Comparison of the Effects of Various Countermeasures on Energy Consumption in a Residential Building

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ABSTRACT: In this paper, we simulated and compared the effects of the various energy consumption countermeasures in residential building in terms of "building specific and outdoor environment", "occupant behavior" and "equipment use". Specifically, we took into consideration the setting in place of high insulation walls, sunroofs and trees as "building countermeasures" and the setting of external blinds, use of cross ventilation, relaxation of preset cooling and heating temperatures, and the effective use of sunshades as "occupant countermeasures." The introduction of high-efficiency air-conditioners and lamps were evaluated as "equipment countermeasures". Our results showed that the energy consumption reduction effects of these countermeasures were 5.8%, 19.4% and 5.0%, respectively. The energy consumption reduction achieved when we introduce these measures in the order of "building countermeasures", "occupant countermeasures" and "equipment countermeasures" in a step-by-step manner were 5.8%, 17.7% and 5.2%, and the total energy reduction was 26.5%. These results showed that the effects of occupant behavior on energy reduction were higher than the other categories.
Keywords: energy reduction, passive cooling and heating, day-lighting, occupant behavior

INTRODUCTION

Recently, the control carbon dioxide emissions and the reduction of the fossil fuel use have become priority issues worldwide as countermeasures against global warming. The Kyoto Protocol was ratified in 2005, and in Japan we have been charged with reducing greenhouse gas emissions by 6%, to the 1990 ratio, in by the first promise period of 2008 to 2012. Carbon-dioxide emissions from the residential sector in Japan have increased by 37% from 1990 levels. This is especially notable in the residential sector where the proportion of energy consumption for air-conditioning is about 34% and lighting is about 5%. Thus, the need for countermeasures for these uses has become even more essential.

Recently, quantitative studies that evaluate the potential of energy conservation normally focus on countermeasures that ignore relations between buildings and the outside environment [Fig. 1], such as a study of a well-insulated and high-efficiency appliances (B. Boardman [1], J. A. Clarke et al [2]). However, insufficient study has been conducted on the impact of the relationship between buildings and the surrounding environment on energy consumption.

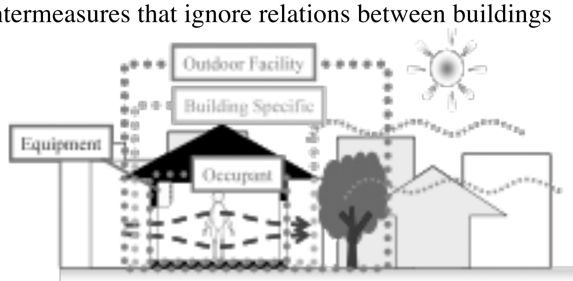

Fig. 1: Ambient environment around a house

Because of the above, H. Habara [3] constructed the "SCIENCE vent" simulation model, which is capable of predicting energy consumption by air-conditioning and lighting for a residential building, and which takes into consideration the relationship between a building and the outside environment, as well as occupant indoor thermal environment control behavior (e.g. cross ventilation use, air conditioning, etc.).

In this paper, we used "SCIENCE vent" to simulate and compare the effects of various energy reduction countermeasures in a residential building. These simulations took into consideration "building specific and outdoor facility" countermeasures, "behavior" and "equipment" countermeasures.

SUMMARY OF SIMULATION MODE

An overview of "SCIENCE vent" is provided in Fig. 2. As can be seen, "SCIENCE vent" consists of three parts, outdoor/indoor radiant environment analysis, outdoor/indoor wind environment analysis and the indoor thermal environment analysis. The simulation calculates

