STUDY ON SIMULATION MODELLING STRATEGY FOR PREDICTING THERMAL ENERGY DEMAND PROFILES OF RESIDENTIAL COMPLEX

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ABSTRACT

In a metropolis such as Seoul, which has a large population in a dense, built-up area, district heating/cooling systems are popular in terms of energy efficiency and carbon reduction. In order to optimise the generation and distribution of energy in district heating/cooling systems, it is crucial to predict accurate energy demand profiles. In the case of a residential complex, identifying hourly demand profiles is a challenge for the energy managers since there can be a variety of buildings, which are affected by a number of variables: location, orientation and configuration. Detailed building simulation techniques can be adopted for the prediction of individual building energy load patterns. However, there are practical issues to consider – modelling large complexes requires time to develop sophisticated models to collect sufficient data to produce accurate results. This paper presents a preliminary study on how accuracy is affected when the complexity of the simulation is reduced, and whether a sufficient analysis of demand profiles can be conducted using a simplified model.

The effect of model resolution is more evident in winter, the effect of building orientation is clearer in summer, and the effect of shade from adjacent buildings is greater in winter.

INTRODUCTION

In Seoul, the domestic and commercial sectors account for 56% of total energy consumption, which is more than twice the Korean national average of 20% (Korea Energy Management Corporation, 2007). This highlights the importance of optimizing urban energy generation and distribution using district heating/cooling systems (Kwon, 2006). When deploying a district energy system in a residential complex, it is difficult to determine the capacity and therefore the operational strategy due to a lack of information on demand profiles of the buildings to be built in the area. To tackle this problem, a number of methods have been developed, including:

- the maximum heating load calculation of multi-family houses, (Cho, 2000);
- using typical daily heating load models for the estimation of energy consumption in an apartment house (Kim, 2005);
- Unit building method (Lee et al., 2007);
- Representative model analysis for calculation of the maximum heating load of a residential apartment (Choi et al., 2007).

These approaches can contribute to estimating the appropriate equipment capacity by predicting (the maximum) heating load. However, they are limited when it comes to accurately predicting hourly demand profiles for district energy supply systems.

A district level demand profile modelling method using historical data has been developed (Shimoda et al., 2007). However, the model does not take into account the effect of orientation of individual buildings, internal configuration, etc. To overcome these limitations, building energy simulation techniques, which usually focus on a single building, could be adopted to predict accurate district energy demand profiles. An issue arising in applying detailed simulation techniques for district-level energy demand prediction is that accuracy can be comprised when the resources (e.g. time and manpower) needed to develop the simulation are limited. Developing a model for all of the buildings in a residential site (as shown in Fig. 1) is not trivial. It is important to identify an appropriate level of complexity for the simulation to produce accurate results. To this end, this paper examines how accuracy is affected when the complexity of the simulation is reduced, and whether a sufficient analysis of demand profiles can be conducted using a simplified model.

Figure 1: The bird's eye view of a Korean typical residential complex.

SIMULATION

In this study, a typical Korean apartment building was chosen. It has four flats on each floor. Figure 2 shows the floor plan of a single apartment. ESP-r was used to predict the hourly cooling/heating load of the apartment. For climate data, the 30-year-standard Seoul climate data (TRY) was used. Table 1 lists the properties of construction materials used for the detailed simulation.

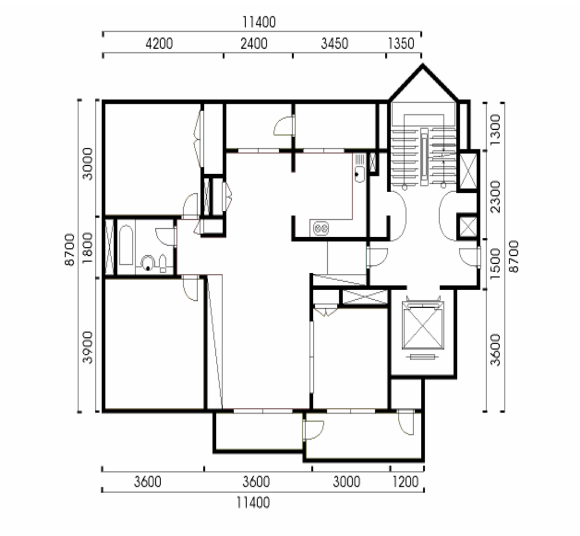

Figure 2: Floor plan of a single flat in a typical Korean apartment building

Since this study focuses on comparing cooling/heating loads of models with different resolutions, an ideal control over the 24 hours in a day is assumed and casual gains are not considered. Set points for control are listed in Table 2.

