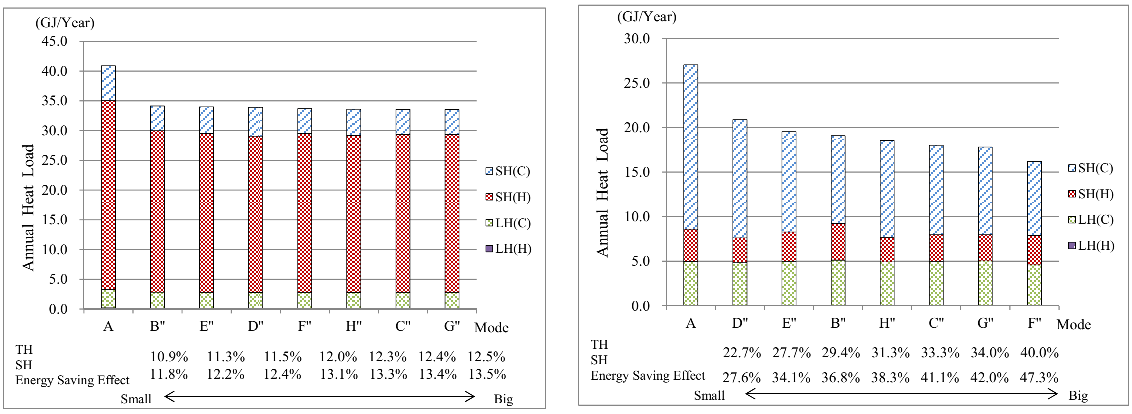
Mode (SCM)' (denoted by prime symbol), and the annual 'Complex' which is a complex of 'Perspiration' in summer and 'Changing Clothes' throughout the year, was called 'Complex Mode (CM)' (denoted by double prime).

4.5. Simulation results

As an example of the examination results in each area, Fig.10 shows the house total annual heat load (cooling load +|heating load|) in the air-conditioning case in each 'CM', where SH(C) denotes Sensible Heat (Cooling), SH(H); Sensible Heat (Heating), LH(C); Latent Heat (Cooling), LH(H); Latent Heat (Heating), and TH; Total Heat (SH +LH), respectively. Table 6 shows the energy saving effect, which is expressed; (heat load$_{\text{NCCM}}$ – heat load$_{\text{CCM, SCM or CM}}$)/ heat load$_{\text{NCCM}}$. Fig.11 shows the relationship of the energy saving effect in sensible heat load in between cooling and heating season in 'CCM' and 'CM'. Fig.12 shows the distribution of the energy saving effect in sensible heat load in 'CCM' and 'CM'. Further as the examination results of natural room temperature in non-air-conditioning case in each area, Table 7 shows the natural room temperature in LD Room, for example, and the maximum temperature difference between the 'NCCM', 'CCM', 'PM' and 'SCM', where the difference of room temperature is expressed; temperature$_{\text{NCCM}}$ – temperature$_{\text{CCM, PM or SCM}}$ in cooling season and temperature$_{\text{CCM}}$– temperature$_{\text{NCCM}}$ in heating season, respectively. In Table 7 the values expressed in 'CCM' and 'PM' were the values when the room temperature differences in 'SCM' became maximum. Table 8 shows the seasonal average natural room temperature in LD room, where the cooling season results were expressed in 'CCM' and 'SCM', while the heating season results in 'CCM'. Fig.13 shows the relationship of the seasonal average natural room temperature in LD room between in cooling and heating season in 'CCM' and 'CM'.