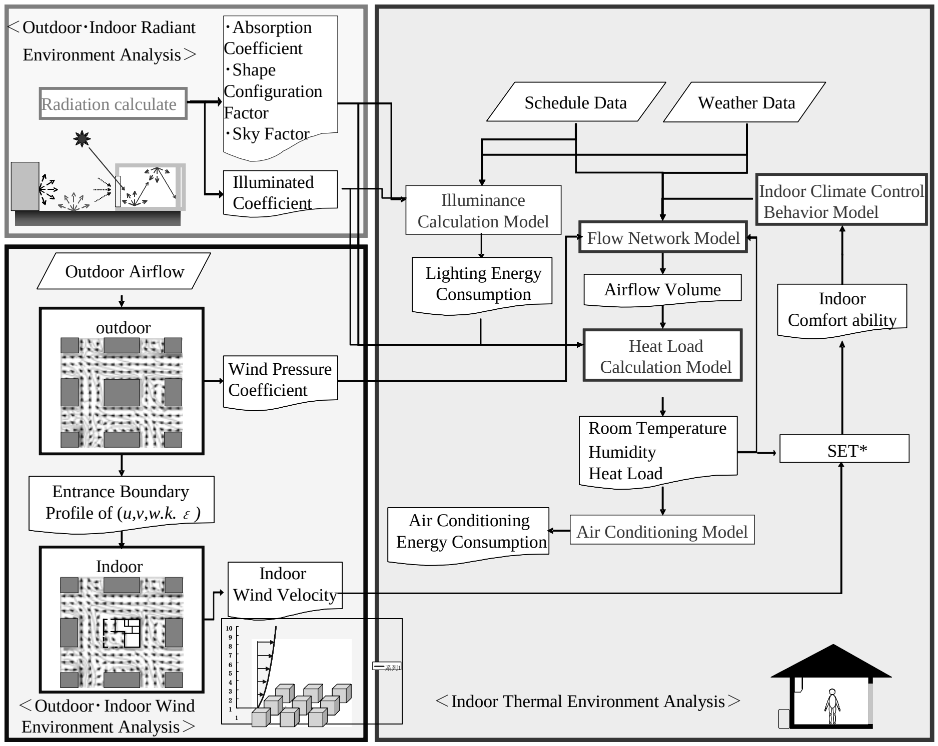

Figure 2: Overview of "SCIENCE vent"

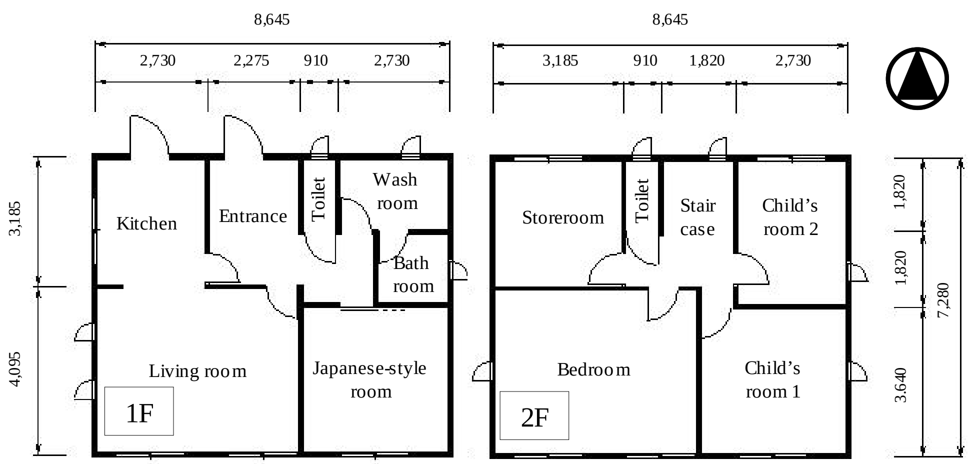

Figure 3: Floor plan of a standard residential house model proposed by the Architectural Institute of Japan

SUMMARY OF SIMULATION MODE

An overview of "SCIENCE vent" is provided in Fig. 2. As can be seen, "SCIENCE vent" consists of three parts, outdoor/indoor radiant environment analysis, outdoor/indoor wind environment analysis and the indoor thermal environment analysis. The simulation calculates each part separately to obtain an absorption coefficient, shape configuration factor and sky factor from the outdoor/indoor radiant environment analysis, and a wind pressure coefficient, and an indoor wind velocity measurement from the outdoor/indoor wind environment analysis. Using these parameters, the occupant indoor thermal environment control behavior, such as the opening or closing windows and the use of the air conditioning and lighting are decided [3] and the energy consumption of those activities are calculated in the indoor thermal environment analysis.