To analyse the hourly cooling/heating load, a typical summer day (July 30th) and a typical winter day (Jan. 29th) were chosen for the simulation.

Table 1: Properties of construction materials in the simulation

Construc-tions	Elemental materials (outside → inside)	Thick-ness (mm)	U-value (W/m²℃)
Roof	Asphalt	19	0.41
	Fibreboard	13	
	Air gap	25	
	Glass fibre quilt	75	
	Gypsum plaster	10	
External wall	Heavy mix concrete	200	1.8
	Air gap	25	
	Gypsum plaster	10	
Internal wall	Light plaster	13	0.97
	Foamed inner block (3% mc) concrete	100	
	Light plaster	13	
Internal floor/ ceiling	Weatherboard wood	25	0.77
	Glass reinforced concrete	65	
	Air gap	25	
	Glass fibre quilt	25	
	Gypsum plaster	16	
Ground floor	Heavy mix concrete	300	1.11
	Cement Screeds and renders	25	
	Air gap	100	
	Flooring wood	12	
	Synthetic carpet	12	
Glazing	Clear float glass	6	2.69
	Air gap	20	
	Clear float glass	6	

Table 2: Set points for control

		Summer	Winter
Infiltration air change rate (ACH)	Rooms Inside	0.5	1.5
	Core	0.5	2
Relative humidity controls (%)	Maximum	60	35
	Minimum	50	30
Cooling/Heating (℃)		25	21

Effect of model resolution

To examine the effect on accuracy by varying the complexity of the simulation model, 3 levels of detail were compared:

- Room Level: zoning each room in the flat. This was the reference model. It was the most detailed and took the most time to develop.
- Floor Level: zoning each floor of the building. This was the simplest model.
- Solar Area Level: zoning areas defined by solar penetration. This divides a floor into 4 zones:

one that includes front and rear glazing, another with only front glazing, another with only rear glazing, and one with no glazing. It assumes the amount of solar penetration which affects each zone differs over time according to the direction of glazing.

Figure 3 shows the floor plans of the 3 Levels. The area of opaque internal wall is as follows: Room Level: 400 m^2, Floor Level: 0 m^2, Solar Area Level: 112 m^2.

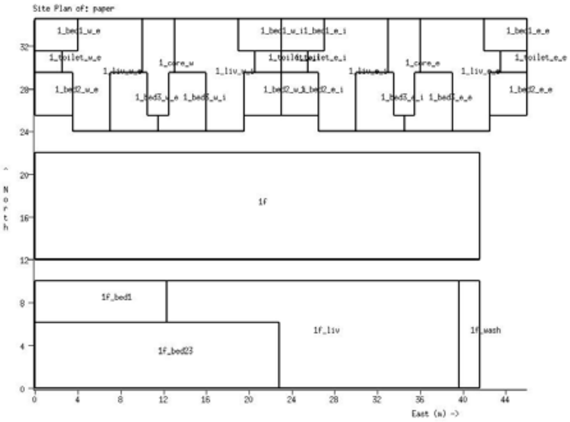

Figure 3. Floor plans of different Levels (from top to bottom): Room Level, Floor Level, Solar Area Level

With the Room Level as reference, hourly cooling/heating load patterns for the Floor and Solar Area Levels were compared and analysed. In all cases, the floor area where control is applied was 416m^2. The front glazing area was 78m^2 and the rear glazing area was 42m^2. It was assumed that there was no shading from adjacent buildings and a South-facing orientation of buildings.

Effect of orientation of building

To examine the effect of orientation of the target building on its cooling/heating load, 4 cases were considered: South, West, East and North facings. With the South-facing case as the reference model, hourly cooling/heating load patterns of the 3 other cases were compared. The Room Level model was used and it was assumed that there was no shading from adjacent buildings.