(a) Sapporo **(b) Tokyo**



(c) Osaka **(d) Naha**

Fig. 10: House total annual heat load in 'Complex Mode (CM)'

Tab.6: Energy saving effect in 'Changing Clothes Mode (CCM)', 'Summer Complex Mode (SCM)' and 'Complex Mode (CM)'

(a) Sapporo

	Cooling Season (%)				Heating Season (%)				Annual (%)			
	Summer Complex				Changing Clothes				Complex			
Effect	SH(C)		SH(C)+LH(C)		SH(H)		SH(H)+LH(C)		SH(C+|H|)		TH	
Big	B'	62.4	B'	31.5	D	2.3	D	2.3	C"	4.0	C"	3.7
↑	F'	60.9	F'	31.0	H	2.3	H	2.3	G"	4.0	G"	3.7
	G'	55.2	G'	28.4	C	2.2	C	2.2	H"	4.0	H"	3.7
	C'	53.3	C'	27.5	G	2.2	G	2.2	D"	3.9	D"	3.7
	E'	51.6	E'	26.5	E	2.1	E	2.1	F"	3.8	F"	3.6
	H'	44.8	H'	23.3	F	2.1	F	2.1	E"	3.6	E"	3.4
↓	I	44.6	I	22.8	B	2.0	B	2.0	B"	3.3	B"	3.0
Small	D'	38.9	D'	20.3								

(b) Tokyo

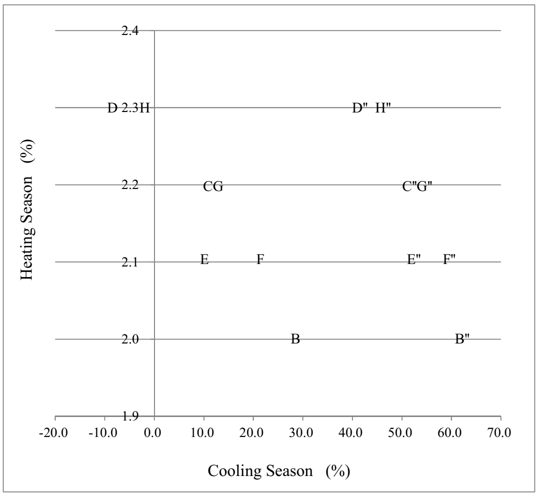
	Cooling Season (%)				Heating Season (%)				Annual (%)			
	Summer Complex				Changing Clothes				Complex			
Effect	SH(C)		SH(C)+LH(C)		SH(H)		SH(H)+LH(C)		SH(C+|H|)		TH	
Big	B'	48.9	B'	39.2	D	4.2	D	4.1	G"	11.4	G"	10.5
↑	F'	48.8	F'	39.2	H	3.9	H	3.8	C"	11.3	C"	10.4
	G'	48.4	G'	38.9	C	3.5	C	3.5	H"	11.3	H"	10.4
	C'	47.5	C'	38.2	G	3.4	G	3.4	F"	10.8	F"	9.9
	H'	44.5	H'	35.8	E	3.0	E	3.0	D"	10.7	D"	9.9
	E'	44.4	E'	35.7	F	3.0	F	3.0	E"	10.2	E"	9.3
↓	D'	38.8	D'	31.3	B	2.0	B	2.0	B"	9.5	B"	8.6
Small	I	35.5	I	28.5								

