appliances, which was investigated by Korean Power Exchange (2013). The data was produced by surveying 4000 households as samples that were precisely chosen to reflect the population of South Korean residents, according to various factors including regions and overall electric consumption. The penetration rates of domestic appliances, schedules and the electric power consumption of each appliance were used in this study. Set-point temperatures for heating and cooling were identified in existing literature (Kim, J. 2013), and the periods for heating and cooling were calculated from degree days.

Identification of the variations of user behaviour

The variations in the usages of domestic appliances were identified by combining regions and the levels of electric consumption in households. Table 1illustrates the range of individual variables in users' controls. The types of domestic appliances were limited up to 50% of the penetration rates. Total 14 appliances were chosen: TV, refrigerator, washing machine, rice-cooker, kimchi fridge, micro wave, vacuum cleaner, hair dryer, electric iron, computer, electric blanket, electric fan, light bulb and fluorescent. Each appliance was grouped by the rooms that the items were used such as a kitchen, living room, bedroom and bathroom.

Table 1.*Range of users' controls of domestic appliance and building systems*

Appliance	Set-point temperature (^{o}C)/ Electricity consumption (W)			Schedule (hour/year)		
	Max	Mean	Min	Max	Mean	Min
Heating (Boiler)	20 (^{o}C)	22 (^{o}C)	24 (^{o}C)	1456	1092	728
Cooling (PTAC)	22 (^{o}C)	24 (^{o}C)	26 (^{o}C)	253	156	92
Rice-cooker	96	169	396	6579	3791	2555
Washing machine	1125	1267	1438	282	205	153
Vacuum cleaner	876.9	1041	1248.1	69	108.6	174
Kimchi fridge	955	1030	1120	8760		
Refrigerator	197	247	361	8760		
Micro wave	190	251	291	84	34	14
TV	109	128.8	146.5	3019	1918	1578
Computer	16	21	23	832	599	411
Electric blanket	159	174	213	1304	576	295
Electric fan	44	48	52.6	1039	580	361
Electric Iron	37	42	47	178	36	15
Hair dryer	877	1041	1248	55	110	182
Fluorescent light	18	29	55	2751	2287	1419
Light bulb	30	63	100	1743	1035	544

Evaluation of the variation of user behaviour in energy modelling

This section was intended to evaluate the effects of individual variables and the combined effects of the variables. Dependent variables were annual energy demands for heating and cooling. The effects of individual variables were calculated by the gaps of heating and cooling demands from the baseline condition to the maximum and minimum conditions. The baseline condition meant that all controls of the variables were the average conditions. The maximum and minimum conditions were the extreme conditions from the ranges of controls as illustrated in Table 1. The combined effects of all variables evaluated total uncertainties of individual variables. These total uncertainties were calculated by Monte Carlo method (Lomas and Eppel, 1992). Stratified random sampling method was used to generate samples, and Probability Density Function (PDF) and relative standard deviation were identified. This study conducted total 380 simulations. The results are described in Results.

The test model was one apartment unit with 128.8m^2 (74.8m^2 of conditioned area) which was the most typical design of apartments in South Korea in the 1980s, not an entire building. This is because the controls of user behaviour mainly occur in apartment units. The plan of unit is given in Figure 2. Thermal properties were based on (Kim, 2010, Kim, 2013 and Song, 1998). Heating system was an underfloor water heating system, and cooling system was a Packaged Terminal Air Conditioner (PTAC).The building simulation was conducted using EnergyPlus 8.0. The typical weather file of "Seoul", which is provided via U.S. Department of Energy (2012), was applied in the simulations.

