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Faults and claims about thermal environments in relation to building equipment and energy saving measures in smaller office buildings

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Abstract

Building equipment, energy-saving systems, and claims of inappropriate indoor thermal environments were analyzed in relation to the floor area using responses to a questionnaire survey of service managers of 157 buildings. Results show the following. 1) In smaller buildings (<5000 m^2), set temperatures are higher in summer and lower in winter, effects of 'uncomfortable radiation from windows' are greater, energy-saving systems decrease indoor thermal comfort, but claims of 'hot' and 'cold' are fewer. 2) Claims of 'hot' and 'cold' are unrelated to the setting temperature and whether the air-conditioning control system is central or local. Finally, 3) the adoption rates of 'COOL-BIZ' or 'WARM-BIZ' are higher than those of temperature mitigation of air conditioning.

Keywords: **s**maller office buildings, energy management, energy saving measures, claims of 'hot' and 'cold'

Introduction

The energy saving regulation code in Japan was revised in 2009. The national government imposed more severe energy saving requirements and CO_2 emissions decreases on building owners and builders. As one revision, the buildings for which builders are obligated to report energy saving methods to the government, both for newly built and reformed areas, were reclassified to 300 m^2 from 2000 m^2. The measure was aimed at more precise regulation of smaller buildings.

Areas of about 40% of the office buildings were less than 2000 m^2 in 2003 in Japan. About 60% are smaller than 5000 m^2. The actual situation of energy consumption and energy management of smaller buildings has, however, remained unclarified. Surveys of energy management on advanced buildings have been conducted, but the examined buildings were larger in scale.

Government reports show that CO_2 emissions are decreasing in the industrial and transportation sectors. Emissions of the industrial sector in 2009 were 19.5% lower than those of 1990. Emissions of the transportation sector in 2009 were 5.5% higher, but they have shown a decreasing trend since 2000. Emissions increased by 31.2% and 26.9%, respectively, in business and residential sectors, although the Kyoto protocol obligated Japan to reduce CO_2 emissions by 6% in 2008–2012 compared with those in 1990.

Surveys of energy management of smaller office buildings were conducted in 2009 by the Kinki branch of SHASE. Based on analyses of the questionnaire surveys, this paper presents analyses of the relation of building equipment and energy saving measures to the occurrence of faults and claims about thermal environments in relation to building size.

Methods

Survey

Questionnaire sheets were sent to building maintenance managers of office buildings through building owner and manager associations. Both owner-occupied buildings and tenant buildings were included. Respondents were general managers of the owner building companies and staff members of outsourcing companies for building equipment management. The survey, which was conducted in January 2009, yielded 157 complete responses.

Questionnaire items

Questionnaire items are the following: 1) fundamental attributes of the building such as size, age, stories, ownership, and building use; 2) building equipment including heat sources, air-conditioning, and ventilation systems; 3) building equipment operation methods; 4) energy saving measures including both those adopting more efficient apparatus or newest developed systems and management operation methods such as mitigation of air-conditioning temperature, turning off of equipment, mitigation of dress codes, which governments call COOLBIZ in summer and WARMBIZ in winter; 5) setting temperatures of air-conditioning equipment in each season; and 6) occurrence of faults and claims from occupants relating to indoor climate. Acknowledgement of the revision of energy saving regulations and its effects on building management, recognition of energy performance of the buildings, history, and planning of reform of the buildings, the way to levy energy charges from tenants, and measured items of indoor environments are also surveyed.

Results and Discussion

Fundamental attributes of the buildings

Of the building sites, 77 are in Osaka prefecture, 16 in Hyogo prefecture, and 10 in Kyoto prefecture. Of the surveyed buildings, 96.5 percent are built in the Kinki area around Osaka prefecture. Regarding their age, 28 were built before 1970, 33 were built during 1970–1979, 34 were built during 1980–1989, 37 were built during 1990–1999, and 14 were built in 2000 or after. Regarding their respective heights, 57.0% are under five stories and 29 have three stories. Only 15 buildings are of over eleven stories.

Figure 1 shows the area distribution of the buildings: 93 of the buildings are smaller than 5000 m^2; 58 are 5000 m^2 or larger. For six buildings, no response indicating the area was given.

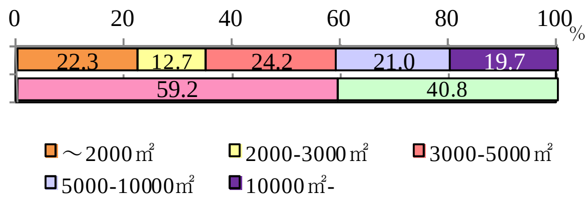


Figure 1. Building floor area.

