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Window-to-Wall-Ratio for Energy Reduction in Early Design Stage of Residential Building

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Abstract In Korea, it is necessary to improve the performance of buildings with respect to the energy efficiency while improving the quality of occupants' lives through a sustainable built environment. During the design and development process, building projects must have a comprehensive, integrated perspective that seeks to reduce heating, cooling and lighting loads through climate-responsive designs. The aim of this study is to assess the optimal window-to-wall ratio of multi-rise residential units in the early design phase in Korea. The study analyzed the variation of annual heating and cooling energy load in two apartment prototype units located in Seoul city using different WWRs. The analysis was conducted using Autodesk Ecotect Analysis 2011 tool. The study found for total annual building load reductions WWR on the south and north face should be studied independently based on the room function. It also found reducing the WWR for bedrooms and windows on the northern façade resulted in reduced total annual building load.

Keywords: Energy Reduction; WWR; Residential Building; Energy Efficiency

1. INTRODUCTION

Energy use in buildings accounts for a large percentage of total energy consumption worldwide, which leads to increasing CO2 emission. Most studies show the building sector consumes around 40% of the world's energy and 30% of greenhouse gas emissions (UNPE , 2009) and (World Energy Council, 2013). In Korea the building sector contributes around 21% of the total energy consumption and a further increase is also expected to reach 40% by 2030 (Chun, 2012). Due to lack of domestic energy source the country relies on imported fuel for about 97% of its primary energy consumption (IEA, 2012). With uncertainty over the availability of fossil fuels into the future, rising demand for fossil fuels and concerns over energy security, it is becoming a necessity to find ways to reduce the energy load in all sectors (Chun, 2012). In the building sector, this can be done by increasing the efficiency of the built environment.

Windows have a significant influence on building energy performance. The proper design of windows can greatly reduce energy consumption in buildings. The natural lighting performance is better when the window-wall ratio increases. However, windows also play a critical role in terms of building thermal insulation which needs to be clearly considered. Most efforts to improve this performance have been based on thermal insulation and air-tightness when actually the cooling load is affected by the solar radiation transmitted through windows in buildings.

1.1. Previous Studies

Most studies of apartment buildings' energy consumption in Korea have primarily been conducted on room heating energy, excluding room cooling. Park Yu-Gwon (2003) analyzed differences in energy consumption with respect to the household location to examine the problem of thermal imbalance in buildings. Choi Won-Gi et al. (2007) analyzed energy consumption patterns with respect to household locations to examine the energy transmitted by adjacent households. Hae Jin Kang and Eon Ku Rhee (2012) analyzed energy consumption patterns in "A Development of Energy Load Prediction Equations for Multi-Residential Buildings in Korea. Kim, Seok-Hyun, et al. (2015) compared the variations of the heating and cooling load on the performance of the windows in the case of

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horizontal shading and the changing position of Venetian blinds. Yang, Qiaoxia, et al. (2015) analyzed the variation of annual heating energy demand, annual cooling energy demand, and the annual total energy consumption in different conditions, including different orientations, patterns of utilization of air conditioning system, window-wall ratio, and types of windows. Kim et al. (2014) have confirmed that the variation of the window elements such as the orientation, window-wall ratio, SHGC, and U-value affect energy consumption. Huh, J. H. and Mun, S. H. (2013) studied the energy demand analysis according to window size and performance for Korean multi-family buildings, they found the necessity to determine whether the performances of the components change relative to changes in the size of the window.

Most of the previous research investigations only considered the whole building. Also, they only confirmed energy consumption according to the variation of the window performance. Specific room function and different operation modes were not considered. Different functions of the room or different usage habits of the room for the same function may result in a great difference in the yearly heating, and cooling energy loads. This study will analyze and investigate the yearly heating, cooling and total heating and cooling energy consumptions of specific rooms as well as the whole area of two prototypes units in an apartment building.

