

Original Article

# Energy-Efficient Design of Building Envelopes for Multi-Story Buildings in Tropical Climates

Sri Yuliani\*<sup>1,2,3</sup>, Bambang Triratma<sup>1,2</sup>, Dyah Susilowati Pradnya Paramita<sup>1,2</sup>, Kartika Tiffania Fairuza Firdaus<sup>1</sup>

<sup>1</sup>Study Program of Architecture, Universitas Sebelas Maret, Surakarta, Indonesia.

<sup>2</sup>Research Group of Sustainable Architecture, Universitas Sebelas Maret, Surakarta, Indonesia.

<sup>3</sup>Center for Regional Information and Development (PIPW), Universitas Sebelas Maret, Surakarta, Indonesia.

<sup>1</sup>Corresponding Author : sriyuliani71@staff.uns.ac.id

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**Abstract** - The building envelope is essential in controlling heat exchange and maintaining thermal comfort within indoor spaces, particularly in multi-story buildings with extensive glass surfaces. This study investigates the thermal performance of building envelopes in a humid tropical climate, using the Overall Thermal Transfer Value (OTTV) as a quantitative measure of energy efficiency. Focusing on the west façade of the Library Building at Universitas Sebelas Maret, the research identifies an OTTV of 61.65 W/m<sup>2</sup>, attributed to the extensive use of untreated glass. This condition results in a high thermal load and increased cooling energy demands. The study also explores the effectiveness of integrating greenery systems on wall surfaces, which achieved a maximum surface temperature reduction of up to 20%. However, this strategy proved to be insufficient if not applied uniformly across all façade orientations. The findings emphasize that minimizing glass proportions and incorporating green elements can significantly reduce thermal loads, particularly on the west side. The study concludes with a recommendation to optimize envelope design and utilize eco-friendly materials to enhance energy efficiency in multi-story buildings located in tropical climates.

**Keywords** - Building Envelope, Multi-Story Building, Overall Thermal Transfer Value, Thermal Performance.

## 1. Introduction

A multi-story building is a building that can provide a visual image of the surrounding area and can even become a landmark. However, the World Energy Use Report states that buildings use the largest amount of energy, which reaches a figure of more than 50% compared to other sectors [1]. Medium-to-high-rise buildings currently almost use a modern concept with the use of futuristic materials, i.e., using various metal, glass, and composite elements, as an effort to form. Magnificent buildings are sometimes not in accordance with the philosophy of green architecture [2- 4].

The design of the building façade actually needs to consider various factors, including the building philosophy according to its function, aesthetics, and efficiency. Regarding efficiency, research that focuses on building energy states that high-rise buildings consume higher energy in supporting building operations and maintenance [5-7]. Building operations are the ability of buildings to provide a room as a place for activities in a safe, comfortable, and healthy manner. One of the important things in supporting building operations is the availability of ventilation components, i.e., Heating, Ventilation, Air Conditioning (HVAC) [8]. An efficient approach to HVAC operation is

largely determined by the building's heat gain, originating from the roof, measured as the Roof Thermal Transfer Value (RTTV), and the walls, indicated by the Overall Thermal Transfer Value (OTTV). The extent of heat transfer is influenced by multiple factors, including the building's orientation, façade design, and the selection of construction materials. [9-12]. In contemporary construction, the selection and use of building materials are increasingly driven by both technological innovation and aesthetic advancement. The choice of exterior materials for multi-story buildings, in particular, has a significant impact on the efficiency and performance of the building envelope. One aspect that has gained growing attention is the performance of building envelopes in minimizing heat transfer, as this greatly influences both energy efficiency and the thermal indoor comfort for users. In this context, numerous studies have highlighted that lowering building energy consumption remains a key challenge in efforts to reduce the global carbon footprint and mitigate environmental warming [4, 5, 6, 13, 14, 15].

Buildings that increasingly fill the earth's surface can have a negative impact when designers do not have enough knowledge to consider building design. Many studies have



been conducted to further explore the relationship between the existence of buildings and the increase in building heat [16-18]. Several studies have concluded that building density has an impact on increasing global warming [9, 11, 18, 19].

This article aims to provide information from studies that have been conducted in depth on the strategic role of building envelopes as a strategic component in reducing the thermal load of multi-story buildings. The building envelope not only serves as a shield from external environmental factors but also as a key component that determines the overall energy efficiency of a building [11, 20, 21, 22, 23, 24]. Considering the latest technological and material developments, the emphasis on intelligent and effective building envelope design can make a major contribution to the improvement of controlled thermal performance in multi-story buildings.

Based on several studies oriented to the design of building envelopes, such as the materials with excellent heat-resistant properties, air ventilation techniques, the use of efficient windows, and the implementation of reflective coatings, this study focuses on the performance of building materials that cover building walls in relation to building heat. By intelligently integrating building material elements, the building envelope can minimize unwanted heat penetration and maintain the temperature in the building. Ultimately, by lowering the building's temperature, heat transfer between the structure and its surroundings is reduced, creating a comfortable indoor environment while consuming less energy.

This research examines the influence of building materials on heat generation in multi-story buildings. Massing and configuration of the east and west façades can be considered inappropriate, leading to building heating. This research's novelty lies in examining building materials and their impact on the sun-exposed façade in the humid tropics. This comprehensive research aims to offer information that is expected to deliver meaningful insights for architects, engineers, and stakeholders in the construction industry to enhance the thermal efficiency of high-rise buildings. Thus, the implementation of thermally efficient building envelope design not only supports environmental sustainability but is also economically beneficial overall.

## 2. Materials and Methods

The research uses a case study of the Universitas Sebelas Maret (UNS) Library Building, which is in a humid tropical area in the city of Surakarta, at 7°33'34.0"S 110°51'24.6"E, as shown in Figure 1. The object of the research was a case study of the Universitas Sebelas Maret Library Building. This building is a case study that considers the function of the building, the building's height, façade treatment, and the use of modern materials as a representation of buildings in

general in urban areas. Figure 2 presents the front and side views of the Library Building of Universitas Sebelas Maret of Surakarta.