Building equipment

Types of heating systems and numbers of buildings that adopted them are as follows. Several types of responses might be given for a building: water-cooled chillers 10, boilers 14, air-cooled heat pump chiller 28, air-cooled electric heat pump of multi-room systems by switching heating and cooling 86, air-cooled electric heat pump of multi-room systems for both heating and cooling 12, air-cooled gas heat pump multi-room systems by switching heating and cooling 20, air-cooled gas heat pump of multi-room systems for both heating and cooling 4, water-cooled heat pump 2, and gas boiled absorption refrigerating machine 40.

Types of air-conditioners and numbers of adopting buildings are air ducted systems 80, ducted fan coil unit systems 33, packaged air-conditioners (cassette) 66, and packaged air-conditioners (concealed) 34.

Types of ventilation systems and numbers of adopting buildings are those supplying air using air-conditioners and exhausting air by electric fans 69, introducing and exhausting air by total heat exchangers 56, supplying and exhausting air by electric fans 25, and those exhausting air by electric fan 29.

Figure 2 shows the relation between building equipment and building size. Smaller buildings are defined in this study as smaller than 5000 m^2 in total area. Figures in parentheses following the equipment type show the percent significant level of chi-square tests between smaller and larger buildings. Gas boiler absorption refrigerating machines tend to be adopted by larger buildings (p=1%). No significant difference is found by building size in other heat source systems.

Fan coil unit systems tend to be adopted in larger buildings (p=1%). No difference is found by building size in adopting duct systems and using packaged air-conditioners.

Ventilation systems with exhausting electric fans tend to be adopted in smaller buildings (p=1%). Ventilation systems with supplying and exhausting electric fans tend to be adopted in larger buildings (p=1%). No significant difference is found according to building size in the other two ventilation systems.

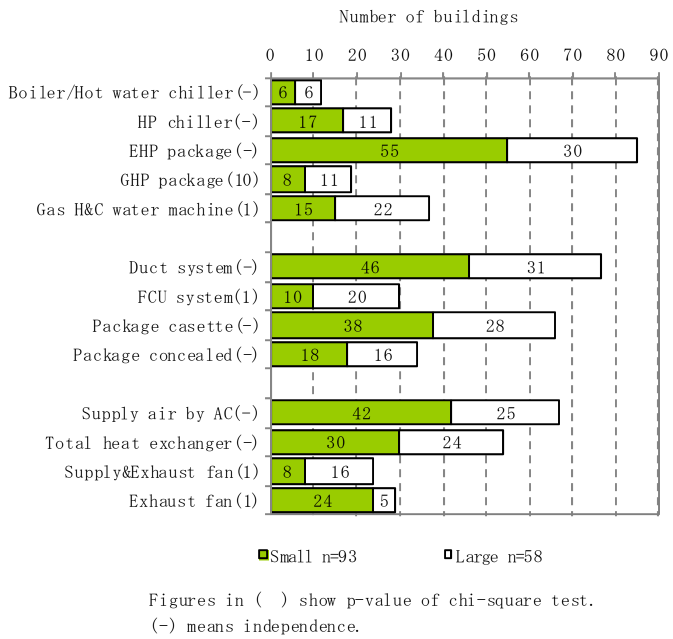


Figure 2 Relation between building equipment and building size.

Energy saving measures

Energy saving systems for lighting and numbers of adopting buildings are as follows: high-frequency lighting fixtures 51, automatically actuating devices for sensing occupancy 33, equipment turned on and off by timers 3, and brightness tuning apparatus by sensing illuminance 7.

Energy-saving systems for air-conditioning and numbers of adopting buildings are as follows: high-efficiency apparatus 18, total heat exchangers 63, variable air volume controllers 23, variable water volume controllers 10, outdoor air cooling 20, natural ventilation systems 14, air volume control by sensing indoor carbon dioxide density 7, supply air volume control into lavatories by sensing occupancy 1, heat storage systems 30, packaged air-conditioner controls by electric power demand 9, and water spray on outdoor units 2.

Energy saving measures related to operation and numbers of adopted buildings are as follows. Air-conditioning setting temperature mitigation for whole buildings 80, air-conditioning setting temperature mitigation for common spaces of buildings 24, time limits of air-conditioning (turning off for overtime work or in natural ventilation season) 46, and dress code mitigation, COOLBIZ or WARMBIZ 108.

Numbers of buildings adopting solar generation are 8, co-generation systems 2, water saving apparatus 39, and rainwater use systems 12.

Figure 3 shows energy saving measures in relation to the building size. Variable water volume controllers, outdoor air cooling, and supply air volume control are adopted in larger buildings (p=1% for each). No difference is found in the ratio of adoption for other measures.