2. METHODS

2.1. Methodology

For this study, two apartment prototype units located in Seoul city were selected. The test buildings were selected based on the unit size, the floor-to-floor height of 2.8m and the ceiling height of 2.4m to properly represent Korean multi-rise residential buildings in general. Thermal analysis was conducted using Autodesk Ecotect Analysis 2011 tool, a user-friendly modeling environment for an early-stage design tool that calculates building energy consumption including heating or cooling energy load for comparative energy analysis. Note that Ecotect's thermal analysis results are not accurate enough for rigorous quantitative analysis of a detailed building that means it is not useful for detailed hourly analysis or for matching true energy use. Here the study focuses only on relative differences, not absolute values like those needed for regulatory work. A thermal model of the prototype units 1 and 2 were constructed on Ecotect. Using varying WWRs the various performance aspects of the thermal design were studied.

2.2. Summary of the Test Units

The target buildings are two 12-story apartment buildings facing due south. There are two apartment units per floor around an elevator. For the purpose of this study the buildings are categorized into two classes: Prototype1 and Prototype 2. In Prototype 1 the floor area is 85m² (total floor area 118.63m² including balconies and service areas). Figure 1 shows the floor plan of prototype 1. In prototype 2 the floor area is 114m² (total floor area including balconies and service areas 152.96m²). Figure 2 shows the floor plan of prototype 2. The general physical features of the test building are presented in Table 1 and 2.

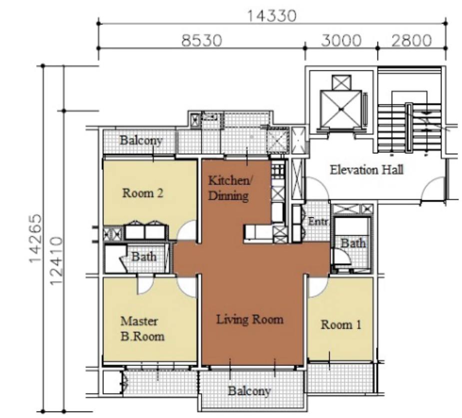

Figure 1. Prototype 1.

Figure 2. Prototype 2.

Table 1. Information about the prototype 1.

Room Name	Room Size (m²)	Exposed wall area (m²)	Windows area (m²)	WWR(%)
Living room	15.83	11.76	10.08	85.7
M.bed room	14.04	10.92	7.56	69.2
Room 1	8.91	10.08	7.56	75.0
Room 2	12.35	7.56	7.00	92.6
Kitchen	12.31	9.97	5.32	53.4

Table 2. Information about the prototype 2.

Room Name	Size (m²)	Exposed wall area (m²)	Windows area (m²)	WWR (%)
Living room	16.97	12.60	10.92	86.7
M.bed room	15.12	11.76	8.40	71.4
Room 1	8.91	7.56	2.88	38.1
Room 2	9.0	8.40	8.40	100
Room 3	10.80	8.40	8.40	100
Kitchen	18.98	11.34	1.92	16.9

In prototype 1 the front facade faces due south and has three windows with front balcony for the living room. The rear, north facade has two windows: room 2 with front balcony and kitchen/dining window. Master bedroom, room 1 and kitchen/dining rooms have frontal service areas. The glazing covers 71.4% of the external south façade of the living room balcony and 45.3% of the external south façade of the master bedroom and room 1 service areas. The glazing covers 59.5% of the external north façade of the room 2 balcony and 64.3% of the external north façade of Kitchen/dining room service area.

In prototype 2 the front facade faces due south and has three windows with front balcony for the living room. The rear north facade has also three windows: room 1, 2 and kitchen windows with front balcony for room 1 and 2. Master bedroom and room 3 have frontal service areas. The glazing covers 61.9% of the external south façade of the living room balcony and 58.9% of the external south façade of the master bedroom and room 3 service areas. The glazing covers 58.3% of the external north façade of the room 1 and 2 balcony area.

In both prototypes, the glazing areas of external facades of balconies and service areas were not changed during the analysis. Only the main living areas WWR were changed and analyzed. The balcony and service areas were modeled as a separate zone with geometrical dimensions. They were not considered as an integral part of the thermal envelope of the main living area. In both units, there are no windows on the east or west façade. For both prototype units, all main windows are made of 22mm thick multi-layered glass with heat transmission coefficient U-Value of 1.178 W/m²k. The airtightness of 0.5ac/h@n50pa was used for the analysis on both prototype units. Table 3 shows the material properties used for the analysis.