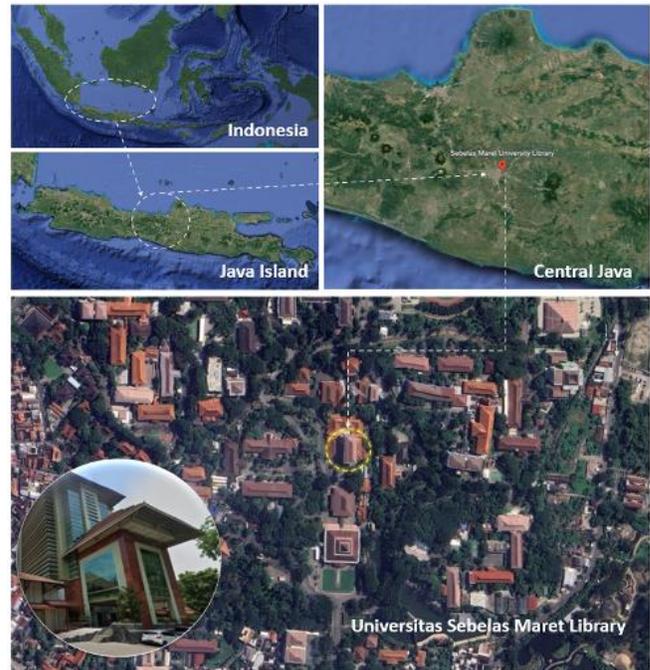


Fig. 1 Research object



Fig. 2 Sebelas maret university library building in surakarta city

The research uses a quantitative method by conducting measurements in the field [25, 26]. The method was determined from several studies using thermal measurements of building materials in the field [27, 28]. The research conducted experiments on types of building materials with samples measured directly on the building. The research data comprises the types and characteristics of building envelope materials, specifically the surface temperature of each material as measured using an infrared thermometer. Measurements are also taken on the dimensions of each material used on the building wall with an infrared distance meter. To identify some material characters, the authors use standards from the literature to determine the conductivity, absorption, and other thermal parameters of building sheathing materials in general. Some building material values are obtained from measurement results and reference values

of material characteristics according to Indonesian National Standards. The data that has been obtained in the experimental model is analyzed using numerical simulations in the Excel program through the OTTV formulation, which is formatted on each sheet.

### 3. Results and Discussion

The research takes a case study in the city of Surakarta, as a representation of a growing city; thus, the research is expected to serve as a reference in formulating design regulations for multi-story buildings in urban areas, aligned with the principles of sustainable development. The city of Surakarta, also known as Solo, experiences a tropical climate characterized by two primary seasons: the rainy season and the dry season [29]. The rainy season is from October to March, with high rainfall peaking in December and January. The average temperature throughout the rainy season ranges from 24°C to 32°C, and humidity is high, often above 80%. Meanwhile, the dry season, from April to September, has low rainfall, and the driest months are usually July and August. The average temperature in the dry season ranges from 22°C to 30°C with relatively lower humidity than in the rainy season, but still quite high, above 50%. The average annual climate data shows average temperatures of 26°C to 28°C, while annual rainfall is around 2,000 mm to 3,000 mm, with average humidity of 75% to 85%. The climate of the city of Surakarta is included in the category of humid tropical climate areas [30, 31] that are characterized by heat and humidity.

The object of the research is the Universitas Sebelas Maret Library Building, with strategic functions and activities of a university. The seven-story building, as a representation of medium-rise buildings in the city of Surakarta, as well as the location of the building in an environment that is not too dense, in addition to facilitating data retrieval, is also a good comparison. The architectural technical information of the research object is presented in Figures 3 and 4.

The library building, generally used as a literacy room that provides a variety of reference books in various forms, requires a design that provides comfort to visitors and managers in reading and doing assignments, compiling papers, theses, final projects, and other tasks related to literacy. For such a reason, the building is designed by utilizing natural lighting around the building, so that it is more efficient. The building has a sheath material dominated by glass material from several sides, both on the front façade facing south, as well as the sides of the east and west, and even the back on the north side, as shown in Figure 4. Building materials used as walls and windows on the west, east, south, and north sides include concrete frame structures for columns and beams, brick walls with stucco, brick walls with granite, glass, aluminum composite panels as secondary skin, and curtain walls in the interior as curtains that can be

controlled to get natural light from the outside. The building material is applied as a building sheath with different variations from the ground floor to the top Floor. The building is located on land that still has a distance between buildings, so it can let in the natural light of the sun without obstruction. The position of the building relative to the sun's orbit is visualized in Figure 5.

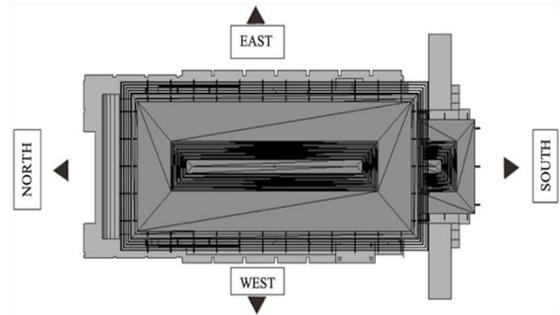


Fig. 3 View of the building

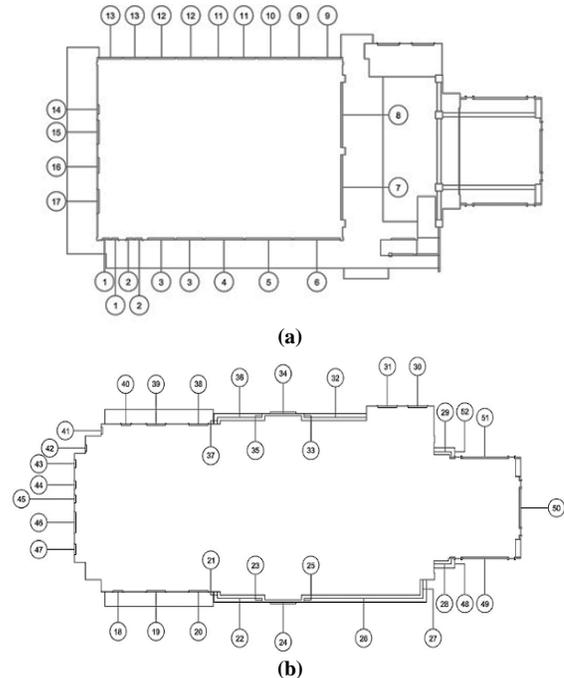
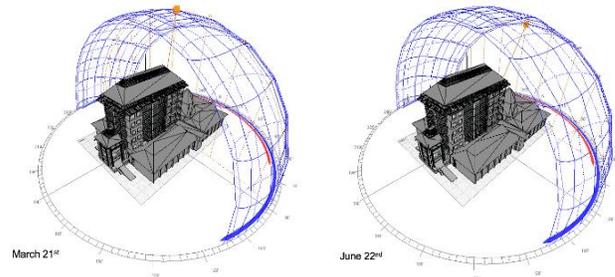