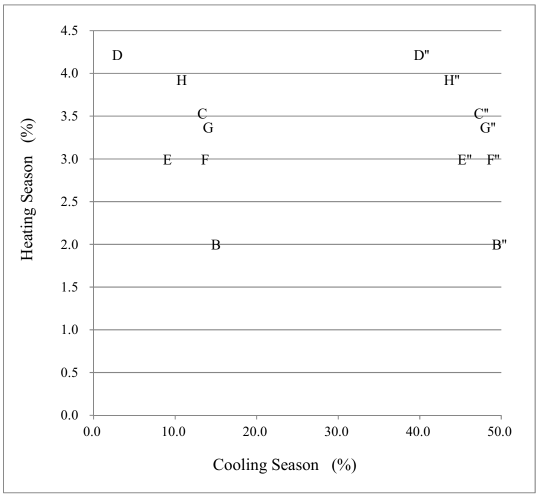
(c) Osaka

	Cooling Season (%)				Heating Season (%)				Annual (%)			
	Summer Complex				Changing Clothes				Complex			
Effect	SH(C)		SH(C)+LH(C)		SH(H)		SH(H)+LH(C)		SH(C+|H|)		TH	
Big	B'	47.3	B'	40.3	D	4.0	D	4.0	G"	13.5	G"	12.5
↑	F'	47.3	F'	40.3	H	3.8	H	3.8	C"	13.4	C"	12.4
	G'	46.9	G'	40.0	C	3.5	C	3.5	H"	13.3	H"	12.3
	C'	46.3	C'	39.5	G	3.5	G	3.5	F"	13.1	F"	12.0
	H'	44.0	H'	37.6	E	3.1	E	3.1	D"	12.4	D"	11.5
	E'	43.6	E'	37.2	F	3.1	F	3.1	E"	12.2	E"	11.3
↓	D'	39.1	D'	33.4	B	2.3	B	2.3	B"	11.8	B"	10.9
Small	I	35.0	I	29.8								

(d) Naha

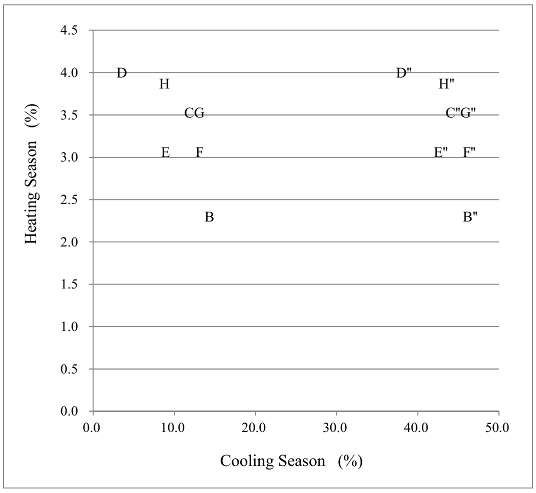
	Cooling Season (%)				Heating Season (%)				Annual (%)			
	Summer Complex				Changing Clothes				Complex			
Effect	SH(C)		SH(C)+LH(C)		SH(H)		SH(H)+LH(C)		SH(C+|H|)		TH	
Big	F'	54.2	F'	48.0	D	26.3	D	26.3	F"	47.3	F"	40.0
↑	B'	46.0	B'	38.7	H	24.8	H	24.8	G"	42.0	G"	34.0
	G'	45.9	G'	38.7	G	20.3	G	20.3	C"	41.1	C"	33.3
	C'	45.0	C'	38.0	C	19.4	C	19.4	H"	38.3	H"	31.3
	H'	41.1	H'	34.8	F	10.9	F	10.9	B"	36.8	B"	29.4
	E'	38.5	E'	32.5	E	10.6	E	10.6	E"	34.1	E"	27.7
↓	D'	28.5	D'	24.2	B	-13.2	B	-13.2	D"	27.6	D"	22.7
Small	I	18.6	I	15.7								

