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A Study on the Development of Building Envelope Elements for Energy Reduction in Multi- Rise Residential Buildings

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Abstract 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 find an optimal thermal transmittance (U-values) for building envelope elements for low energy multi-rise residential buildings in the early design phase in Korea. The study found that using small U-values of 0.15 w/m²K for exterior walls, ceilings and floors and 1.0 w/m²K for south and north facing windows has resulted in energy reduction of 22.1%-59.4% in the south facing rooms and 43%-77.6% of the north facing rooms. It has also found the energy load reduction potential of using small U-values are higher on the north facing rooms. The findings of this study can be suggested to be used as a baseline case for low energy consumption studies. It can also be used to determine appropriate envelope materials and insulation values.

Keywords: Building Envelope; Residential Building ; Energy Reduction; U-value

1. INTRODUCTION

Energy use in buildings accounts for a large percentage of total energy consumption worldwide, which leads to increasing CO2 emissions. 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).

New buildings present a good opportunity to save energy over the long term. If decided upon in the early design phase, energy efficiency is often considerably less expensive since increased insulation will have only marginal costs for the increased layers of insulation, increased thickness of construction or increased efficiency in appliances (IEA, 2008). The majority of heat is lost through fabric elements through walls, windows, doors and roofs. These building envelope elements have usually built with materials that have high thermal transmittance which result in high heat loss. The insulation materials are also built within the structure, which will create thermal bridges. In Korea conventional apartments have a heating energy consumption of 9,088 kWh/ unit/year and an electricity consumption of 300 kWh/ unit/month (Dong, et al., 2015). This heating and electricity demand can be reduced to 1,689 kWh/unit/year and 45 kWh/unit/month respectively, when built with a concept of zero carbon (Dong, et al., 2015). There are a lot of efforts to improve this performance based on thermal insulation and air-tightness. The main aim of this paper is to find an optimal thermal transmittance (U-values) for building envelope elements for low energy multi-rise buildings in Korea.

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 horizontal shading and the changing position of Venetian blinds. Yang, Qiaoxia, et al. (2015) analyzed the variation

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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.

Most of the previous research investigations only considered the whole building. 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 analyzed and investigated the yearly heating, cooling and total heating and cooling energy consumptions of specific rooms as well as the whole area of two prototype units in an apartment building.

2. METHODS

2.1. Methodology

This study focuses on finding optimal U-values for building envelope elements for low energy multi-rise buildings. First, four case studies of low and zero energy residential buildings were studied and examine with regard to the energy reduction potential of building envelope elements.

Secondly, we performed building energy simulation tests on two apartment prototype units located in Seoul city. 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. By **changing the U-values of envelope materials** the various performance aspects of the thermal design were studied.

2.2. Summary of the Case Study Buildings

Four case studies were selected for review.

- Case Study 1: BedZED – Beddington Zero Energy Development, UK
- Case Study 2: Lummerlund houses (Hannover), Germany
- Case Study: 1 Kolon e+ Green Home, Korea
- Case Study: 2 Green Tomorrow, Korea
- Case Study: 3 Daelim Green home Plus, Korea

The first case study BedZED is a compact urban development project with 82 mixed use units and the other case studies are detached single-family residential projects, known for their striking example of energy efficiency optimization and zero-emissions. The cases were included because they demonstrate how low energy and emission reduction in residential development can be implemented.

2.3. 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.

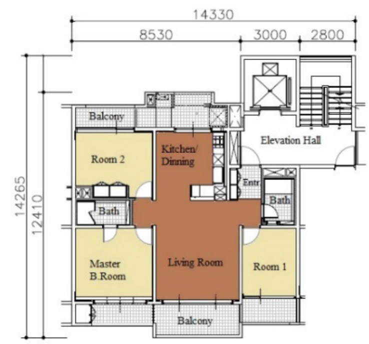

Figure 1. Prototype 1

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 2. Prototype 2

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

Table 1. Information about the prototype 1.