Fig. 4 Wall and windows configuration (a) 2<sup>nd</sup> floor, and (b) 3<sup>rd</sup>—7<sup>th</sup> floor



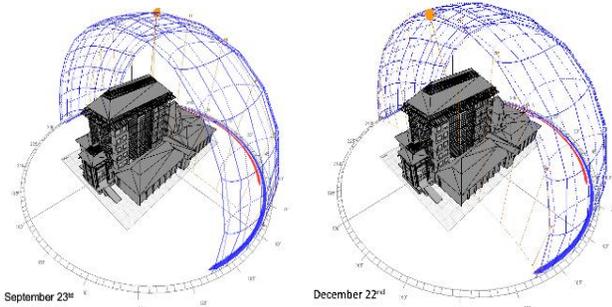


Fig. 5 The position of the sun on the building object

Research on the performance of building envelopes as a component of thermal reduction in tall buildings usually involves several methods to measure, analyze, and evaluate thermal performance. This study uses a quantitative paradigm [25, 26] with a measurement method in the field with thermal measuring tools, i.e., thermometers, thermocouples, and thermal cameras, to measure surface temperature and heat distribution in the building envelope.

How to analyze data using a mathematical model through the calculation of heat transfer values based on the SNI formulation. Based on SNI 6389-2020, the formulation to determine the magnitude of the Overall Thermal Transfer Value (OTTV) uses Equation (1).

$$OTTV = \alpha [U_w \times (1-WWR) \times TD_{Ek}] + (U_f \times WWR \times \Delta T) + (SC \times WWR \times SF) \quad (1)$$

- OTTV = The overall thermal transmittance value of the exterior wall varies depending on its specific orientation or direction (W/m<sup>2</sup>).
- $\alpha$  = Solar radiation absorption
- UW = Thermal transmittance of transparent or translucent walls (W/m<sup>2</sup>K)
- WWR = The ratio of window area to the total exterior wall area for a given orientation
- TD<sub>Ek</sub> = Equivalent temperature difference (K); (see Table 1)
- SF = Solar radiation factor (W/m<sup>2</sup>)
- SC = Shading coefficient of the window system
- U<sub>f</sub> = Thermal transmittance of fenestration (W/m<sup>2</sup>K);
- $\Delta T$  = The difference in planning temperature between the outside and the inside. (taken at 5K)

Table 1. Temperature equivalent difference for the wall

Weight/area (kg/m <sup>2</sup> )	TD <sub>Ek</sub> (K)
Less than 125	15
126 ~ 195	12
More than 195	10

The evaluation of heat transfer values in buildings is intended to analyze the performance of the building envelope as a research objective in formulating a thermal reduction strategy for multi-story buildings in humid tropical areas. Based on the calculation with the detailed OTTV formulation in Tables 2, 3, 4, and 5 (in appendix 1, 2, 3, and 4), several determining components are measured and calculated in detail in the excel program, so that it is more practical to get more accurate results, as in the example of Tables 6 and 7 (in appendix 5). Calculations by including OTTV formulations in Excel programs make analysis with mathematical studies faster and more accurate, although in the preparation of the program, it is necessary to connect several sheets in the file. The formula for calculating OTTV is derived from each component of the material, with the characteristics of the material on each sheet, and is integrated with the formulation to calculate each element in the heat transfer of the building.

Thermal research on buildings in general has a target of managing the lowest possible building energy, but in architectural considerations, it is also necessary to consider the aesthetic façade of the building [3, 4, 5, 32, 33]. Table 8 shows the results of the Overall Thermal Transfer Value (OTTV) calculation based on the formulation of SNI 6389-2020.

Table 8. OTTV calculation results at the UNS Library Building

Façade	Partial OTTV (W/m <sup>2</sup> )	Area of the envelope (m <sup>2</sup> )	Thermal Transmittance (Watt)	Window-to-Wall Ratio
West	61,65	890,85	54.921,03	0,48
South	30,39	509,98	15.495,94	0,27
East	30,62	898,90	27.521,26	0,42
North	17,13	448,25	7.680,39	0,13
<b>Total</b>		2.747,97	105.618,62	

Based on SNI 6389-2020, the design criteria for the entire exterior wall of the building in the efficient category have a maximum value of 35 Watt/m<sup>2</sup>. The calculation shows that the amount of OTTV is 105,618.62 divided by 2,747.97 Watt/m<sup>2</sup> and the total OTTV obtained reaches 38.44 Watt/m<sup>2</sup>. The figures obtained from the UNS Library Building show a value above the efficient category, and the building refers to a structure characterized by energy inefficiency. The main cause of the high OTTV in the building is the green Ray-Ban glass material, which has a thickness of 8mm, a U-value of 5.7 W/m<sup>2</sup>K, and an SC of 0.58. The character of such a glass material dominates the west side, which results in the heat transfer value in the largest building from the west side. The study found that the façade contributing the greatest amount of heat was the western part, which reached 61.65 W/m<sup>2</sup> while the lowest was in the northern part, which was 17.13 W/m<sup>2</sup>. The factors that cause heat in the west wall are the area of the wall, the

use of glass materials, and the lack of shade for the building, so that the heat conduction in the west area is remarkably high. For such a reason, it is necessary to review each material on the building envelope on each side. Exterior building materials, particularly those on the west and east sides, are exposed to solar radiation, which can potentially increase indoor temperatures, especially in buildings located in tropical regions. In humid tropical conditions, heat exposure can potentially reduce humidity; however, if not accompanied by sufficient wind speed, it may instead trap even more heat, as observed in the research.

The use of glass in the Universitas Sebelas Maret Library Building has an impact on increasing building heating, so that it provides a high cooling load on the HVAC system, in line with the research by Jand D. et al. [8]. The results of this study add to the evidence that the use of glass needs to be limited to multi-story buildings [34, 35]. This study also proves that the building envelope requires more careful attention in the configuration of shapes and material elements [19, 36, 39].

**Table 9. OTTV revision with greenery systems at the UNS library building**

Façade	Partial OTTV	Description
West	49,32	OTTV can be corrected, but its value is still inefficient.
South	30,39	The greenery system cannot be implemented in this area, and OTTV cannot be corrected yet.
East	24,5	OTTV can be corrected, and its value indicates energy efficiency.
North	17,13	OOTV has already proven its effectiveness in enhancing energy efficiency.