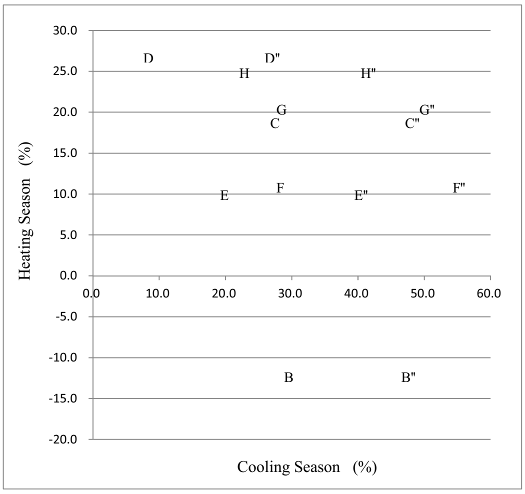




(a) Sapporo

(b) Tokyo

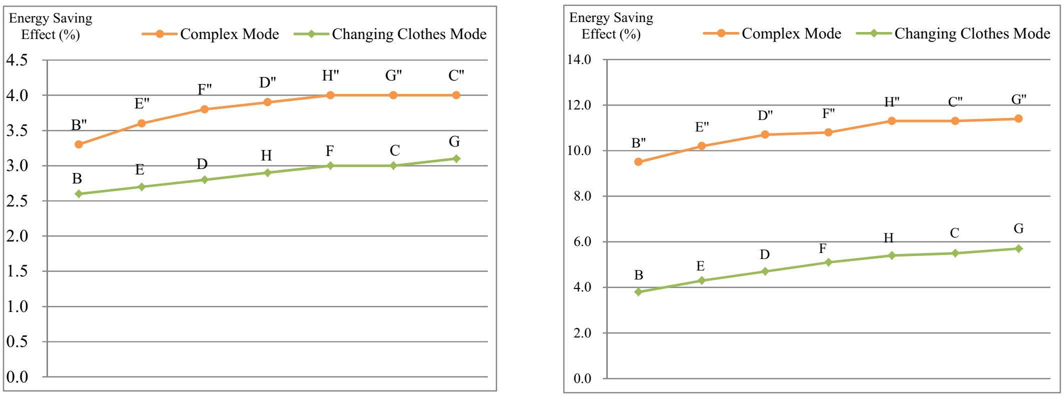




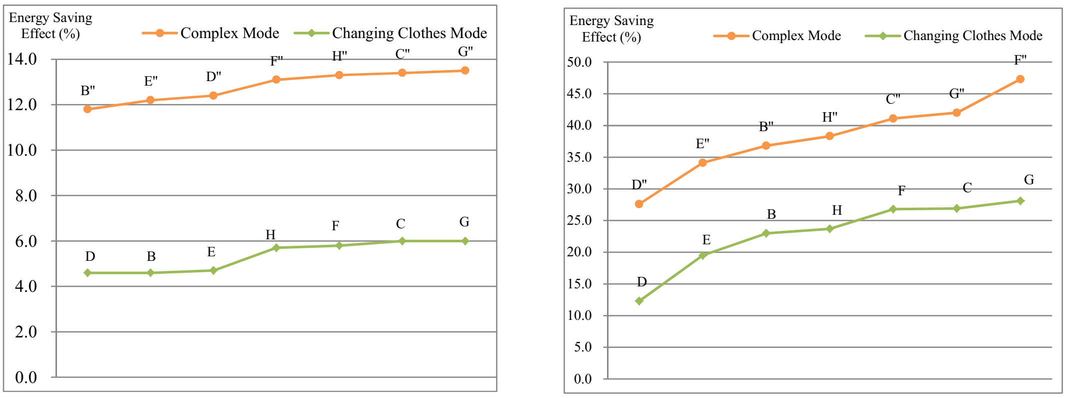
(c) Osaka

(d) Naha

Fig. 11: Relationship of energy saving effect in sensible heat load in between cooling and heating season in 'Changing Clothes Mode (CCM)' and 'Complex Mode (CM)', (double prime)



(a) Sapporo **(b) Tokyo**



(c) Osaka **(d) Naha**

Fig. 12: Distribution of energy saving effect in sensible heat load (cooling +|heating|) in 'Changing Clothes Mode (CCM)' and 'Complex Mode (CM)', (double prime)

Tab. 7: Natural room temperature and maximum room temperature difference between Normal Mode (Mode A), 'Changing Clothes Mode (CCM)' , 'Perspiration Mode (PM)' and 'Summer Complex Mode (SCM)' (LD Room)

(a) Cooling season

	Room Temperature (C˚)						Temperature Difference (C˚)			Time and Date (Example)
	Normal (Mode A)	Changing Clothes		Perspiration	Summer Complex		Changing Clothes	Perspiration	Summer Complex	
Sapporo	30.7	B	30.0	29.2	B'	28.5	0.7	1.5	2.2	7/ 8 18:00
Tokyo	34.9	B	34.1	32.9	B'	32.1	0.8	2.0	2.8	7/19 18:00
Osaka	34.3	B	33.5	32.2	B'	31.5	0.8	2.0	2.8	7/17 16:00
Naha	35.5	B, C, F	33.6	34.5	B', C', F'	32.5	1.9	1.0	3.0	7/18 16:00