Room Name	Room Size (m^2)	Exposed wall area (m^2)	Windows area (m^2)	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	Room Size (m^2)	Exposed wall area (m^2)	Windows area (m^2)	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

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. 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.	00.51
Internal wall- 110mm concrete block with 10mm plaster either side.	11.80
Floor-100mm thick concrete slab on ground.	00.88
External walls of balcony and service area- 80mm framed wall as air gap, with 10mm plasterboard either side.	2.2
Ceiling- 10mm roof screed outside, 25mm screed, 150mm Concrete Floor, 600mm airgap, 50mm wool insulation and 12mm gypsum (Mineral) inside	00.49
Window- 22mm thick double glazed with timber frame. SHGC(0.8) and Visible transmittance (0.65)	11.178
External Windows in balcony and service area- 6mm single pane with timber frame	5.1

3. RESULTS AND DISCUSSION

3.1. Case Study Findings

The studied buildings are located in mixed climates. In mixed climates the recommended U-values for windows are 0.97 to 1.93 W/m²K to have low energy demand. In the studied buildings, all windows are either double or triple glazed argon or krypton filled with U-values ranging from 0.695 to 1.2W/m²K. For low energy standard houses it is recommendable for exterior walls, roofs and floors to have a U-value less than 0.2W/m²K. On the studied buildings the exterior walls, roofs and floors are built with U-values less than 0.15 W/m²K. Table 4. Summary of the U-value of building

Table 4. Summary of the U-value of building elements.

	Exterior wall U-value W/m²k	Roof	Floor	Window	References
Korea standard U-value	0.47	0.29	0.35	3.84	Samoo architects & engineers. (2010)
Passivhaus standard	0.15	0.15	0.15	0.85	(IPHA)
ASHREA for LEED	0.5	0.36	0.29	2.61	Samoo architects & engineers. (2010)
Case Study 1- BedZED	0.11	0.10	0.10	1.2	(Dunster, Bill, 2003)
Case Study 2-Lummerlund Houses	0.13	0.10	-	0.8	(IEA)
Case Study 3- Kolon e+ Green Home	0.107	-	-	0.75	ArchDaily, and Schuetze & Hagen , 2014
Case Study 4- Green Tomorrow	0.0928	0.077	0.088	0.695	(Samoo architects & engineers. , 2010 and ZEB-ISTIS, 2013)

elements in the first case study building, BedZED a 90% reduction in space heating demand was achieved compared to a standard suburban home built to 1995 building regulations. On the second case study building, Lummerlund Houses an energy consumption reduction of 75% was achieved compared to a standard home. On the third case study building, Kolon e+ Green Home an annual energy consumption reduction of 73% was achieved compared to the standard base model. In the fourth case study, Green Tomorrow an energy consumption reduction of 56% was achieved compared to a standard home.

From the case studies, it was found that the U-values for exterior walls, roofs/ceilings, and floors should be less than 0.2 and less than 1.2 for windows.

3.2 Heating and cooling Load Studies

The yearly heating and cooling loads of the two prototype units were analyzed and studied using U-values of the building envelope elements mentioned in Table 3.

- **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).

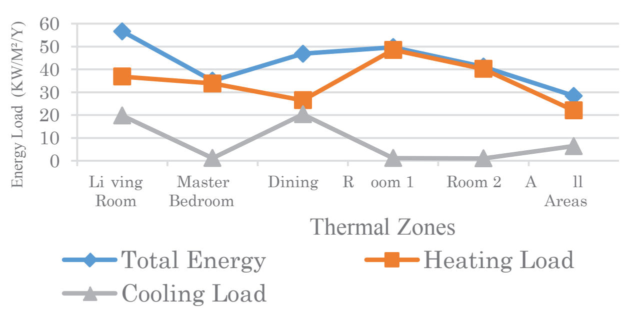

Figure 3. Prototype 1 yearly energy load

- **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).

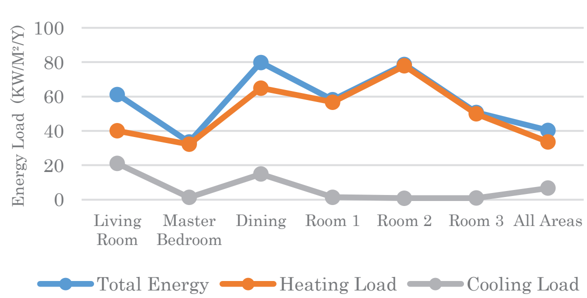

Figure 4. Prototype 2 yearly energy load

Further analysis was conducted by changing the properties and U-Values of walls, ceiling, floor and windows as listed in the Table 5. This was done to find out whether there would be any difference in the heating and cooling energy load result with a change in the properties and U-values of building envelope elements.

Table 5. Material properties.