In a framework that includes efficiency and renewable energy to minimize energy use and carbon emissions, building energy adequacy is a major concern for policymakers and development. Although the building sector has an important role to play in the success of energy management planning, especially tall buildings [7] and climate, research on driving factors, technologies [12], and effective policy instruments to achieve building energy adequacy in the operational phase of buildings is still limited. The characteristics of occupant demands in building operational services can be categorized into four dimensions: temporal and spatial factors, qualitative and quantitative aspects, controllability and adaptability, and flexibility [23, 24]. In addition, architectural considerations related to the sheathing system and the energy system also need to be reviewed [7, 40, 41]. The use of glass as a wall material for multi-story buildings needs to be limited as a primary wall material because it has a high heat transfer value. Another

solution can be done by using a secondary skin on the western glass wall. The OTTV calculation in Table 9 demonstrates that the application of a green wall effectively reduces surface temperature, contributing to improved thermal performance. However, energy efficiency gains were observed only on the east façade, while the west façade still requires additional envelope interventions. This highlights the need for alternative strategies, which will be explored in future research to achieve a fully optimized and energy-efficient building façade. Finally, the implications and recommendations of building envelope design policies are beneficial and multidisciplinary in nature by demonstrating the need for further research and accelerating the implementation of development policies in developed and developing countries.

#### 4. Conclusion

The building envelope on the Library Building on the west wall is dominated by green Ray-Ban glass material. In the western position of the building in general throughout the season, it receives direct sunlight exposure, so the heat radiation in this part is exceedingly high. The west wall side contributes significant heat, so that the cooling load in the space is even greater. Building thermals cause heat load conditions that the building must reduce through the HVAC system. This leads to high energy consumption and makes the building not energy efficient. The main factors that play a particularly important role in causing high building heat are the use of glass materials and the extent of the wall area exposed to direct solar radiation, particularly on the east and west orientations, which experience higher solar intensity and duration, resulting in greater heat absorption and increased thermal load on the building envelope. The lack of shading elements in the wall openings allows more solar heat to penetrate directly into the building without any filtering.

This research provides recommendations for optimal glass usage restrictions in tropical high-rise building construction. Alternative materials that can be used together with glass are wall covering elements with green walls or buildings made of advanced materials.

As part of efforts to enhance building energy efficiency, the building envelope plays a crucial role as it directly influences the building's heat transfer. The design of an environmentally friendly multi-story building envelope is a determinant of building energy use. The findings highlight a novel, climate-responsive approach to energy-efficient building envelope design that goes beyond conventional considerations of orientation, sun-exposed wall area, material selection, and façade configuration. Specifically, this study reveals that in humid tropical regions, simply incorporating glass for natural lighting and views in high-rise buildings is insufficient for thermal comfort. Instead, it is strongly recommended that more than half of the glass surfaces be integrated with greenery systems, a strategy proven to

significantly reduce surface temperatures and mitigate solar heat gain. This combined approach offers a practical and innovative solution tailored to the unique challenges of tropical climates, advancing sustainable building design by harmonizing aesthetics, functionality, and energy efficiency.

### Conflicts of Interest

Sri Yuliani (SY) initiated the research idea, determined the procedure and research object, and finalized the manuscript. Bambang Triratma (BT) collected field data, identified building sheath materials on the research object, made a model of the building in digital drawing format, and prepared a draft manuscript. Dyah Susilowati Pradnya Paramita (DSPP) conducted data analysis, calculated the heat transfer of buildings, and identified research problems. Kartika Tiffania Fairuza Firdaus (KTFF) conducted data

verification, data processing verification, and research results. The authors declare that there is no conflict of interest regarding the publication of this paper.