SUMMARY OF SIMULATION

The calculation target was the standard residential house model proposed by the Architectural Institute of Japan (AIJ) [4]. For simplification, the roof was assumed to be flat. Fig. 3 shows the floor plan of the target house. For the outdoor condition, it was assumed that there were no other buildings around the target house. For weather calculation conditions, we used expanded AMeDAS

Table 1: Setup contents

Article		Setup Content
Outdoor Condition	Weather	Expanded AMeDAS Weather Data : 1981～2000Standard Year(Osaka)[5]
	Solar Reflectance	Ground : 16% Wall Surface : 40%
Building Specific	Name	The Standard Residential House Model Proposed by AIJ
	Construction	Wooden
	Insulation	Equivalent to Old Energy Saving Code (Thermal Transmittance : 0.922 W/m2)
Lifestyle	Household Composition	A Couple and Their Two Children
	Curtain	Bedtime : Shade+Lace, Else Time : Lase
	Preset Temperature and Humidity	Cooling : 27°C, 60%, Heating : 21°C
	Opening Pattern	Door : Close, Window : Open (Occupant in the Room)
	Heat Generation by Equipment	Set by Auto Setup Program of Schduling 「SCHEDULE」[6]
	Heat Generation by Lighting	5 W/m^2 （When Occupant is in the Room, Illuminance of the Room≦75lx）

Table 2: The relationship of each countermeasure

Case name	Content	Case name	Content	Case name	Content	Case name	Content
"Hi-In"	Set highly-insulated outer wall	"Build"	Countermeasure to Building	"B-O"	Countermeasure of "Build" and "Occ"	"B-O-E"	Countermeasure of "B-O" and "Equ"
"Sunroof"	Set sunroof						
"Tree"	Set trees						
"Blind"	External blind use	"Occ"	Countermeasure by Occupant Behavior				
"Vent"	Cross ventilation use						
"Temp"	Change preset temperature						
"Shade"	Effective use of shade						
"Air"	High-efficiency air conditioner use	"Equ"	Countermeasure by High-Efficiency Equipment				
"Lamp"	High-efficiency lamp use						

weather data of a standard year in Osaka [5]. However, since this data is provided in 1-hour intervals, it was interpolated at 15-minute intervals (calculation time-step) at calculation using Lagrange polynomial interpolation. For the building specifications, the insulation efficiency was set at the equivalent for the old energy saving standard in Japan. The window glass was single pane and the 0.65-meter-long eaves were set in position 0.20 m from the top of the window. The household was considered to be a family of four: husband (employed), wife (housewife) and 2 children (boy and girl, both at school). The schedule of occupancy and heat generation were set by applying "SCHEDULE" [6], which was an automatic setup scheduling program. Regarding the use of sunshades, a heavy curtain was used at bedtime and lace curtains were used at other times. Electric air conditioner was used for cooling and heating, and the preset temperature and humidity are levels were set at 27 and 60% for cooling and 21 °C for heating [Table 1]. The details of various simulation cases are explained below, and Table 2 shows the relationship of each countermeasure. In addition, it was assumed that the compound countermeasures were introduced in order of to building, by occupant behavior and to the equipment.

Base Case (“Base”) This was simulated using the conditions shown above to provide a baseline in order to observe the energy reduction effectiveness of various countermeasures.

High Insulation Case (“Hi-In”) The insulation efficiency was changed from "Base" (thermal transmittance: 0.922 W/m^2) to the equivalent of the next generation energy saving standard (0.692 W/m^2), and the window glass was changed from single to double pane.