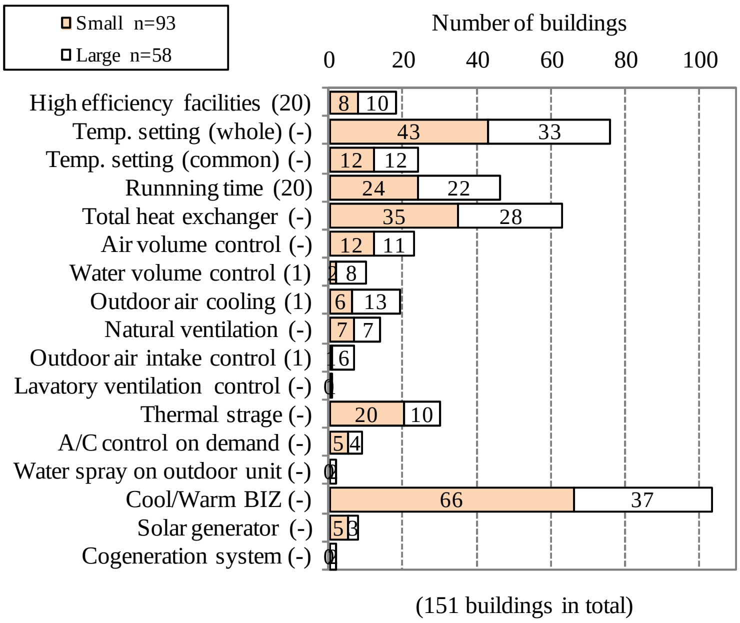
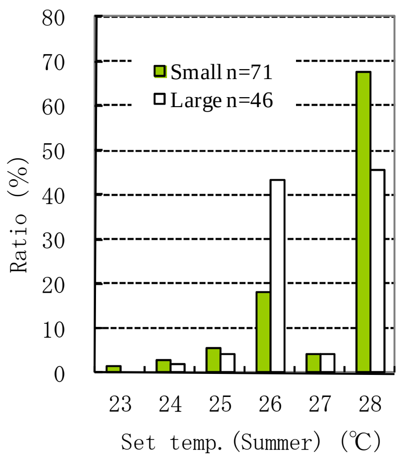


Figure 3 Energy saving measures and building size.

Setting temperature

Figure 4 portrays a frequency distribution of setting temperatures for smaller buildings (<5000 m^2) and larger buildings. In summer, 26°C is the setting in 43.5% and 28°C is the setting in 45.7% in larger buildings, although 28°C is the setting 67.6% in smaller buildings. In winter, 19°C is the setting in 6.4% in larger buildings, although it is 30.0% in smaller buildings. Setting temperatures in smaller buildings are higher in summer and lower in winter.



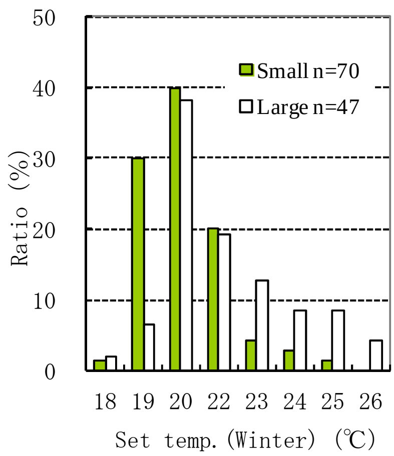


Figure 4 Setting temperature of air-conditioning in smaller and larger buildings.

Setting temperature mitigation and COOLBIZ or WARMBIZ

Figure 5 shows ratios of adoption of setting temperature mitigation and COOL-BIZ or WARM-BIZ. Adoption of setting temperature mitigation and BIZ are not related to building size, as noted before. The figure shows that the adoption of BIZ is unrelated to the building size for each setting temperature. However, the ratio of setting temperature mitigation is higher in larger buildings than in smaller buildings in summer. The figure also shows that the ratio of BIZ is higher than those of temperature mitigation for each setting temperature. This result shows that some buildings adopt only BIZ without temperature mitigation.