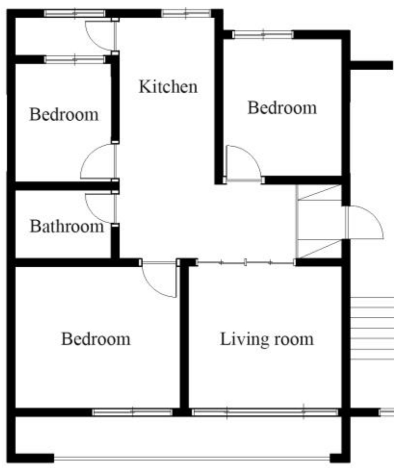

Figure 1.*Plan of the test model*

RESULTS

Uncertainties of individual variables

Figure 3 shows the effects of individual variables on annual heating and cooling demands. The baseline model with the average condition demanded

100.6kWh/m^2/year for heating and 26.5kWh/m^2/year for cooling. There are three influential variables to change heating and cooling demand: set-point temperatures, the operating hours of heating and appliances in a living room. Set-point temperatures for heating and cooling caused 10.6% (10.7kWh/m^2/year) and 21.5% (5.8kWh/m^2/year), respectively. Operating hours for heating resulted in 30.6% (30.8kWh/m^2/year), and the hours of domestic appliances in a living room indicated 47.8% (12.6kWh/m^2/year) of uncertainty for cooling demand and 22.4% (22.6kWh/m^2/year) for heating demand. However, the electric power consumption of appliances was not as significant as the other variables.

The gaps from baseline model to maximum and minimum conditions in set-point temperatures and operating hours showed nearly symmetrical results whilst the schedule of appliances indicated asymmetrical results. Particularly, the gap in the operating hours of appliances in a living room was significantly asymmetric; the maximum conditions decreased heating demand up to 21.8kWh/m^2/year and increased cooling demand up to 12.3kWh/m^2/year while the minimum conditions increased heating demand up to only 0.8kWh/m^2/year and decreased cooling demand only 0.4kWh/m^2/year. This is because that the range of variations in each appliance were not normal distribution but were based on the real survey data which indicated the lower and upper limits.

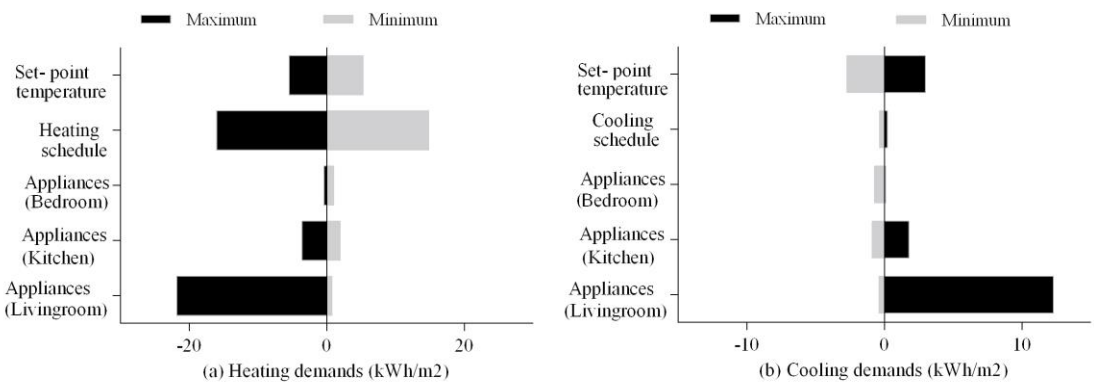

Figure 2 *Uncertainties of individual effects in users' controls: (a) heating demands, (b) cooling demands*

Uncertainties of combined effects

Figure 4 and 5 illustrate the uncertainties of the combined effects by Monte Carlo Method. The shape of PDF is normal distribution with heating demand but skewed with cooling demand, which is log-normal distribution (Figure 3). There are several reasons why log-normal distribution is appeared (Limpert, 2001). In existing literature, the skewed distribution was described as an index of non-linear correlation between inputs and outputs (Prada et al. 2014) and a result of the non-stationary nature of system (Lomas and Eppel, 1992). The cooling demand in this study, which was mainly electricity consumption, are affected by the asymmetrical ranges of users' controls in electric appliances from the survey data, as identified in Table 1. The relative standard deviation (Figure 4), which is an indicator to represent the significance of the uncertainty, reached 23.8% for heating demand and 53.4% for cooling demand and became steady after about 250 simulations.