(b) Heating season

	Room Temperature (C˚)			Temperature Difference (C˚)	Time and Date (Example)
	Normal (Mode A)	Changing Clothes		Changing Clothes	
Sapporo	1.9	H	2.3	0.4	2/19 12:00
Tokyo	8.6	D	9.2	0.6	2/26 13:00
Osaka	7.9	H	8.3	0.4	2/11 17:00
Naha	16.6	D	17.2	0.6	2/ 3 11:00

4.6. Considerations

The annual energy saving effect due to 'Changing Clothes' in each region became the most evident in mode G (3.1% in sensible heat load (SH)) and mode G,C,F (2.9% in total heat load (TH)) in Sapporo, in G (5.7% in SH) and G (5.2% in TH) in Tokyo, in G,C (6.0% in SH) and G (5.7% in TH) in Osaka, and in G (28.1% in SH) and G (22.8% in TH) in Naha. The energy saving effect in cooling season due to the evaporating cooling by roof 'Perspiration' without 'Changing Clothes' (mode I) became the most evident (44.6% in sensible heat load (SH)) and 22.8% in total heat load (TH)) in Sapporo, 35.5% (SH) and 28.5% (TH) in Tokyo, 35.0% (SH) and 29.8% (TH) in Osaka, and 18.6% (SH) and 15.7% (TH) in Naha. As the results, the annual saving energy effect in 'Complex' due to the 'Perspiration' and 'Changing Clothes' became the most evident in mode C",G",H" (4.0% in SH) and mode C",D",G",H" (3.7% in TH) in Sapporo, in G" (11.4% in SH) and G"

Tab.8: Seasonal average natural room temperature in 'Changing Clothes Mode (CCM)' and 'Summer Complex Mode (SCM)' (LD Room)

(a) Sapporo

	Cooling Season				Heating Season	
	Changing Clothes		Summer Complex		Changing Clothes	
Effect	Mode	Room Temperature(°C)	Mode	Room Temperature(°C)	Mode	Room Temperature(°C)
Big	B	25.0	B'	24.3	C	6.7
↑	F	25.1	F'	24.4	D	6.7
	A	25.3	C'	24.6	E	6.7
	C	25.3	E'	24.6	F	6.7
	E	25.3	G'	24.6	G	6.7
	G	25.3	I	24.7	H	6.7
	H	25.5	H'	24.8	B	6.6
↓	D	25.6	D'	24.9	A	6.4
Small			A	25.3		

(b) Tokyo

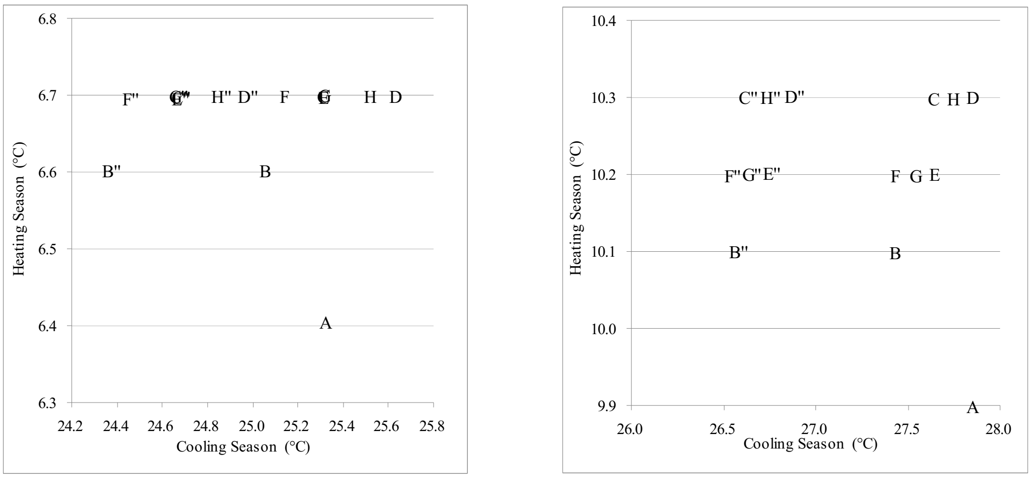
	Cooling Season				Heating Season	
	Changing Clothes		Summer Complex		Changing Clothes	
Effect	Mode	Room Temperature(°C)	Mode	Room Temperature(°C)	Mode	Room Temperature(°C)
Big	B	27.4	B'	26.5	C	10.3
↑	F	27.4	F'	26.5	D	10.3
	G	27.5	C'	26.6	H	10.3
	C	27.6	G'	26.6	E	10.2
	E	27.6	E'	26.7	F	10.2
	H	27.7	H'	26.7	G	10.2
	A	27.8	D'	26.9	B	10.1
↓	D	27.8	I	26.9	A	9.9
Small			A	27.8		