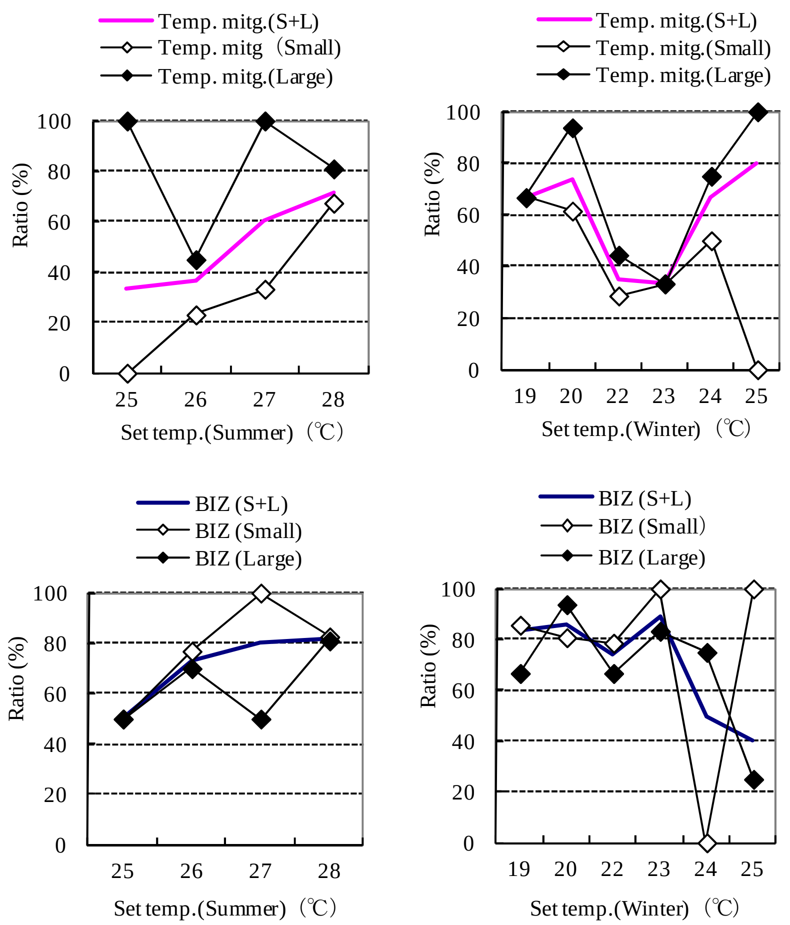


Figure 5 Ratios of adoption of setting temperature mitigation and COOL-BIZ or WARM-BIZ.

Faults and claims from occupants related to indoor climates

Faults and claims related to lighting and the numbers of buildings with claims are as follows: darkness in work spaces 2, darkness in common spaces 2, and division of spaces with and without lighting 17.

Faults and claims relating to air-conditioning and the number of buildings claimed are as follows: hotness in work space 47, coldness in work space 33, vertical temperature difference 23, horizontal temperature difference 22, division of space for conditioning on and off 31, division of space for temperature control 28, infiltration 4, window radiation 23, hotness in common space 8, coldness in common space 9, high humidity in work space 1, low humidity in work space 21, draft 6, and air-conditioning noise 7.

Claims of ‘hot’ and ‘cold’ and building size

Figure 6 shows the relation between faults and claims and building size. Faults and claims occur in relation to the thermal environment. For example, 43 buildings are reported as ‘hot in the work space’ and 29 are reported as ‘cold in the work space’. However, faults and claims related to air movement and noise are fewer. 39.7% of larger buildings are ‘hot’ and 31.0% are ‘cold’. Faults and claims of ‘hot’ and ‘cold’ occur in larger buildings at about as twice and three times the rates as in smaller buildings, respectively (p=2% and 1%, respectively). No difference is found in the ratio of occurrence for other faults and claims other than ‘hot’ and ‘cold’.

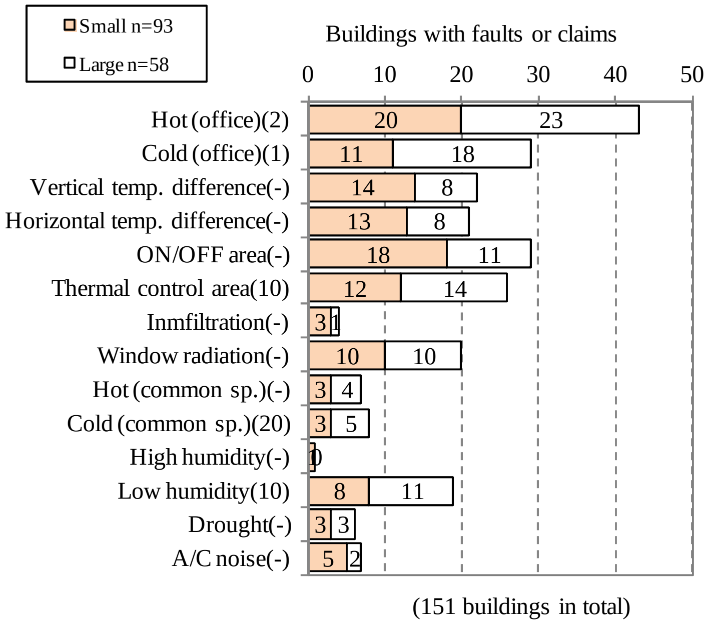


Figure 6 Relation between faults and claims and building size.

Setting temperature and claims of 'hot' and 'cold'

Figure 7 shows the ratios of occurrence of 'hot' and 'cold' for each setting temperature. The ratio of 'hot' is 36.4% for 26°C and 25.4% for 28°C in summer. The ratio of 'cold' is 12.5% for 19°C and 21.4% for 20°C in winter. No significant difference is found in the setting temperature in summer (in winter) between occurrence and not occurrence of 'hot' ('cold') in larger or smaller buildings. It can be said that the setting temperature is not so related to the occurrence of claims of 'hot' and 'cold'.