Sunroof Case (“Sunroof”) Sunroofs that were 0.75 m square were set in bedroom, child's room 1 and child's room 2 on the second floor. Direct sunlight was blocked by the blind when there was no occupant in the room during the summer season, and onset at the same insulation level used for curtains on outer wall windows during the winter season.

Tree Case (“Tree”) The 6.0-meter-high trees were added to the "Base" conditions and set near the south face and west face of the target building. In the winter season, it is presumed to have lost its leaves.

External Blind Case (“Blind”) External window blinds were added the "Base" conditions. These were presumed to be used when there was no occupant in the room in the daytime.

Cross Ventilation Case (“Vent”) Cross ventilation was added to the "Base" conditions and presumed to be used during the summer. Opening or closing of the window was decided based on H. Habara's result [3].

Preset Temperature Relaxation Case (“Temp”) The preset air conditioning temperature was relaxed 1 °C compared with “Base”: cooling was set at 28 °C and heating was set at 20 °C.

Effective Use of Sun Shades Case (“Shade”) The usage of sunshades was changed from “Base” to optimal conditions

High-Efficiency Air Conditioner Case (“Air”) A high-efficiency air conditioner was used and compared with “Base” conditions [Table 3].

High-Efficiency Lamp Case (“Lamp”) A high-efficiency lamp (4.5 W/m2) was used and compared with “Base” conditions (5.0 W/m2).

Occupant Behavior Case (“Occ”) Each condition of “Vent”, “Tem” and “Shade” was considered in addition to “Base” conditions.

High-Efficiency Equipment Case (“Equ”) Each “Air” and “Lamp” condition was applied to the “Base” condition and considered.

Building Countermeasure Case (“Build”) Each condition stipulated in “Hi-In”, “Sunroof”, “Blind” and “Tree” was applied to the “Base” condition and considered in addition to “Base”.

”Build” + “Occ” Case (“B-O”) Each condition stipulated in “Occ” was considered in addition to “Build”.

”B-O” + “Equ” Case (“B-O-E”) The condition stipulated in “Equ” was considered in addition to “B-O”.

Table 3: Air conditioner COP (coefficient of

Size	“Base”-COP		“Air”-COP	
	cooling	heating	cooling	heating
For 10 m^2	6.03	5.98	6.47	6.76
For 15 m^2	5.75	5.67	6.02	6.67
For 20 m^2	4.19	5.16	5.26	5.68

SIMULATION RESULTS

Energy consumption in each condition and proportion of energy reduction are shown in Table 4, and details are explained below.

High Insulation Case (“Hi-In”) When compared with the “Base” condition, decreased heat flow through outer wall from outside reduced energy consumption for cooling 7.0% and for heating was 9.2%. However, due to the reduced amount of solar insolation penetrating the room resulting from the use of double-pane window glass, energy consumption for lighting increased by 4.7%. As a result, total yearly energy consumption was reduced by 5.7%.

Sunroof Case (“Sunroof”) When compared with the “Base” condition, even though there was an increase in radiation cooling at night during the summer months, it was offset by the increased heat load imposed from outside during the day. As a result, energy consumption

Table 4: Results of the simulation

Case	Energy consumption [kWh/year]				Proportion of Energy Reduction to Base [%]			
	cooling	heating	lighting	total	cooling	heating	lighting	total
Base	332	1112	420	1864	0.0	0.0	0.0	0.0
Hi-In	309	1010	439	1758	7.0	9.2	**-4.7**	5.7
Sunroof	332	1112	413	1858	**-0.2**	0.0	1.5	0.3
Tree	301	1112	442	1855	9.4	0.0	**-5.3**	0.5
Blind	310	1112	420	1842	6.6	0.0	0.0	1.2
Vent	311	1112	415	1839	6.2	0.0	1.0	1.3
Temp	263	960	420	1643	20.7	13.7	0.0	11.9
Shade	307	1020	406	1733	7.5	8.3	3.1	7.0
Air	294	1093	420	1807	11.3	1.8	0.0	3.1
Lamp	331	1115	382	1828	0.3	**-0.3**	8.9	1.9
Occ	226	875	402	1503	32.0	21.3	4.2	19.4
Equ	293	1096	382	1771	11.6	1.5	8.9	5.0
Build	296	1010	450	1756	10.8	9.2	**-7.3**	5.8
B-O	207	814	425	1446	37.6	26.8	**-1.3**	22.4
B-O-E	185	799	387	1370	44.3	28.2	7.8	26.5