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Appendix 1

Table 2. OTTV Calculation using Excel program for the west façade

OTTV PARTIAL WEST FAÇADE CALCULATION																																								
ORIENTATION		WEST																																						
BUILDING ENVELOPE		2nd Floor					3rd Floor					4th Floor					5th-6th Floor					7th Floor					Unit													
Type of wall		Brick n 60 cm	Colum 20 cm	Curtai Wall n 3	Curtai Wall n 4	ACP 2	ACP 4	ACP 1	Curtai n Wall 5	Curtai n Wall 5	Brick + Granit e 2	Beam 40 cm	GRC ornament	ACP 2	ACP 4	ACP 1	Curtai n Wall 5	Curtai n Wall 5	ACP 1	ACP 2	ACP 4	ACP 3	Curtai n Wall 1	Curtai n Wall 5	ACP 1	ACP 2	ACP 4	ACP 3	Curtai n Wall 1	Curtai n Wall 5	ACP 1	ACP 2	ACP 4	ACP 3	Curtai n Wall 1	Curtai n Wall 5				
$\alpha$ (absorption)	=	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,26	0,26	0,84	0,84	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,40	0,26	0,26				
$U_w$ (U-value)	=	3,25	1,32	2,67	0,36	0,28	0,35	0,30	0,34	0,94	0,35	3,04	1,40	2,38	0,35	0,30	0,34	0,94	0,35	4,69	0,35	0,30	0,34	0,94	0,35	4,69	0,35	0,30	0,34	0,94	0,35	4,69	0,35	0,30	0,34	0,94	0,35	W/m <sup>2</sup>		
$A_w$ (Floor square)	=	22,58	2,70	3,24	5,11	8,76	66,39	6,30	6,51	7,21	0,84	10,92	4,74	7,40	66,39	6,30	6,51	7,21	0,84	1,80	66,39	6,30	6,51	7,21	0,84	1,80	50,58	5,11	6,51	7,21	0,84	1,80	50,58	5,11	6,51	7,21	0,84	m <sup>2</sup>		
$A_{w0}/\sum A_w$	=	0,53	0,06	0,08	0,12	0,21	0,60	0,06	0,06	0,07	0,01	0,10	0,04	0,07	0,76	0,07	0,07	0,08	0,01	0,02	0,75	0,07	0,07	0,08	0,01	0,02	0,70	0,07	0,09	0,10	0,01	0,01	0,01	0,01	0					
1-WWR	=	0,44					0,49							0,45						0,46						0,41														
Weight/ square	=	282,0	1349,0	40429,0	405,60	259,31	241,8	1317,2	397,2	405,60	259,12	339,60	1267,1	9,67	241,8	1317,2	397,2	405,60	259,12	9,50	241,8	1317,2	397,2	405,60	259,12	0,00	9,50	241,8	1317,2	397,2	405,60	259,12	0,00	9,50	241,8	1317,2	397,2	405,60	259,12	kg/m <sup>2</sup>
$TD_{ik}$	=	10	10	10	10	10	10	10	10	10	10	10	15	10	10	10	10	10	10	15	10	10	10	10	10	10	15	10	10	10	10	10	10	10	10	10	10	0	K	
<b>OTTV Wall</b>	=	3,07	0,15	0,36	0,05	0,07	0,00	0,41	0,03	0,04	0,08	0,00	1,23	0,25	0,48	0,04	0,05	0,09	0,00	0,00	0,00	0,26	0,48	0,04	0,05	0,09	0,00	0,00	0,28	0,40	0,03	0,05	0,10	0,00	0,00	0,00	W/m <sup>2</sup>			
Type of window		W01	W02	W03	W04	W05	W06	W18	W19	W20	W22	W24	W26	W28	W49	W18	W19	W20	W22	W24	W26	W2	W56	W57	W58	W60	W62	W64	W6	W97	W98	W99	W101	W103	W105	W107				
$U_i$ (U-value of window)	=	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	W/m <sup>2</sup>		
$A_i$ (Window area)	=	0,49	0,49	8,88	13,07	15,75	15,7	2,20	4,30	4,30	20,75	9,96	56,03	8,30	11,07	2,20	4,30	4,30	20,75	9,96	56,03	8,30	2,20	4,30	4,30	20,75	9,96	56,03	8,30	2,20	4,30	4,30	20,75	9,96	56,03	8,30	56,03	8,30	m <sup>2</sup>	
$A_{i0}/\sum A_i$	=	0,01	0,01	0,16	0,24	0,29	0,29	0,02	0,04	0,04	0,18	0,09	0,48	0,07	0,09	0,02	0,04	0,04	0,20	0,09	0,53	0,08	0,02	0,04	0,04	0,20	0,09	0,53	0,08	0,02	0,04	0,04	0,20	0,09	0,53	0,08	0,02	0,08		
WWR	=	0,56					0,51								0,55					0,54								0,59												
$\Delta T$	=	5					5								5					5								5										K		
<b>OTTV conduction</b>	=	0,14	0,14	2,59	3,81	4,59	4,59	0,28	0,54	0,54	2,60	1,25	7,03	1,04	1,39	0,32	0,63	0,63	3,06	1,47	8,27	1,23	0,32	0,63	0,63	3,03	1,46	8,19	1,21	0,35	0,69	0,69	3,32	1,46	8,98	1,33	8,98	1,33	W/m <sup>2</sup>	
$SC_i$ (SC glass)	=	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58		
$SC_{int}$ (Sc shading device)	=	0,41	0,43	0,42	0,48	0,44	0,47	0,56	0,55	0,51	0,56	0,75	0,54	0,52	0,79	0,56	0,55	0,51	0,56	0,75	0,54	0,52	0,56	0,56	0,62	0,85	0,60	0,52	0,70	0,72	0,72	0,61	0,78	0,57	0,50	0,57	0,50			
SC	=	0,24	0,25	0,24	0,28	0,26	0,27	0,32	0,32	0,30	0,32	0,43	0,32	0,30	0,46	0,32	0,32	0,30	0,32	0,43	0,32	0,30	0,33	0,32	0,32	0,36	0,49	0,35	0,30	0,40	0,42	0,42	0,35	0,46	0,33	0,29	0,33	0,29		
SF	=	243					243								243					243								243												
<b>OTTV radiation</b>	=	0,29	0,31	5,37	9,04	9,99	10,6	0,76	1,47	1,36	7,17	4,61	18,92	2,66	5,43	0,90	1,73	1,60	8,43	5,42	22,2	3,13	0,90	1,74	1,73	9,33	6,09	24,12	3,11	1,21	2,44	2,45	9,97	5,66	25,27	3,31	25,27	3,31	W/m <sup>2</sup>	
<b>OTTV Window</b>	=	0,43	0,45	7,96	12,85	14,57	15,2	1,04	2,01	1,90	9,77	5,86	25,95	3,70	6,81	1,22	2,36	2,24	11,50	6,89	30,5	4,36	1,22	2,37	2,36	12,36	7,55	32,32	4,32	1,57	3,13	3,14	13,29	7,12	34,25	4,64	34,25	4,64	W/m <sup>2</sup>	
Envelope square (A)	=	97,78					227,2								193,0													177,8									m <sup>2</sup>			
Total of envelope square	=	890,8													9												9										m <sup>2</sup>			
<b>OTTV typical</b>	=	55,22					59,54								59,77													63,41									W/m <sup>2</sup>			
<b>OTTV façade (partial)</b>	=	61,65																																			W/m <sup>2</sup>			