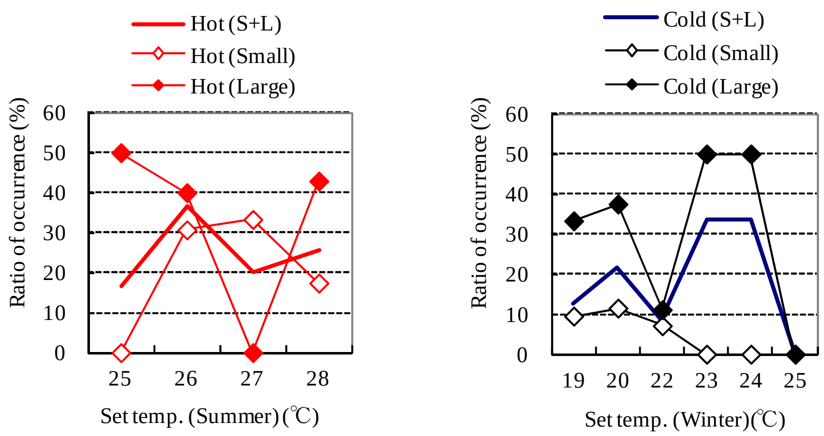


Figure 7 Relation between setting temperature and occurrence of claims of ‘hot’ and ‘cold’ in smaller and larger buildings.

Non-uniform thermal environment and claims of ‘hot’ and ‘cold’

Table 1 presents the *p* values of uniformly consistent tests among claims relating to thermal environment for each building size. The ‘vertical temperature distribution’ is not related to ‘hot’ and ‘cold’ for each size of building, although it is related to the ‘horizontal temperature distribution’ (*p*=1% for each). It can be said that the ‘vertical temperature distribution’ and ‘horizontal temperature distribution’ tend to occur at the same time irrespective of the building size but are not so related to claims of ‘hot’ and ‘cold’.

However, ‘improper radiation from windows’ is related to ‘hot’ and ‘cold’ in smaller buildings (*p*=1%, 2%) and larger buildings (*p*=5%, 20%). That fact indicates that radiation from windows tends to cause to be ‘hot’ and ‘cold’ only in smaller buildings.

No difference is found among numbers of workers in typical office rooms between smaller and larger buildings. In more than half of the buildings, 40 workers work in an office room. It is presumed that vertical and horizontal temperature differences occur because the room is large but differences are not sufficiently large to provoke claims of being ‘hot’ or ‘cold’. However, irradiation from windows occurs even if office rooms are large. It affects workers near windows, causing claims of the room being ‘hot’ or ‘cold’.

Table 1 Faults and claims of thermal environment in smaller and larger buildings

Claims	Buildings	*n*	Hot *p* %	Cold *p* %	Vert. *p* %	Horiz. *p* %
Hot	L+S	43				
	Large	23				
	Small	20				
Cold	L+S	29	1			
	Large	18	1			
	Small	11	1			
Vertical temp. difference	L+S	22	—	—		
	Large	14	—	—		
	Small	8	—	—		
Horizontal temp. difference	L+S	21	20	20	1	
	Large	13	20	20	1	
	Small	8	—	—	1	
Radiation from windows	L+S	20	1	1	5	5
	Large	10	5	1	20	20
	Small	10	1	20	20	20

Building equipment and claims of 'hot' and 'cold'

Figure 8 portrays the relation between numbers of claims of 'hot' and 'cold' and building equipment in smaller and larger buildings.

Heat source systems and ventilation systems are unrelated to the occurrence of 'hot' and 'cold' for all building sizes. Both 'hot' and 'cold' claims occur more frequently for fan coil unit systems in larger buildings (p=5% for each). However, fan coil unit systems are not related to 'hot' and 'cold' claims in smaller buildings. Both 'hot' and 'cold' claims occur more frequently for buildings with duct systems for all buildings (p=2% each, figure is omitted).

Packaged air-conditioners are not related to 'hot' and 'cold' in either smaller or larger buildings, but there are no 'cold' buildings among smaller buildings with packaged air-conditioners (concealed) (p=10%).

More than one type of air-conditioning system is sometimes adopted. Buildings with only duct systems or only with fan coil unit systems are 44, with only packaged air-conditioners are 37, and those with duct or fan coil unit systems for some rooms and packaged air-conditioners for other rooms are 48. Adoption of a type of air-conditioning in these tree types is independent of the building size. 'Hot' claims occur more frequently for the third type in smaller buildings (p=1%).

Air-conditioning operation methods such as a change of temperature and turning on and off are as follows. Buildings with individual operation by occupants are 78. Centrally operated buildings in which occupants are unable to operate air-conditioners, with operation by building managers, scheduled operation by timers, and remotely controlled operation from other buildings, are 33. Adoption of a type of operation in these two types does not depend on the building size. ‘Hot’ is claimed more frequently and ‘cold’ occurs less frequently in centrally operated buildings (p=5% and 10% respectively). Methods of air-conditioner operation are unrelated to the occurrence of ‘hot’ and ‘cold’.