Table 3. Material properties.

Materials	U-Value (w/m²K)
External wall- 10mm plaster outside, 50mm fibreboard preformed, 180mm concrete block with 10mm gypsum plasterboard inside.	0.51
Internal wall- 110mm concrete block with 10mm plaster either side.	1.80
Floor-100mm thick concrete slab on ground.	0.88
External walls of balcony and service area- 80mm framed wall as air gap, with 10mm plasterboard either side.	2.2
Roof/Ceiling- 10mm roof screed outside, 25mm screed, 150mm Concrete Floor, 600mm airgap, 50mm wool insulation and 12mm gypsum (Mineral) inside	0.49
Window- 22mm thick double glazed with timber frame. SHGC(0.8) and Visible transmittance (0.65)	1.178
External Windows in balcony and service area- 6mm single pane with timber frame	5.1

3. RESULTS AND DISCUSSION

3.1 Heating and cooling Load Studies

The yearly heating and cooling loads of the two prototype units were analyzed and studied.

Prototype 1

The energy load analysis has shown this unit has a 22 KW/m².y heating demand and 6.4 KW/m².y cooling demand with a total of 28.4 KW/m².y heating and cooling energy load (Fig. 3).

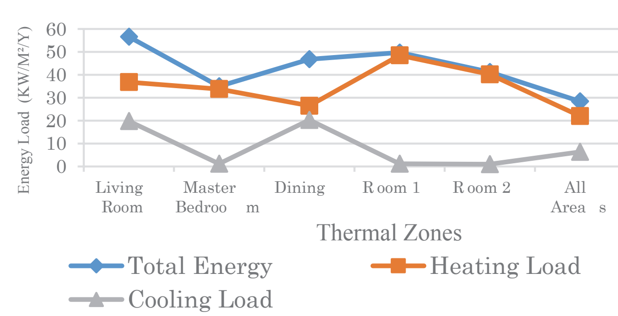

Figure 3. Prototype 1 yearly energy load

Prototype 2

The energy load analysis has shown the unit has a 33.68 KW/m².y heating demand and 6.65 KW/m².y cooling demand with a total of 40.33 KW/m².y heating and cooling energy load (Fig. 4).

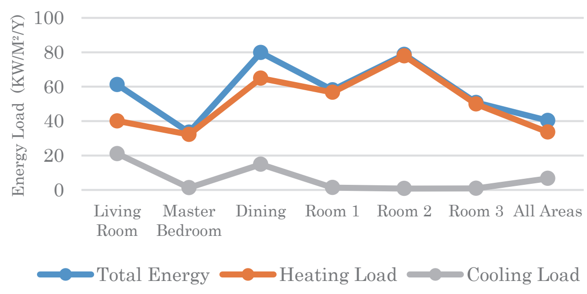

Figure 4. Prototype 2 yearly energy load

Using WWRs of 20%, 30%, 40%, 60% and 80% further analysis of heating and cooling loads were conducted and compared on the south and north façade.

This was done to find out whether there would be any difference on the result when using different WWRs.

Prototype 1

In prototype 1 the sample unit has a WWR of 74.6% internal façade area. When the WWR decreases the energy load also decreases. It decreases by 4.20, 3.44, 2.74 and 1.97 KW/m².y in 20%, 30%, 40% and 50% WWR respectively. In 80% WWR the energy load increases by 0.31 KW/m².y comparing with the base model.