for cooling increased by 0.2%. However, the increased amount of solar energy penetrating the room, reduced energy consumption for lighting by 1.5% and yearly energy consumption was reduced by 0.3%.

Tree Case (“Tree”) When compared with the “Base” condition, due to the reduction in solar energy penetrating the room, energy consumption for cooling was reduced by 9.4% and energy consumption for lighting increased by 5.3%. As a result, yearly energy consumption was reduced by 0.5%.

External Blind Case (“Blind”) When compared with the “Base” condition, due to a reduction in solar energy penetrating the room when no occupant was present, energy consumption for cooling was reduced by 6.6%. As a result, yearly energy consumption was reduced by 1.2%.

Cross Ventilation Case (“Vent”) When compared with the “Base” condition, energy consumption for cooling was reduced by 6.2%. Due to the increase in the amount of solar energy allowed to penetrate the room by opening the window, energy consumption for lighting was reduced by 1.0%. As a result, yearly energy consumption was reduced by 1.3%.

Relaxation of Preset Temperature Case (“Temp”) When compared with the “Base” condition, energy consumption for cooling was reduced by 20.7% and energy consumption for heating was 13.7%. As a result, yearly energy consumption was reduced by 11.9%.

Effective Use of Sun Shades Case (“Shade”) When compared with the “Base” condition, by effectively permitting and permitting solar energy from penetrating the room, energy consumption for cooling was reduced by 7.5%, consumption for heating was reduced 8.3% and consumption for lighting was reduced 3.1%. As a result, yearly energy consumption was reduced by 7.0%.

High-Efficiency Air Conditioner Case (“Air”) When compared with the “Base” condition, energy consumption for cooling was reduced by 11.3% while consumption for heating was reduced 1.8%. As a result, yearly energy consumption was reduced by 3.1%.

High-Efficiency Lamp Case (“Lam”) When compared with the “Base” condition, due to the reduction of heat generation caused by lighting, energy consumption for cooling decreased by 0.3% while consumption for heating increased by 0.3% and consumption for lighting decreased by 8.9%. As a result, yearly energy consumption was reduced by 1.9%.

Occupant Behavior Case (“Occ”) When compared with the “Base” condition, due to the reasons stipulated by “Vent”, “Temp” and “Shade”, energy consumption for cooling was reduced by 32.0%, for heating by 21.3% and for lighting by 4.2%. As a result, optimum occupant behavior reduced yearly energy consumption by 19.4%.

High-Efficiency Equipment Case (“Equ”) When compared with the “Base” condition, due to the reasons stipulated by “Air” and “Lamp”, energy consumption for cooling was reduced by 11.6%, for heating by 1.5% and for lighting by 8.9%. As a result, yearly energy consumption was reduced by 5.0%.

Countermeasure to Building Case (“Build”) When compared with the “Base” condition, for the reasons stipulated by “Hi-In”, “Sunroof”, “Tree” and “Blind”, energy consumption for cooling was reduced by 10.8% and for heating by 9.2%, but consumption for lighting increased by 7.3%. As a result, yearly energy consumption was reduced by 5.8%.

”Build” + “Occ” Case (“B-O”) When compared with the “Base” condition, for the reasons stipulated by “Build” and “Occ”, energy consumption for cooling and heating was reduced by 37.6% and 26.8%, respectively. However, consumption for lighting increased by 1.3%. As a result, yearly energy consumption was reduced by 22.4%. When compared with “Build”, due to the reasons stipulated in “Occ”, energy consumption for cooling was reduced by 30.1%, heating by 19.4% and by lighting was 5.6%. As a result, yearly energy consumption was reduced by 17.7%.