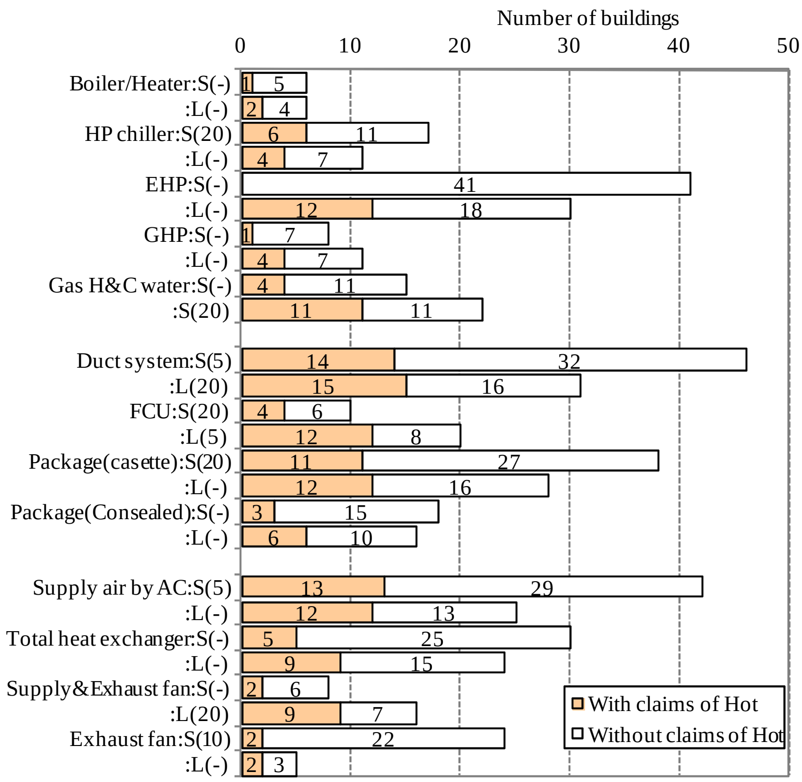
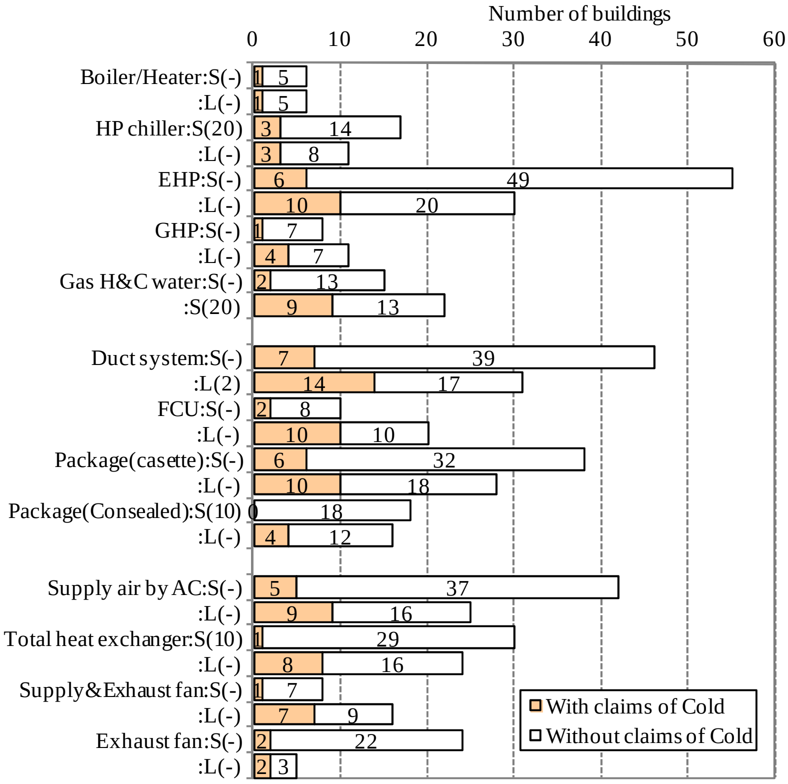


Figure 8 Relation between building equipment and occurrence of claims of ‘hot’ and ‘cld’ in smaller and larger buildings. (Continued)



Figures in （） show p%-values of chi-square tests between adoption of equipment and occurrence of claims of Hot or Cold. (-) mean independence.

Figure 8 Relation between building equipment and occurrence of claims of ‘hot’ and ‘cold’ in smaller and larger buildings.

Energy saving measures and claims of ‘hot’ and ‘cold’

Figure 9 presents the numbers of buildings with claims of ‘hot’ and ‘cold’, along with energy saving measures. Adoption of ‘limitation of running time of air-conditioning’, ‘variable air volume’, and ‘heat storage system’ are related to ‘hot’. Adoption of ‘variable water volume’ and ‘outdoor air cooling’ are related to ‘cold’ in smaller buildings (p=1% for each). Faults and claims of the thermal environment might result from adoption of these energy saving measures in smaller buildings. However, energy saving measures are unrelated to thermal environments in larger buildings, except for adoption of BIZ, for which ‘hot’ occurs more frequently (p=2%).