Materials	U-Value (w/m²K)
External wall- 10mm plaster outside, 110mm phenolic molded low-density insulation,100mm brick plus, 200mm concrete block with 10mm gypsum plaster inside.	0.15
Internal wall- 110mm concrete block with 10mm plaster either side.	0.47
Floor-100mm thick concrete floor, 110mm phenolic molded high density, 10mm cement screed, 10mm ceramic tile	0.15
Ceiling- 10mm roof screed outside, 25mm screed, phenolic molded 110mm 150mm Concrete Floor, 600mm airgap, 50mm wool insulation and 12mm gypsum (Mineral) inside	0.15
Window- 22mm thick double glazed with timber frame. SHGC (0.8) and Visible transmittance (0.65)	1.0

- **Prototype 1**

Comparing with the built-in unit energy load, with a change in properties of envelope materials and the use of a small U-values, the total heating and cooling energy load has reduced by 12.12 KW/m².y. A heating and cooling load has reduced by 11.5 KW/m².y and 0.62 KW/m².y respectively. (Fig. 5).

In this prototype unit the study has found for rooms located on the south the small U-values applied has reduced the energy load by 50.7%, 56.5% and 59.4% in room1, master bedroom and living room respectively. For rooms located on the north it has reduced the energy load by 43% and 52.2% in dining and room 2 respectively. For the whole unit, it has reduced the energy load by 42.7% compared with the built-in unit.

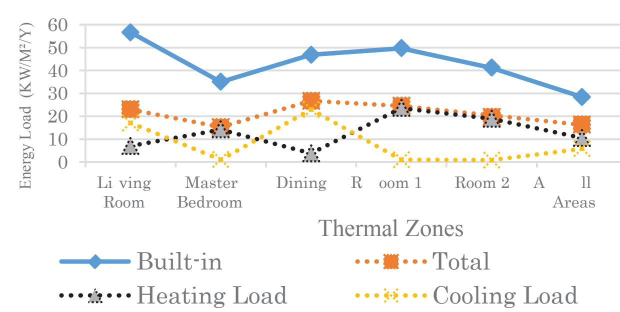

Figure 5. Prototype 1 yearly energy load comparison

- **Prototype 2**

Comparing with the built-in unit energy load, with a change in properties of envelope materials and the use of a small U-values, the total heating and cooling energy load has reduced by 12.97 KW/m².y. A heating load has shown a reduction of 14.74 KW/m².y while the cooling load increases by 1.77 KW/m².y (Fig. 6).

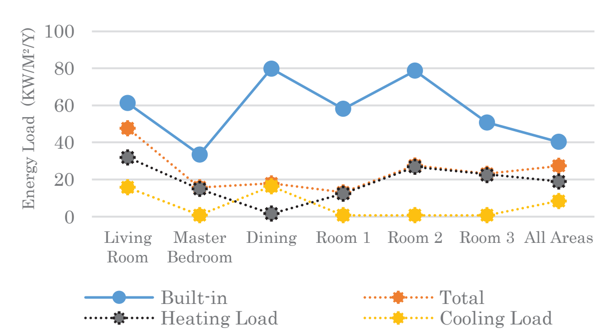

Figure 6. Prototype 2 yearly energy load comparison

In this prototype unit the study has found for rooms located on the south the small U-values applied has reduced the energy load by 22.1%, 53% and 54.6% in living room, master bedroom and room 3 respectively. For rooms located on the north it has reduced the energy load by 64.9%, 77.5% and 77.6% in room 2, room 1 and dining rooms respectively. For the whole unit, it has reduced the energy load by 32.2% compared with the built-in unit.

4. CONCLUSIONS

In this study, four case studies of low and zero energy residential buildings were reviewed to find an optimal U-value for energy load reductions. Based on the findings from the case study a simulation analysis was conducted for two prototype units of an apartment building located on the first floor. First, the analysis was conducted using U-values of 0.51 for exterior walls, 0.49 for ceilings, 0.88 for floors, 1.8 for internal partition walls, and 1.178 w/m^2K for all south and north facing windows. Secondly, it was conducted using U-values of 0.15 for exterior walls, ceilings and floors, 0.47 for internal partition walls and 1.0 w/m^2K for all south and north facing windows.

The study found that using small U-values of 0.15 for exterior walls, ceilings and floors and 1.0 w/m^2K for south and north facing windows has resulted in energy reduction of 22.1%-59.4% in the south facing rooms and 43%-77.6% of the north facing rooms. It has found the energy reduction potential of a small U-values are higher on the north facing rooms. For the whole unit, it has reduced the energy load by 32.2%-42.7% compared with the built-in unit.

The findings of this study can be suggested to be used as a baseline case for low energy consumption studies. It can also be used to determine appropriate envelope materials and insulation values.

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