”B-O” + “Equ” Case (“B-O-E”) When compared with the “Base” condition, for the reasons stipulated in “B-O” and “Equ”, energy consumption for cooling was reduced by 44.3%, heating by 28.2% and lighting by 7.8%. As a result, yearly energy consumption was reduced by 26.5%. When compared with “Build”, for the reasons stipulated in “Occ” and “Equ”, energy consumption for cooling was reduced by 37.5%, heating by 20.9% and lighting by 14.1%. As a result, yearly energy consumption was reduced by 22.0%. When compared with “B-O”, for the reasons stipulated in “Equ”, energy consumption for cooling was reduced by 10.7%, heating by 1.8% and lighting by 9.0%. As a result, yearly energy consumption was reduced by 5.2%.

Compared with Each Condition A comparison of the effects of each energy conservation countermeasure showed that “Temp” had the largest effect, while “Shade” had the second largest. Additionally, it was found that the large-scale countermeasures like “Sunroof” and “Tree” had no major effect. When compared with “Build”, “Occ” and “Equ”, the energy reduction effects were 5.8%, 19.4% and 5.0%, respectively [Fig. 4], and “Occ” was 3~4 times larger than the others. Furthermore, the effects of energy reduction when we introduced these countermeasures in the order of “Build”, “Occ” and “Equ” step-by-step were 5.8%, 17.7% and 5.2%. These results showed that occupant behavior made a dramatic contribution to reducing energy consumption [Fig. 5]. The results also showed that when all the above countermeasures were introduced, energy consumption declined by 26.5%.

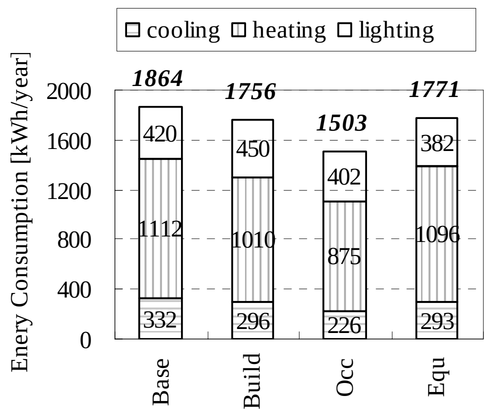

Figure 4: Energy consumption of “Base”, “Build”, “Occ” and “Equ”

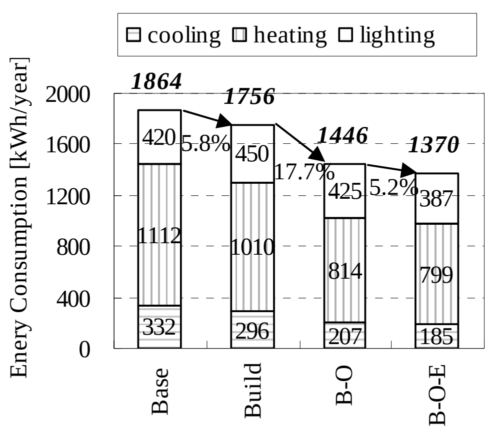

Figure 5: Energy consumption of “Base”, “Build”, “B-O” and “B-O-E”

CONCLUSION

In this paper, we conducted a quantitative comparison of the various countermeasures for energy conservation. As a result, it was determined that the energy reduction effects were 5.8% for building countermeasures, 19.4% for occupant countermeasures, and 5.0% for equipment countermeasures. In addition, when these countermeasures were introduced step-by-step, the reductions were 5.8%, 17.7% and 5.2%, respectively. Furthermore, when we introduced all countermeasures, energy consumption was reduced by 26.5%. From the above results, it was shown that the use of easy countermeasures by residential occupants had a significant effect on energy conservation.

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