Effect of shading from adjacent buildings

To examine the effect of shade from adjacent building on cooling/heating loads of the target building, 2 cases were compared. One was with adjacent buildings located 20m in front and behind the target building. The other case involved no adjacent buildings and was used as a reference. The hourly cooling/heating load patterns. The Room Level model was used and it was assumed that the buildings had a South-facing orientation.

RESULT ANALYSIS

Effect of model resolution

Figure 4 shows the comparison of hourly cooling loads (kW) of a typical summer day. Compared to the Room Level, the Floor Level showed a standard deviation of 3.57 and the Solar Area Level 3.17. As solar penetration increases in the morning, the Floor Level generates 14% and the Solar Area Level 4% more load compared to the reference case. After sunset, the Floor level generates 14% less load compared to 11% less load for the Solar Area Level.

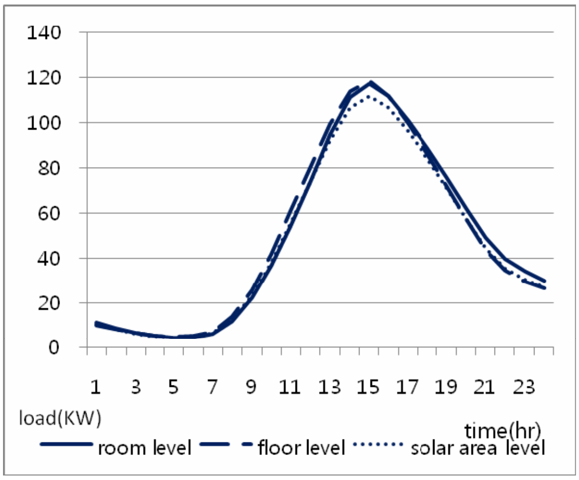

Figure 4: Cooling load comparison according to model resolution (kW)

Figure 5 shows the comparison of hourly heating loads (kW) of a typical winter day. Compared to the Room Level reference, the Floor Level shows a standard deviation of 11.6 and the Solar Area Level a standard deviation of 6.13. Compared to the Room Level, between 11:00 and 17:00, the Floor Level generates 42% and the Solar Area Level 18% less heating load.

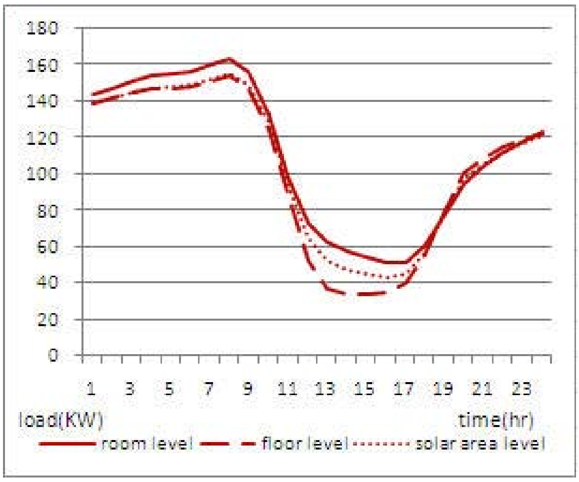

Figure 5: Heating load comparison according to model resolution (kW)

These differences are caused by the opaque internal walls that absorb solar radiation and retain heat. Because the inclination of the sun affects amount of shade, the effect of model resolution on cooling load of a typical summer day is less significant than the heating load of a typical winter day.

Table 3 shows the comparison of the total loads of typical summer and winter days according to model resolution. **R** refers to Room Level, **F** for Floor Level, and **S** for Solar Area Level.

Table 3: Total load comparison according to model resolution (kWh)

	COOLING			HEATING		
	R	F	S	R	F	S
SUM	1,139	1,162	1,113	2,658	2,467	2,540
	Base	2.0%	-2.3%	Base	-7.2%	-4.4%
5F	281.3	286.3	275.9	579.5	545.9	555.2
	Base	1.8%	-1.9%	Base	-5.8%	-4.2%
4F	244.8	252.7	241.1	487.9	444.4	461.1
	Base	3.2%	-1.5%	Base	-8.9%	-5.5%
3F	244.8	258.4	241.5	488.9	441.9	463.3
	Base	5.6%	-1.3%	Base	-9.6%	-5.3%
2F	242.6	247.1	238.9	491.1	450.4	467.3
	Base	1.8%	-1.5%	Base	-8.3%	-4.8%
1F	125.7	117.6	115.7	610.7	584.8	593.1
	Base	-6.5%	-7.9%	Base	-4.3%	-2.9%

Looking at the total cooling load for a typical summer day, compared to the Room Level, the Floor Level generates 2% more load, and the Solar Area Level generates 2% less load. For the Floor Level, an increased cooling load in the morning is due to the lack of internal walls. This is greater than the decreased load as a result of no accumulated heat in the internal walls after sunset. This is in contrast to the Solar Area Level, where it seems the existence of some internal walls cause the opposite to happen.