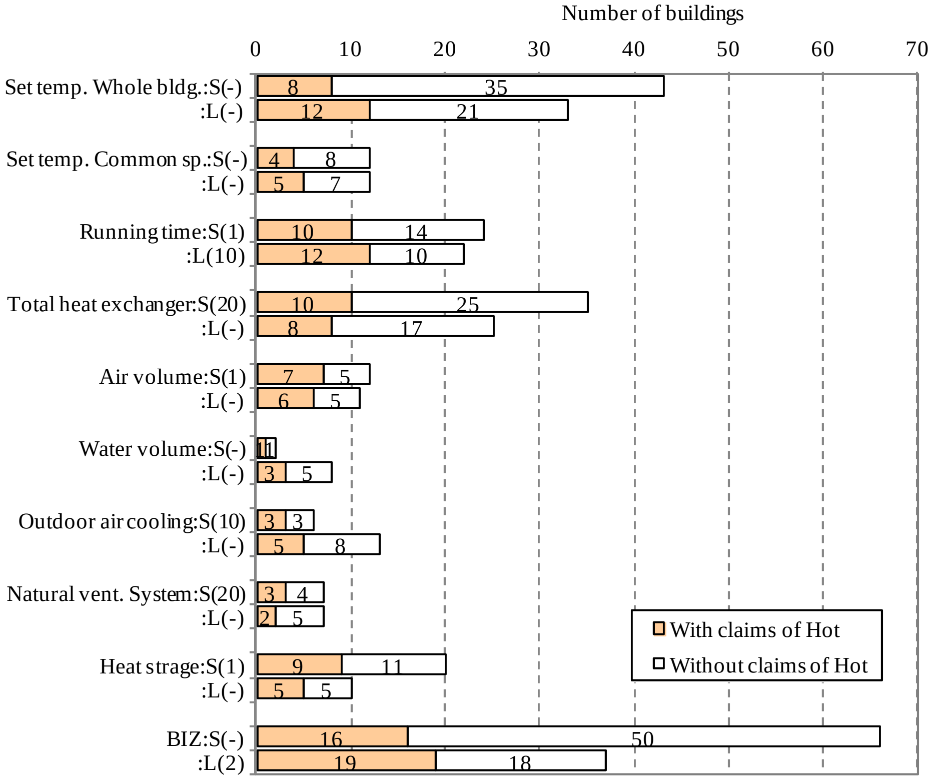


Figure 9 Relation between energy-saving measures and occurrence of claims of ‘hot’ and ‘cold’ in smaller and larger buildings. (Continued)