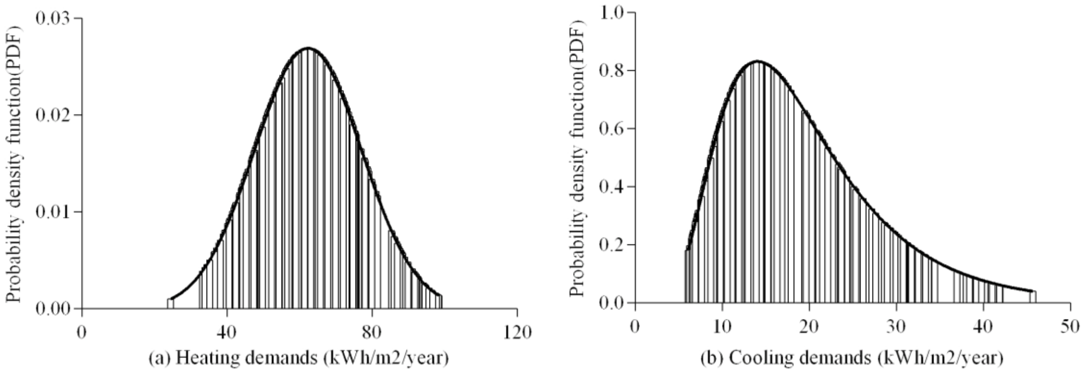

Figure 3.*Probability Density Function (PDF) graphs: (a) heating demands and (b) cooling demands*

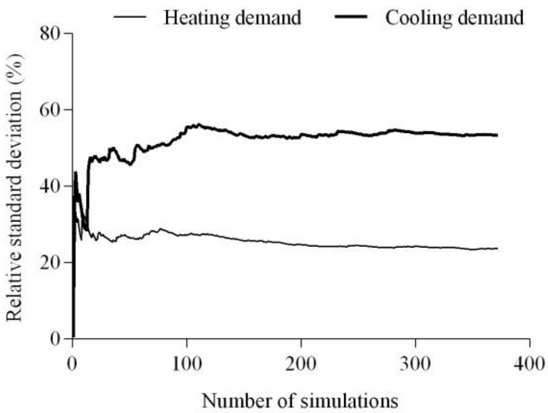

Figure 4.*Relative standard deviation of heating and cooling demands*

DISCUSSION

There are three important findings in this analysis. Firstly, the direct controls for heating and cooling, set-point temperatures and operating schedules for heating and cooling, showed the most significant effects, which means the higher uncertainties. Unlike normal expectation that internal gains with appliance controls are not significant, the controls of domestic appliances in a living room, secondly, presented significant impacts: the second largest uncertainty for heating demands and the largest for cooling demands. As a result, the shape of PDF for cooling demands was skewed as log-normal distribution. Thirdly, the electric power consumption of domestic appliances did not present significant influence in energy demands, which may be possible to be negligible for energy modelling to be more efficient.

The possible limitations and errors in this data analysis can be caused by two reasons. Firstly, the penetration rates of appliances were limited up to 50%; thus the variations which are caused by the number and types of items in each household were not taken into account. Secondly, the operating hours and electric power consumption of appliances were changed by rooms. For example, all appliances in kitchen were changed if operating hours in kitchen was the maximum condition. Therefore, the variations due to the detailed usages of individual appliances in each room were also not taken into account.

CONCLUSION AND IMPLICATIONS

This study argues that energy modelling with large apartment simulations needs a set of data on user behaviour not only specific enough to reflect the distinctive characteristic in the energy usage but also general enough to represent the common trend of energy usage. The uncertainty analysis was conducted to evaluate the impacts of the variations of user behaviour which were identified by regional difference and the level of electricity consumption in households.

The model of user behaviour with the average condition resulted in 100.6kwh/m^2/year for heating demand and 25.6kWh/m^2/year for cooling demand. However, the results showed how significant energy modelling for large buildings can bring about inaccurate estimations if it does not consider the variations caused by diversity in the effects of residents.; individual variables caused the maximum 30.6% and 47.8% of uncertainties in heating and cooling demands. The combined effects of the variables also indicated 23.8% and 52.4% of uncertainties in heating and cooling demands.

To reduce the uncertainties of user behaviours in energy modelling the input parameters need to be separately created by at least regions such as metropolitan cities, small cities and village in the country sides, and the levels of households' electricity consumption. This approach would be able to optimise the input parameters to cause less discrepancy in building energy simulations.

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