(c) Osaka

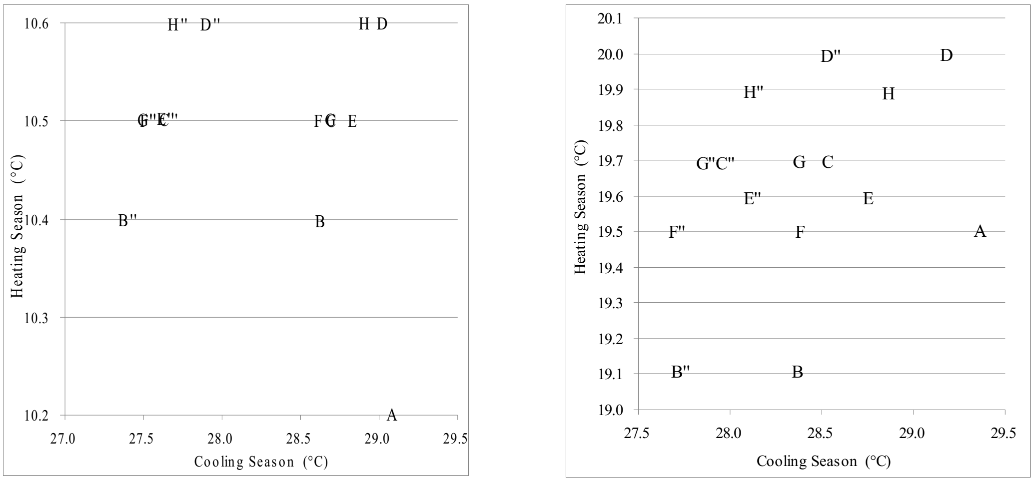
	Cooling Season				Heating Season	
	Changing Clothes		Summer Complex		Changing Clothes	
Effect	Mode	Room Temperature(°C)	Mode	Room Temperature(°C)	Mode	Room Temperature(°C)
Big	B	28.6	B'	27.4	D	10.6
↑	F	28.6	F'	27.5	H	10.6
	C	28.7	G'	27.5	C	10.5
	G	28.7	C'	27.6	E	10.5
	E	28.8	E'	27.6	F	10.5
	H	28.9	H'	27.7	G	10.5
	D	29.0	D'	27.9	B	10.4
↓	A	29.1	I	27.9	A	10.2
Small			A	29.1		

(d) Naha

	Cooling Season				Heating Season	
	Changing Clothes		Summer Complex		Changing Clothes	
Effect	Mode	Room Temperature(°C)	Mode	Room Temperature(°C)	Mode	Room Temperature(°C)
Big	B	28.4	B'	27.7	D	20.0
↑	F	28.4	F'	27.7	H	19.9
	G	28.4	G'	27.8	C	19.7
	C	28.5	C'	27.9	G	19.7
	E	28.7	E'	28.1	E	19.6
	H	28.8	H'	28.1	A	19.5
	D	29.2	D'	28.5	F	19.5
↓	A	29.4	I	28.7	B	19.1
Small			A	29.4		