Appendix 2

Table 3. OTTV Calculation using Excel program for the south façade

OTTV PARTIAL SOUTH FASADE CALCULATION																																							
ORIENTATION		SOUTH																																					
BUILDING ENVELOPE		2nd Floor					3rd Floor					4th Floor					5th Floor					6th Floor					7th Floor			Unit									
Type of wall	Brick Colum Beam n 60 20 cm GRC Brick Brick Colu Beam Curta Curtai ACP ACP ACP GRC ACP ACP 3ACP 4Curta Curtai Brick ACP ACP 3ACP 4Curta Curtai ACP ACP 3ACP 4Curta Curtai ACP ACP 3ACP 4Curta Curtai																																						
$\alpha$ (absorption)	-0,40	0,40	0,40	0,40	0,84	0,84	0,84	0,84	0,26	0,26	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,26	0,26				
$U_w$ (U-value)	-3,25	1,32	2,67	1,63	1,48	3,04	1,29	1,40	0,94	1,00	0,35	0,30	0,34	0,34	2,38	0,35	0,30	0,34	0,94	1,00	0,35	0,30	0,34	0,94	0,35	0,35	0,30	0,34	0,94	0,35	0,35	0,30	0,34	0,94	0,35				
$A_w$ (Floor square)	-16,26	9,45	4,90	21,91	12,60	10,39	12,60	3,93	12,87	0,42	18,47	6,30	1,56	6,65	18,47	6,30	1,56	12,87	0,42	36,16	28,43	6,30	1,56	3,05	0,84	28,43	6,30	1,56	3,05	0,84	22,61	5,11	1,56	3,05	0,84				
$A_{w, \Sigma} A_w$	-0,24	0,14	0,07	0,33	0,15	0,12	0,15	0,05	0,15	0,00	0,22	0,07	0,02	0,08	0,24	0,08	0,02	0,17	0,01	0,48	0,71	0,16	0,04	0,08	0,02	0	0,71	0,16	0,04	0,08	0,02	0	0,68	0,15	0,05	0,09	0,03	0	
1-WWR	-0,72				0,80										0,84					0,48						0,20					0,42								
Weight/ square	-282,0	1349,0	429,0	009,72	1230,	339,6	1406,	1267,1	1405,6	258,60	241,8	1317,	397,2	9,67	241,8	1317,2	397,2	22405,6	258,60	282,00	241,8	1317,2	397,2	22405,6	258,60	259,12	241,8	1317,2	397,2	22405,6	259,12	259,12	259,12	259,12	120,00	kg/m <sup>2</sup>			
$TD_{sk}$	-10	10	10	15	10	10	10	10	10	10	10	10	10	15	10	10	10	10	10	10	10	10	10	10	10	0	10	10	10	10	10	10	10	10	10	0	K		
OTTV Wall	-2,29	0,54	0,57	2,32	1,45	2,46	1,26	0,43	0,29	0,01	0,24	0,07	0,02	0,88	0,28	0,08	0,02	0,35	0,01	5,18	0,41	0,09	0,03	0,09	0,01	0,0	0,20	0,04	0,01	0,04	0,00	0,00	0,40	0,08	0,03	0,09	0,01	0,00	W/m <sup>2</sup>
Type of window	W07 W08 W27 W48 W50 W52 W27 W54 W55 W65 W87 W89 W9 W1 W65 W92 W94 W96 W106 W128 W130 W1 32																																						
$U_f$ (U-value of window)	-5,70	5,70			5,70	5,70	5,70	5,70	5,70					5,70	5,70	5,70	5,70	5,70		5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70			
$A_f$ (Window area)	-21,27	4,45			7,89	2,49	9,03	2,49						7,89	3,50	3,50			7,89	13,86	7,74	13,	86	6	7,89	13,86	9,96	13,8	6	7,89	13,86	9,96	13,8	6	13,8	m <sup>2</sup>			
$A_w / \Sigma A_f$	-0,83	0,17	0	0	0	0,36	0	0,11	0,41	0,11	0	0	0	0	0,53	0	0,24	0,24	0	0	0,18	0	0,32	0,18	0,3	0	0,17	0	0,30	0,22	0,30	0	0,17	0	0,30	0,22	0,30		
WWR	-0,28				0,20										0,16					0,52						0,80					0,58								
$\Delta T$	-5				5										5					5						5				5									
OTTV conduction	-6,58	1,38	0,00	0,00	0,00	2,09	0,00	0,66	2,39	0,66	0,00	0,00	0,00	0,00	0,00	2,48	0,00	1,10	1,10	0,00	0,00	2,69	0,00	4,73	2,64	4,7	0,00	3,92	0,00	6,89	4,95	6,89	0,00	2,85	0,00	5,02	3,61	5,02	W/m <sup>2</sup>
$SC_g$ (SC glass)	-0,58	0,58			0,58	0,58	0,58	0,58	0,58					0,58	0,58	0,58	0,58	0,58		0,58	0,58	0,58	0,58	0,58	0,5	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58		
$SC_{sh}$ (Sc shading device)	-0,67	0,67			0,69	0,68	0,80	0,68						0,69	0,66	0,66			0,69	0,66	0,92	0,6	0,9	0,6	0,69	0,70	0,88	0,70	0,69	0,69	0,69	0,69	0,69	0,69	0,69	0,69	0,69		
SC	-0,39	0,39	0,00	0,00	0,00	0,40	0,00	0,39	0,46	0,39	0,00	0,00	0,00	0,00	0,00	0,40	0,00	0,39	0,38	0,00	0,00	0,40	0,00	0,38	0,53	0,4	0,00	0,40	0,00	0,41	0,51	0,41	0,00	0,40	0,00	0,40	0,46	0,40	
SF	-97				97										97					97						97				97									
OTTV radiation	-8,71	1,82	0,00	0,00	0,00	2,84	0,00	0,88	3,77	0,88	0,00	0,00	0,00	0,00	0,00	3,37	0,00	1,44	1,43	0,00	0,00	3,66	0,00	6,15	4,79	6,4	0,00	5,34	0,00	9,59	8,59	9,52	0,00	3,89	0,00	6,87	5,66	6,84	W/m <sup>2</sup>
OTTV Window	-15,29	3,19	0,00	0,00	0,00	4,92	0,00	1,54	6,16	1,54	0,00	0,00	0,00	0,00	0,00	5,85	0,00	2,54	2,53	0,00	0,00	6,35	0,00	10,88	7,43	11,	0,00	9,26	0,00	16,48	13,54	16,4	0,00	6,75	0,00	11,89	9,27	11,8	W/m <sup>2</sup>
Envelope square (A)	-92,11				107,6										90,66											57,31				78,72								m <sup>2</sup>	
Total of envelope square	-509,9				8																																	m <sup>2</sup>	
OTTV typical	-24,33				21,30										16,85											36,48				55,99								40,38	W/m <sup>2</sup>
OTTV façade (partial)	-30,39																																						W/m <sup>2</sup>