In the living room, all WWRs used have reduced the energy load by 0.42 KW/m².y in 80% to 4.42 KW/m².y in 20%. In the dining/ kitchen room, the energy load has reduced by 19.88, 5.4, 3.13 and 0.85 KW/m².y in 20%, 30%, 40% and 50% WWR respectively while increasing by 5.95 KW/m².y in 80% WWR. In the master bedroom, the WWR of 20% and 80% has increased the energy load by 4.27 and 1.62KW/m².y. The energy load has decreased by 6.49, 4.91 and 3.26 KW/m².y in 30%, 40%, and 50% ratios respectively. In room 1 and 2, all WWR used have reduced the energy load. In room 1, the reduction ranges from 2.56 KW/m².y in 80% to 14.75 KW/m².y in 20%. In room 2, it ranges from 1.2 KW/m².y in 80% to 9.62 KW/m².y in 20% WWR (Fig. 5.).

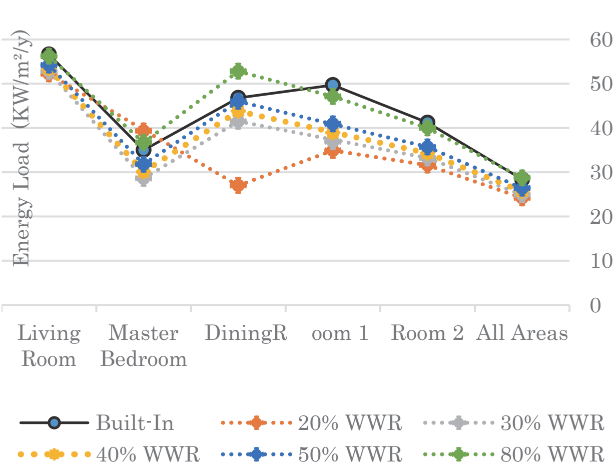

Figure 5. Prototype 1 energy load reductions by WWR.

In this prototype unit the study has found for rooms located on the south WWRs 20-50% has reduced the energy load by 4.3% in 50% WWR to 29.7%in 20% WWR. For rooms located on the north WWRs, 20-50% has reduced the energy load by 1.8% in 50% WWR to 42.4% in 20% WWR. In bedrooms (room 1 and 2) inhabited by one person using 20%, WWR resulted in energy load reduction of 6-8 times than that of 80% WWR. For the whole unit WWRs, 20-50% has reduced the energy load by 6.9% in 50% WWR to 14.8% in 20% WWR. 80%WWR has increased the energy load by 1.1%. Table 4 shows the comparison of energy load with different WWRs.

Prototype 2

In prototype 2 the sample unit has a WWR of 68.1% internal façade area. When the WWR of the whole unit decreases the energy load also decreases. It decreases by 4.43, 3.58, 2.72 and 1.85 KW/m².y in 20%, 30%, 40% and 50% WWRs respectively. In 80% WWR the energy load increases by 0.8 KW/m².y comparing with the base model.

In the living room, all WWRs used have reduced the energy load by 1.32 KW/m².y in 80% to 11.26 KW/m².y in 20%. In dining/kitchen room, all WWRs used have increased the energy load by 0.43, 1.96, 3.48, 5.04 and 9.75 KW/m².y in 20%, 30%, 40%, 50% and 80% WWRs respectively. In the master bedroom except the WWR of 80% which increased the energy load by 0.55 KW/m².y the other WWRs used have decreased the energy load by 9.34, 7.75, 6.14 and 4.47 KW/m².y in 20%, 30%, 40%, and 50% WWRs respectively. In room 1, 20%, 30%, and 40% WWRs have reduced the energy load by 4.88, 3.05 and 1.22 KW/m².y respectively. The 50% and 80% WWRs have increased the energy load by 0.64 and 6.27 KW/m².y comparing with the base model. In room 2 and 3, all window ratios used have reduced the energy load. In room 2, the reduction ranges from 5.59 KW/m².y in 80% to 18.26 KW/m².y in 20%. In room 3, it ranges from 4.28 KW/m².y in 80% to 14.98 KW/m².y in 20% WWR (Fig. 6.).