In general, changing the model resolution has less impact on cooling loads than heating loads.

Effect of orientation of the building

Figure 6 shows the comparison of hourly cooling loads (kW) of a typical summer day. Compared to a South facing, the West facing has a standard deviation of 16.3, the East facing 9.46, and the North facing 6.69.

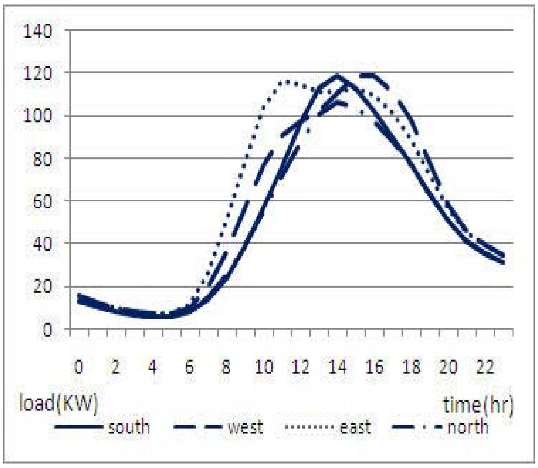

Figure 6: Cooling load comparison according to orientation (kW)

Compared to the South facing, the East facing generates 113% more cooling load as the solar radiation penetrates the front glazing, which covers the largest area. The West facing also generates 47% more load as the solar radiation penetrates the rear glazing. The North facing generates 15% less load around noon. Figure 7 shows the comparison of hourly heating loads (kW) of a typical winter day.

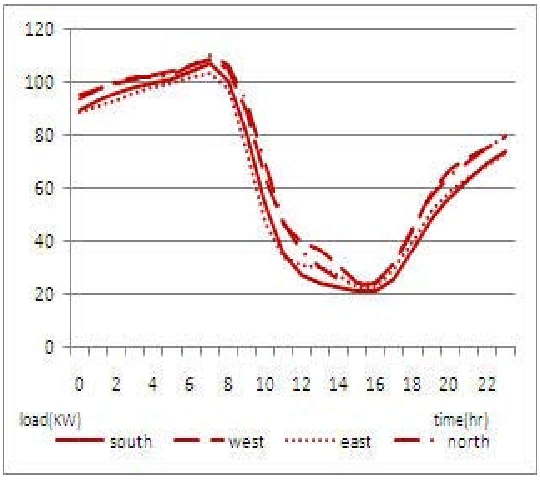

Figure 7: Heating load comparison according to orientation (kW)

The summer shows a bigger difference from the reference model than the winter. In summer, the angle of the sun is set at 70 degrees, which is twice that of the winter period. The period of sunshine is 14 hours, which is 1.5 times longer than that of winter. Therefore, the weighting of solar penetration increases, making the effect of building orientation greater.

Table 4 shows the comparison of total load of typical days in summer and winter according to the orientation of the building. The **S** refers to 'South',

W ‘West’, **E** ‘East’, and **N** ‘North’. This table also shows that the effect of building orientation is increased as the weighting of solar penetration in summer is increased. This is evident in the East-facing and West-facing cases, though not in the North-facing case, because it is less affected by solar penetration than the other 3 cases.