Appendix 3

Table 4. OTTV Calculation using Excel program for the east façade

OTTV PARTIAL EAST FASADE CALCULATION																																																				
ORIENTATION		EAST																																																		
BUILDING ENVELOPE		2nd FLOOR					3rd FLOOR					4th FLOOR					5th-6th FLOOR					7th FLOOR					Unit																									
WALL	Type of wall α (absorption)	Brick	Bea	Curtai	Curtai	ACP	ACP	ACP	ACP	ACP	Brick	Beam	GRC	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	ACP	Unit																		
		m	20 n	Walln	Wall	2	4	n	Walln	Wall	+	40	cm	ornam	2	4	n	Walln	Wall	1	2	3	4	n	Walln	Wall	1	2	3	4	n	Walln	Wall																			
		cm	1	2						Grani	te	Grani																																								
	U <sub>w</sub> (U-value)	= 0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,26	0,26	0,84	0,84	0,40	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,40	0,26	0,26	0,40	0,40	0,40	0,40	0,26	0,26	W/m <sup>2</sup>																					
	A <sub>w</sub> (Floor square)	= 11,00	3,31	5,18	8,88	87,26	3,15	9,00	4,97	0,84	10,92	4,74	7,40	87,26	3,15	9,00	4,97	0,84	1,80	87,26	3,15	9,00	4,97	0,84	4,69	0,35	0,30	0,34	0,94	0,35	4,69	0,35	0,30	0,34	0,94	0,35	K															
	A <sub>wa</sub> /ΣA <sub>wa</sub>	= 0,39	0,12	0,18	0,31	0	0,68	0,02	0,07	0,04	0,01	0,09	0,04	0,06	0	0	0,83	0,03	0,09	0,05	0,01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																
	1-WWR	= 0,52				0,56								0,54																					0																	
	Weight/ square	= 282,0	429,0			0,0	241,8	1317,2	397,2			1230,6	1267,1			241,8	1317,2	397,2			241,8	1317,2	397,2			241,8	1317,2	397,2			241,8	1317,2	397,2	kg/m <sup>2</sup>																		
	TD <sub>s</sub>	= 10	10	10	10	10	10	10	10	10	10	10	15	0	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0	0	0K															
	OTTV Wall	= 2,61	0,65	0,23	0,42	0	0,54	0,02	0,05	0,05	0,00	1,23	0,25	0,46	0,00	0,00	0,63	0,02	0,06	0,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00W/m <sup>2</sup>														
WINDOW	Type of window	W09	W10	W11	W12	W1	W29	W30	W31	W32	W34	W36	W38	W39	W40	W5	W29	W30	W31	W32	W34	W3	W3	W3	W4	W67	W68	W69	W70	W72	W74	W7	W7	W7	W10	W10	W110	W11	W113	W115	W11	W11	W11	W11								
		3	5,7	7,7	0,1	8	0,8	0,4	0,4	0,30	0,10	0,21	0,04	0,04	0,04	0,02	0,03	0,09	0,05	0,05	0,34	0,11	0,24	5	5	3	0,09	0,05	0,05	0,34	0,11	0,24	5	5	3	0,09	0,05	0,05	0,34	0,10	0,24	0,05	0,05	0,03	0,45							
	U <sub>i</sub> (U-value of window)	= 5,70	5,70	5,70	5,70	0	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70	5,70					
	A <sub>r</sub> (Window area)	= 8,88	8,88	8,04	9,21	1	8,30	4,30	4,30	29,47	9,96	20,75	4,30	4,30	2,20	7	8,30	4,30	4,30	29,47	9,96	5	0	0	0	8,30	4,30	4,30	29,47	9,96	20,75	0	0	0	8,30	4,30	4,30	29,47	9,96	20,75	4,30	4,30	2,20	2,20	2,20	2,20	2,20	2,20	2,20	2,20		
	A <sub>w</sub> /ΣA <sub>r</sub>	= 0,21	0,21	0,19	0,22	8	0,08	0,04	0,04	0,30	0,10	0,21	0,04	0,04	0,04	0,02	0,03	0,09	0,05	0,05	0,34	0,11	0,24	5	5	3	0,09	0,05	0,05	0,34	0,11	0,24	5	5	3	0,09	0,05	0,05	0,34	0,10	0,24	0,05	0,05	0,03	0,45							
	WWR	= 0,48				0,44																																														
	ΔT	= 5				5																																														
	OTTV conduction	= 2,85	2,85	2,58	2,96	7	1,04	0,54	0,54	3,70	1,25	2,60	0,54	0,54	0,28	0,31	1,23	0,63	0,63	4,35	1,47	3,06	3	3	2	1,21	0,63	0,63	4,31	1,46	3,03	3	3	0	1,21	0,63	0,63	4,31	1,31	3,03	0,63	0,63	0,32	0,32	0,32	0,32	0,32	0,32	0,32			
	SC <sub>g</sub> (SC glass)	= 0,58	0,58	0,58	0,58	8	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58	0,58			
	SC <sub>sh</sub> (Sc shading device)	= 0,49	0,44	0,51	0,44	3	0,50	0,53	0,52	0,56	0,75	0,56	0,52	0,55	0,53	0,81	0,50	0,53	0,52	0,56	0,75	0,56	2	5	3	0,50	0,84	0,84	0,61	0,84	0,62	0,7	7	3	0,48	0,80	0,80	0,57	0,77	0,60	0,72	0,73	0,69	0,69	0,69	0,69	0,69	0,69	0,69			
	SC	= 0,28	0,26	0,30	0,26	5	0,29	0,31	0,30	0,32	0,43	0,32	0,30	0,32	0,31	0,47	0,29	0,31	0,30	0,32	0,43	0,32	0	2	1	0,29	0,49	0,49	0,36	0,49	0,36	0,3	3	1	0,28	0,46	0,46	0,33	0,45	0,35	0,42	0,42	0,40	0,40	0,40	0,40	0,40	0,40				
	SF	= 112				112																																														
	OTTV radiation	= 3,18	2,86	3,00	2,96	2	1,18	0,65	0,64	4,72	2,13	3,30	0,64	0,68	0,34	0,00	1,39	0,76	0,75	5,55	2,51	3,88	6	0	0	1,38	1,20	1,20	6,01	2,79	4,27	1	1	9	1,34	1,15	1,15	5,57	2,31	4,17	1,04	1,05	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51		
	OTTV Window	= 6,03	5,70	5,58	5,92	9	2,22	1,19	1,18	8,41	3,38	5,90	1,18	1,22	0,61	0,31	2,62	1,40	1,38	9,90	3,98	6,95	9	4	2	2,60	1,83	1,83	10,32	4,25	7,31	4	1	9	2,55	1,77	1,77	9,88	3,61	7,20	1,67	1,67	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83		
	Envelope square (A)	= 88,83				227,2											193,0																																			
	Total of envelope square	= 0				0											0																																			
	OTTV typical	= 32,04				27,9				30,5				31,8				32,0																																		
	OTTV façade (partial)	= 30,62																																																		



Appendix 5

Table 6. Excel program calculations for each building component.