(a) Sapporo **(b) Tokyo**



(c) Osaka **(d) Naha**

Fig.13: Relationship of seasonal average natural room temperature in between cooling and heating season in 'Changing Clothes Mode (CCM)' and 'Complex Mode (CM)', (double prime) (LD Room)

(10.5% in TH) in Tokyo, in G" (13.5% in SH) and G" (12.5% in TH) in Osaka, and in F" (47.3% in SH) and F" (40.0% in TH) in Naha. The energy saving effect values both in cooling and heating period of 'Complex Mode' were positive, and the 'Complex' effect of 'Changing Clothes Function' and 'Perspirable Function' proved to be good in all the regions. The energy saving effect grew bigger in cold region, mild region and hot region in that order, because the cooling load also grew bigger in that order, and the decrease of the cooling load due to evaporation cooling by 'Perspiration' in summer was remarkable, and thermal effect by 'Changing Clothes' was added to this. In Fig.11 the difference in saving energy effect between the same symbols (B"-B, for example) in cooling season showed the thermal effect of evaporative cooling by 'Perspiration'. Fig.14 shows the relationship between wall thermal properties determined by 'CCM' and average outdoor temperature in summer and winter in each area. From Fig.14, since the surface state at the average outdoor temperature in winter became effective selective absorption (solar absorptivity(a) at 0.9, emissivity(ε) at 0.2) in all modes and regions, except mode B in Naha, there was no such big difference in the energy saving effect. On the contrary, in summer the most effective mode was different in all regions, because there were modes where the surface state at the average outdoor temperature already became perfectly selective emission (solar absorptivity(a) at 0.2, emissivity(ε) at 0.9) (Mode B,F,G for Tokyo, Osaka, and Naha) or modes where the surface state did not become the selective emission (Mode C,D,E,H for Tokyo, Osaka, and Naha). The mode where the surface was in effective state (selective emission) demonstrated the high energy saving effect in summer. The improvement effect of a natural room temperature in non-air-conditioning case had a similar tendency. The maximum decrease of the natural room temperature in cooling season became the most evident in mode B (0.7°C) in Sapporo, in B (0.8°C) in Tokyo, in B (0.8°C) in Osaka, and in B,C,F(1.9°C) in Naha due to the 'Changing Clothes' and in mode B' (2.2°C) in Sapporo, in B'(2.8°C) in Tokyo, in B' (2.8°C) in Osaka, and in B',C',F' (3.0°C) in Naha due to the 'Summer Complex ', while the maximum increase of the natural room temperature in heating season became the most evident in mode H (0.4°C) in Sapporo, in D (0.6°C) in Tokyo, in H (0.4°C) in Osaka, and in D (0.6°C) in Naha due to the 'Changing Clothes'. Furthermore the maximum decrease of the seasonal average natural room temperature in cooling season became the most evident in mode B (0.3°C) in Sapporo, in B (0.4°C) in Tokyo, in B (0.5°C) in Osaka, and in B,F,G(1.0°C) in Naha due to the 'Changing Clothes' and in mode B' (1.0°C) in Sapporo, in B'(1.3°C) in Tokyo, in B' (1.7°C) in Osaka, and in B',F' (1.7°C) in Naha due to the 'Summer Complex', while the maximum increase of the seasonal average natural room temperature in heating season became the most evident in mode C (0.3°C) in Sapporo, in C,D,H (0.4°C) in Tokyo, in D,H (0.4°C) in Osaka, and in D (0.5°C) in Naha due to the 'Changing Clothes'. As for the 'Changing Clothes Mode' and 'Complex Mode', the mode which demonstrated the biggest energy saving effect all through the year was mode G in Sapporo (cold region), Tokyo and Osaka (mild region), and mode F in Naha (hot region). Mode B and F had a great effect in the cooling period for any area, because solar absorptivity is small while emissivity is big even at a low surface temperature. Mode D was effective in the heating period for any area, because solar absorptivity is big while emissivity is small even at a high surface temperature.