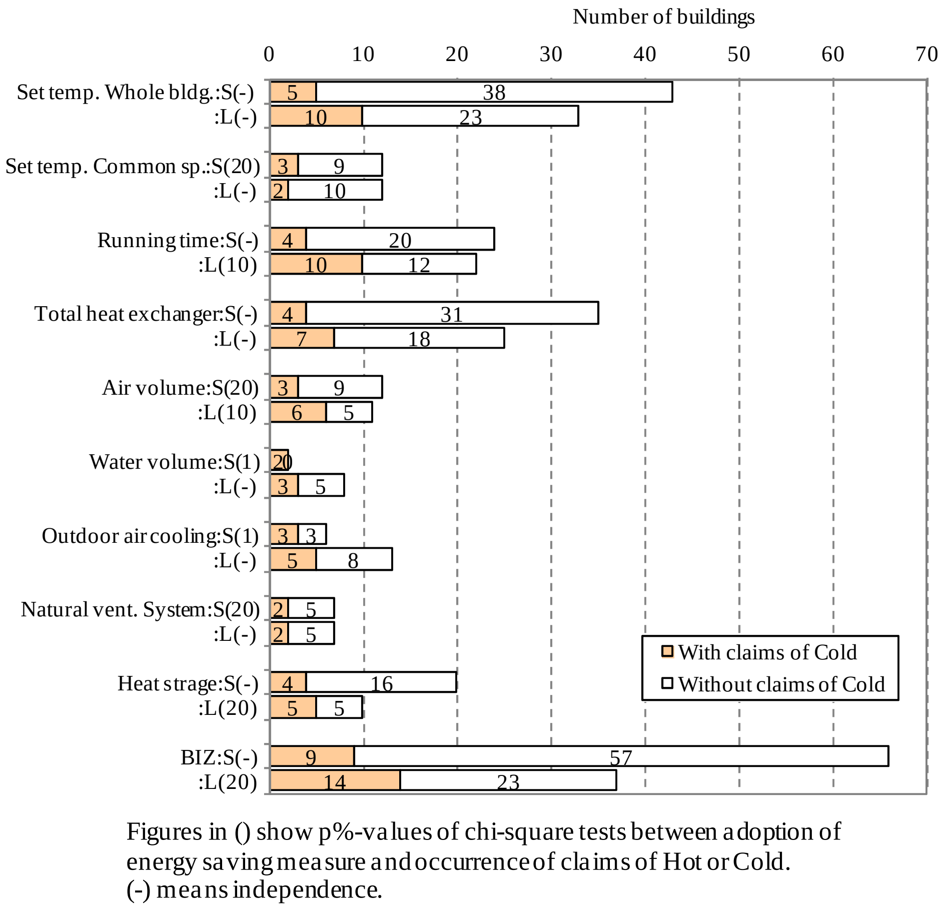


Figure 9 Relation between energy-saving measures and occurrence of claims of ‘hot’ and ‘cold’ in smaller and larger buildings.

Discussion

Set temperatures are higher in summer and lower in winter in smaller buildings. In summer, 28°C is the setting of 67.6% of smaller buildings. In larger buildings, 26°C was the setting in 43.5% and 28°C was the setting in 45.7%. In winter, 19°C was the setting in 6.4% in larger buildings, although it was 30.0% in smaller buildings. It can be said that occupants in smaller buildings are in a poor thermal environment. Differences of financial circumstances of building owners, such as size of capital and capacity for borrowing are inferred as underlying causes of these results.

Faults and claims related to air movement and noise are fewer; those of thermal environments occur more often. Those of ‘hot’ and ‘cold’ occur respectively in 39.7% and 31.0% of larger buildings. However, faults and claims of ‘hot’ and ‘cold’ occur less frequently in smaller buildings, at about a half and a third respectively, irrespective of the air-conditioning temperature setting.

The ratios of occurrence of ‘hot’ and ‘cold’ for each setting temperature were assessed. The ratio of ‘hot’ was 36.4% for 26°C and 25.4% for 28°C in summer. The ratio of ‘cold’ is 12.5% for 19°C and 21.4% for 20°C in winter, with no significant difference between the setting temperature and the occurrence of ‘hot’ and ‘cold’.

To investigate the difference of claims of ‘hot’ and ‘cold’ by building size, effects of non-uniform thermal environments such as vertical and horizontal temperature difference and radiation from windows on the difference of occurrence of ‘hot’ and ‘cold’ by building size were assessed. Thermal environments depend on non-uniform thermal radiation from windows rather in smaller buildings. ‘Improper radiation from windows’ is related to ‘hot’ and ‘cold’ in smaller buildings (p=1%, 2%). That relation shows that occupants of smaller buildings might sit near windows. Environments might increase claims of ‘hot’ and ‘cold’ in smaller buildings, but the reverse is true.

Effects of building equipment were also investigated. Heat source systems and ventilation systems are unrelated to ‘hot’ and ‘cold’ for all building sizes. Both ‘hot’ and ‘cold’ claims occur more frequently for fan coil unit systems in larger buildings (p=5% for each), but fan coil unit systems are unrelated to ‘hot’ and ‘cold’ in smaller buildings. Package air-conditioners are unrelated to ‘hot’ and ‘cold’ in smaller and larger buildings. Buildings having only duct systems, those with only fan coil unit systems, and those with only package air-conditioners are compared, but the type of air-conditioning operation is independent of the building size.

Effects of energy-saving measures on ‘hot’ and ‘cold’ were also assessed. Energy-saving measures are related to ‘hot’ and ‘cold’ rather more in smaller buildings. ‘Limitation of air-conditioning running time’, ‘variable air volume’, and ‘heat storage system’ are related to ‘hot’ and ‘variable water volume’ and ‘outdoor air cooling’ are related to ‘cold’ in smaller buildings. It can be said that faults and claims related to thermal environments might result from adoption of these energy-saving measures in smaller buildings. However, energy-saving measures are unrelated to the occurrence of ‘hot’ and ‘cold’ in larger buildings, although adoption rates of energy saving measures are not significantly different between smaller and larger buildings.

Results clarify that claims of ‘hot’ and ‘cold’ are fewer in smaller buildings despite the poorer thermal environments. Fewer claims are unrelated to a difference in setting temperature, non-uniform thermal environments, building equipment, and adoption of energy-saving measures. Additional investigations are needed, but the difference might be attributable to thermal control measures by occupants. Occupants in smaller buildings sit near windows. They have good access to thermal control through windows. Differences in claim-gathering systems must also be considered. Occupants of smaller buildings might have fewer means to bring claims.

Conclusions

Results of the survey reveal that smaller buildings (<5000 m^2) present difficulty in regulating thermal environments as follows. Setting temperatures are higher in summer and lower in winter in smaller buildings. Thermal environments depend on non-uniform thermal radiation from windows in smaller buildings. Energy conservation measures sometimes cause claims of ‘hot’ and ‘cold’ in smaller buildings. Nevertheless, faults and claims of ‘hot’ and ’cold’ occur less frequently in smaller buildings than in larger buildings.

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