Column 60 cm + Granite		
1#	Material	Granite
	Surface properties	Smooth
	Color	Red
	Absorption	0,84
	Thickness	20 mm
	Thermal conductivity	3,49 W/mK
	Density	2880 Kg/m <sup>3</sup>
2#	Material	Plaster
	Thickness	25 mm
	Thermal conductivity	0,82 W/mK
	Density	1680 Kg/m <sup>3</sup>
3#	Material	Concrete
	Thickness	550 mm
	Thermal conductivity	1,046 W/mK
	Density	2300 Kg/m <sup>3</sup>
4#	Material	Plaster
	Thickness	25 mm
	Thermal conductivity	0,82 W/mK
	Density	1680 Kg/m <sup>3</sup>
	<b>Weight / Area</b>	<b>1407 Kg/m<sup>2</sup></b>

Beam 20 cm		
1#	Material	Plaster
	Surface properties	normal
	Color	Cream
	Absorption	0,4
	Thickness	25 mm
	Thermal conductivity	0,82 W/mK
	Density	1680 Kg/m <sup>3</sup>
2#	Material	Concrete
	Thickness	150 mm
	Thermal conductivity	1,046 W/mK
	Density	2300 Kg/m <sup>3</sup>
3#	Material	Plaster
	Thickness	25 mm
	Thermal conductivity	0,82 W/mK
	Density	1680 Kg/m <sup>3</sup>
	<b>Weight / Area</b>	<b>429 Kg/m<sup>2</sup></b>

Aluminum CP 3		
1#	Material	ACP
	Surface properties	Metalic
	Color	Light grey
	Absorption	0,4
	Thickness	5 mm
	Thermal conductivity	0,33 W/mK
	Density	1900 Kg/m <sup>3</sup>
2#	Material	Air gap
	Thickness	550 mm
	Thermal conductivity	0,216 W/mK
	Density	Kg/m <sup>2</sup> Kg/m <sup>3</sup>
3#	Material	Concrete
	Thickness	550 mm
	Thermal conductivity	1,046 W/mK
	Density	2300 Kg/m <sup>3</sup>
4#	Material	Plaster
	Thickness	25 mm
	Thermal conductivity	0,82 W/mK
	Density	1680 Kg/m <sup>3</sup>
	<b>Weight / Area</b>	<b>1317 Kg/m<sup>2</sup></b>

Curtain Wall 1		
1#	Material	Panasap green
	Surface properties	Smooth
	Color	Light green
	Absorption	0,26
	Thickness	8 mm
	Thermal conductivity	1 W/mK
	Density	2300 Kg/m <sup>3</sup>
2#	Material	Air gap
	Thickness	150 mm
	Thermal conductivity	0,216 W/mK
	Density	1,3 Kg/m <sup>3</sup>
3#	Material	Concrete
	Thickness	150 mm
	Thermal conductivity	1,046 W/mK
	Density	2300 Kg/m <sup>3</sup>
4#	Material	Plaster
	Thickness	25 mm
	Thermal conductivity	0,82 W/mK
	Density	1680 Kg/m <sup>3</sup>
	<b>Weight / Area</b>	<b>406 Kg/m<sup>2</sup></b>

Table 7. U-value calculations with Excel format.

U-VALUE	Brick + Granite Wall 1	
	Outermost surface properties	Smooth
External surface	Resistance	0,065 m <sup>2</sup> K/W
Granite	Width	20 mm
	Thermal conductivity	3,49 W/mK
	Resistance layer 1	0,006 m <sup>2</sup> K/W
Plaster	Width	25 mm
	Thermal conductivity	0,82 W/mK
	Resistance layer 2	0,03 m <sup>2</sup> K/W
bata	Width	550 mm
	Thermal conductivity	1,297 W/mK
	Resistance layer 3	0,424 m <sup>2</sup> K/W
Plaster	Width	25 mm
	Thermal conductivity	0,82 W/mK
	Resistance layer 4	0,03 m <sup>2</sup> K/W
Internal surface	Resistance	0,12 m <sup>2</sup> K/W

U-value **1,48** W/m<sup>2</sup>K

U-VALUE	Beam 20 cm	
	Outermost surface properties	Normal
External surface	Resistance	0,05 m <sup>2</sup> K/W
Plaster	Width	25 mm
	Thermal conductivity	0,82 W/mK
	Resistance layer 1	0,031 m <sup>2</sup> K/W
Concrete	Width	150 mm
	Thermal conductivity	1,046 W/mK
	Resistance layer 2	0,143 m <sup>2</sup> K/W
Plaster	Width	25 mm
	Thermal conductivity	0,82 W/mK
	Resistance layer 3	0,03 m <sup>2</sup> K/W
0	Width	0 mm
	Thermal conductivity	0 W/mK
	Resistance layer 4	0 m <sup>2</sup> K/W
Internal surface	resistance	0,12 m <sup>2</sup> K/W

U-value **2,67** W/m<sup>2</sup>K

U-VALUE	Aluminium CP 3	
	Outermost surface properties	Metalic
External surface	Resistance	0,078 m <sup>2</sup> K/W
ACP	Width	5 mm
	Thermal conductivity	0,33 W/mK
	Resistance layer 1	0,015 m <sup>2</sup> K/W
Air gap	Width	550 mm
	Thermal conductivity	0,216 W/mK
	Resistance layer 2	2,546 m <sup>2</sup> K/W
Concrete	Width	550 mm
	Thermal conductivity	1,046 W/mK
	Resistance layer 3	0,526 m <sup>2</sup> K/W
Plaster	Width	20 mm
	Thermal conductivity	0,82 W/mK
	Resistance layer 4	0,024 m <sup>2</sup> K/W
Internal surface	Resistance	0,12 m <sup>2</sup> K/W

U-value **0,3** W/m<sup>2</sup>K

U-VALUE	Curtain Wall 1	
	Outermost surface properties	Smooth
External surface	Resistance	0,065 m <sup>2</sup> K/W
Panasap green	Width	8 mm
	Thermal conductivity	1 W/mK
	Resistance layer 1	0,008 m <sup>2</sup> K/W
Air gap	Width	150 mm
	Thermal conductivity	0,216 W/mK
	Resistance layer 2	0,694 m <sup>2</sup> K/W
Concrete	Width	150 mm
	Thermal conductivity	1,046 W/mK
	Resistance layer 3	0,143 m <sup>2</sup> K/W
Plaster	Width	25 mm
	Thermal conductivity	0,82 W/mK
	Resistance layer 4	0,03 m <sup>2</sup> K/W
Internal surface	Resistance	0,12 m <sup>2</sup> K/W

U-value **0,94** W/m<sup>2</sup>K