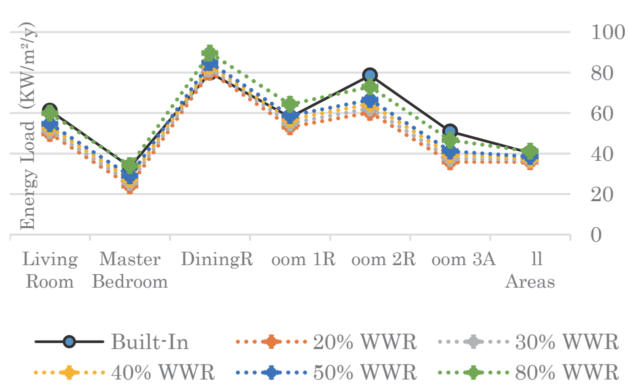

Fig. 6. Prototype 2 energy load reductions by WWR

In this prototype unit, the study has found a similar result as prototype 1 where small WWRs resulted in reduced heating and cooling energy load. (Table 5). For rooms located on the south WWRs, 20-50% has reduced the energy load by 10.6%

Table 4. Comparison of energy load with different WWRs

Total Energy load (KW/m².y)	All areas	Living room	Dinning/Kitchen	Master room	Room 1	Room 2
With built-in WWR	28.40	56.59	46.88	35.04	49.69	41.19
20% WWR	-4.20	-4.42	-19.88	+4.27	-14.75	-9.62
30% WWR	-3.44	-3.78	-5.40	-6.49	-12.77	-7.96
40% WWR	-2.74	-3.16	-3.13	-4.91	-10.73	-6.85
50% WWR	-1.97	-2.41	-0.85	-3.26	-8.76	-5.44
80% WWR	+0.31	-0.42	+5.95	+1.62	-2.56	-1.20

Table 5. Comparison of energy load with different WWRs

Total Energy Load (KW/m².y)	All areas	Living room	Kitchen/ dining	Master room	Room 1	Room 2	Room 3
With built-in WWR	40.33	61.16	79.85	33.43	58.07	78.60	50.87
20% WWR	-4.43	-11.26	+0.43	-9.34	-4.88	-18.26	-14.98
30% WWR	-3.58	-9.72	+1.96	-7.75	-3.05	-16.17	-13.23
40% WWR	-2.72	-8.11	+3.48	-6.14	-1.22	-14.07	-11.43
50% WWR	-1.85	-6.46	+5.04	-4.47	+0.64	-11.98	-9.67
80% WWR	+0.80	-1.30	+9.75	+0.55	+6.27	-5.59	-4.28

in 50% WWR to 29.4% in 20% WWR. For bedrooms (room 1 and 2) located on the north WWRs, 20-40% has reduced the energy load by 2.1% in 40% WWR to 23.2% in 20% WWR. On the south facing bedrooms (master bedroom and room 3) using 20%, WWR resulted in energy load reduction of 1.5-2.1 times than that of 50% WWR. On the north facing bedrooms (room 1 and 2) using 20%, WWR resulted in energy load reduction of 1.5-9.5 times than that of 50% WWR. For the whole unit WWRs, 20-50% has reduced the energy load by 4.6% in 50% WWR to 11% in 20% WWR. 80%WWR has increased the energy load by 2%.

4. CONCLUSIONS

In this study, a simulation analysis was conducted for apartment units located on the first floor to find out the proper WWRs. It was studied using different WWRs.

The results indicate that for total annual building load reduction the optimal WWRs are WWR less than 50% on the south facing windows and less than 40% on the north facing windows. On the south facing bedrooms using 20%, WWR resulted in total annual building load reduction of 1.3-1.5 times than that of 40% WWRs. On the north facing bedrooms using 20%, WWR resulted in total annual building load reduction of 1.3-4 times than that of 40% WWRs. For the whole unit, an total annual building load reduction of 11-14.8% with 20% WWR; 8.9-12.1% with 30% WWR; 6.7-9.6% with 40% WWR and 4.6-6.9% with 50% WWR was achieved. The 80% WWR which is larger than the built-in WWRs of both studied units has resulted in an increase in total annual building load of 1.1-2%.

The finding in this study indicates different WWRs have a significant impact on the heating and cooling loads in multi-rise residential buildings. The WWR on the south and north face should be studied independently based on the room function. A detailed WWR analysis needs to be adopted to assess the energy performance of Korea apartments.

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