5. Conclusion

The thermal effect of "Biomimetic Building (BB)" with a 'Complex' of 'Perspiration Function (PF)' and 'Changing Clothes Function (CCF)' was estimated theoretically, and the desirable changing mode of thermal properties of the 'CCF' were demonstrated, by comparing the results obtained from the common building without 'PF' and 'CCF'. The energy saving effect due to the 'Complex' of 'CCF' and 'PF' in the typical detached house in Japan was 4 to 47% in house sensible heat load and 3.7 to 40 % in house total (sensible + latent) heat load. The thermal effect was remarkable in all the regions such as a cold region (Sapporo), mild regions (Tokyo and Osaka), and a hot region (Naha), and it became remarkably better in the hot weather region than in the cold weather region, because the energy saving due to the decrease of the cooling load by 'Perspiration' in summer was efficient. The maximum decrease of natural room temperature for each area in non-air-conditioning case in summer in 'Complex' was 2.2 to 3.0°C, while the maximum increase in winter in 'Changing Clothes' was 0.4 to 0.7°C. The improvement of the building environment in 'Complex' of 'CCF' and 'PF' was also effective in all the regions and the regional thermal characteristics were confirmed. Moreover the desirable modes of the 'Changing Clothes' annual and seasonal for each region in Japan were determined.

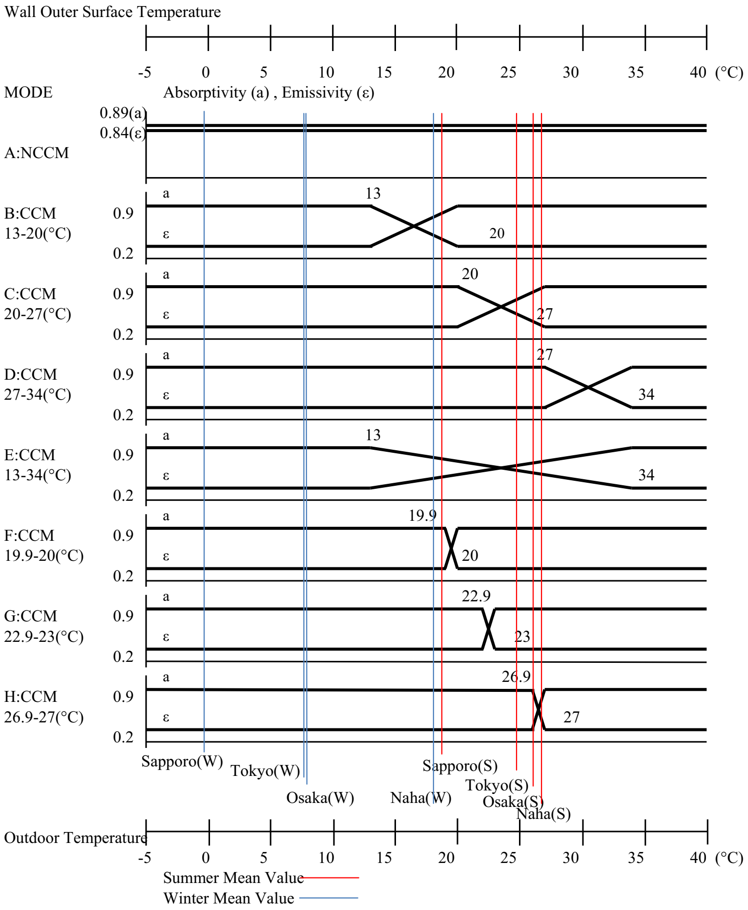


Fig.14: Relationship between 'Changing Clothes Mode (CCM)' and seasonal average outdoor temperature in each area

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