Table 4: Total load comparison according to orientation (kWh)

	COOLING				HEATING			
	S	E	W	N	S	E	W	N
SUM	1,139	1,371	1,280	1,066	2,658	2,731	2,880	2,883
	Base	20.3%	12.4%	-6.4%	Base	2.7%	8.3%	8.5%
5F	281.3	329.6	310.9	266.3	579.5	594.8	625.0	625.5
	Base	17.1%	10.5%	-5.3%	Base	2.6%	7.9%	7.9%
4F	244.8	293.3	274.5	229.8	487.9	501.9	532.7	533.4
	Base	19.8%	12.1%	-6.1%	Base	2.9%	9.2%	9.3%
3F	244.8	293.3	314.9	229.8	488.9	502.8	533.3	534.1
	Base	19.8%	28.7%	-6.1%	Base	2.8%	9.1%	9.2%
2F	242.6	291.4	309.8	227.6	491.1	504.9	534.6	535.4
	Base	20.1%	27.7%	-6.2%	Base	2.8%	8.8%	9.0%
1F	125.7	163.1	170.4	112.9	610.7	626.7	654.4	655.0
	Base	29.7%	35.5%	-10.2%	Base	2.6%	7.1%	7.2%

Effect of shading from adjacent buildings

Regarding the hourly cooling loads (kW) of a typical summer day, compared to the case without shade, the 5th floor of the building in shade shows a 0.03 standard deviation, the 4th floor 0.07, the 3rd floor 0.11, the 2nd floor 0.12 and the ground floor 0.1. The whole building shows a standard deviation of 0.43. While the effect of shade from adjacent buildings is less than 1% on all floors, a lower cooling load was recorded.

Regarding the hourly heating loads (kW) of a typical winter day, compared to the case without shade, the 5th floor of the building in shade shows a 0.19 standard deviation, the 4th floor 0.35, the 3rd floor 0.43, the 2nd floor 1.02 and the ground floor 2.64. The whole building shows a 4.13 standard deviation, which is greater than that of the cooling load case.

Table 5 shows the comparison of the total load of typical summer and winter days according to shade from adjacent buildings. **X** refers to the case without shade, and **O** the case with shade.

Regarding the total cooling loads for a typical summer day, compared to the case without shade, the case with shade shows a -1% difference, however regarding the total heating load for a typical winter day the difference is 3%. This is associated with the extent of shadow cast on the target building as the inclination of the sun changes with the seasons. Therefore, shade from adjacent buildings has a greater effect on heating load in winter than on the cooling load in summer.

Table 5: Total load comparison according to shading (kWh)

	COOLING		HEATING	
	X	O	X	O
SUM	1,139	1,131	2,658	2,747
	Base	-0.75%	Base	3.33%
5F	281.33	280.67	579.46	583.27
	Base	-0.23%	Base	0.66%
4F	244.76	243.23	487.91	493.22
	Base	-0.63%	Base	1.09%
3F	244.78	242.59	488.94	497.46
	Base	-0.89%	Base	1.74%
2F	242.58	240.19	491.12	511.65
	Base	-0.99%	Base	4.18%
1F	125.7	123.9	610.7	661.1
	Base	-1.42%	Base	8.25%

CONCLUSION

This paper has shown the effect of model resolution, orientation of buildings, and shade from the adjacent buildings on the energy load of the target building to make up hourly load data of a typical Korean residential complex. From these findings, we can make the following conclusions.

The load patterns of middle floors are quite similar, whereas the top and ground floors have their own distinct values. This suggests simplifying the models for those middle spaces is feasible. Also in summer, as the inclination of the sun increases, solar penetration between the top floor and ground floor decreases, and the effect of ground temperature is increased.

The three model resolutions feature varying areas of internal wall, which block solar radiation and retain heat. Therefore the effect of model resolution has more significance in winter when the inclination of the sun is lower than in the summer.

The effect of building orientation is more significant in summer when the duration of sunshine is 1.5 greater than in winter. This is clearer in the East-facing and West-facing cases. The North-facing case is not significantly affected, since it is less affected by solar penetration.

The effect of shade from adjacent buildings is greater in winter than in summer, since in winter, the shadow cast on the target building is longer due to the lower inclination of the sun. Both in summer and winter,

the effect of shade is greater in the flats closer to the ground. However, the shade from adjacent buildings does not significantly affect the accuracy of the overall results in summer.
These patterns of hourly load data will be able to contribute to define the appropriate resolution of a building within a residential complex. Also this study can suggest an allowable tolerence when operating and controling district energy systems using a detailed simulation model.

In the future, more effective and precise complex unit prediction models will be required; however the findings of this initial study give an insight into some of the areas that will need to be considered.

ACKNOWLEDGEMENT

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