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Effect of Balcony's Design Parameters on Energy Performance of Residential Buildings

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***Abstract*- Residential buildings have a critical role in energy consumption, contributing to produce greenhouse gases and creating urban heat island. For this reason, optimizing the building energy usage is avital issue. Balconies can be considered one of the building façade elements that have considerable thermal performance. The main aim of the paper is to assess the contribution of various balcony design parameters on indoor thermal performance and energy consumption of residential buildings.**

A simulation study was conducted for a residential villa located in hot climate country, Cairo Egypt. Different design parameters were investigated and 6 case studies were compared in order to study the effect of each one on building's thermal performance. Results show that southwest oriented balcony with wall insulation material and using double clear glazing for window are the most effective parameters on cooling loads of the studied bedroom space in residential villa located in hot climate of Cairo, therefore affecting building energy consumption.

Finally, the research highlights the effect of various balcony design parameters on building thermal performance in order to reduce energy consumption in residential buildings.

***Keywords*- Energy Performance, Balconies, Residential Buildings, Thermal Comfort.**

I. INTRODUCTION

Globally, there is an increasing demand for more energy efficient buildings, where buildings contribute for 30% of the global greenhouse gas emissions, 40% of all energy consumed and 31% of all generated waste [1,2]. Moreover, buildings contribute with a 6.5% of the world economy [3,4]. In the last decade, environmental and economic impacts have been taken into consideration in order to enhance the buildings sustainability [5].

The building envelope including energy efficient glazing facades, cladding materials and thermal insulation materials which are the most important contributors to obtain a large saving in the energy demand and thus enhance building's energy performance. [6]. It is constructed to protect the building from environmental conditions by acting a thermal barrier while providing thermal comfort to inhabitants. Residential and commercial buildings account for about 30% of energy consumption in most of the developed countries. Therefore, building envelope design affects energy consumption [6].

Accordingly, balcony plays a major role in residential buildings where it acts as a bridges between the internal and external environment. Thus, it is act as a "buffer space" between inside and outside of the building where it can enhance indoor environment and thermal comfort [7]. Moreover, researches show how balcony design can play a critical role in increasing residents' satisfaction [8,9]. Therefore, residential balcony design can be considered as an essential part in the process of sustainability development and energy efficiency.

II. BALCONIES BACKGROUND

In many traditions, the balcony is considered one of the main architectural elements in residential building [10]. According to the architectural trends and building techniques development, the balconies shape, structure, and materials have been altered. Within 1970s and 1980s, a huge scale of cast iron balconies was developed. Then, by the twentieth century reinforced concrete balcony slabs started to be used. [11]. Nowadays, there are three main types of balcony spaces: The first type is the Open balcony, where shading systems such as blinds, curtains or even vegetation are being part of this type. The second one is the Glazed balcony, where a border such as glass is being used between inside and outside. As for the third one, it is the Eliminated balcony, where a balcony is connected to the interior of the building.

Building envelope development depends on the development of light weight ventilated façade typology that surrounds the building. Since balconies are projected out of the facades, then previous continuity skin is in convenient with balconies. So, most recent buildings' facades are light-flat surfaces. However, balconies design cannot be ignored as it plays an important role in achieving more sustainable architecture within next years. Therefore, combining technological advances with its incorporation in facades have to be taken into consideration. Balcony development help in introducing new unresolved demands and requirements [10].

III. ENVIRONMENTAL FUNCTIONS OF BALCONIES

Balconies have two main roles in residential building design process. One of the main functions is creating an important interior space for various activities which is important for the occupants. So balcony space design requires specific criteria in order to enhance the connection between indoor and outdoor environment. However, designers usually use balcony to give external form of residential building, which may lead to ignoring other functional roles within residential buildings. [12].

The balcony is considered one of the considerable elements

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that form buildings' facades. Aside from connecting internal and external environments, balconies have a valuable role in buildings [12]. Achieving thermal comfort is considered one of these roles. It was found that if balconies parameters were designed according to specific standards, thermal comfort can be achieved. Therefore, reducing cooling and heating loads and thus energy consumption by minimizing demand of HVAC. [13]. So, designing elements of a balcony, such as the balcony dimension, glazing properties, window-to-wall ratio, affects the solar radiation entering the building and gives a significant impact on the cooling loads [13].

IV. IMPACT OF BALCONY DESIGN PARAMETERS ON BUILDINGS' THERMAL PERFORMANCE

There are various researches that work about buildings thermal performance which are installed with balcony. Hilliaho et al. [14] studied the effect of different types of glazed balconies on buildings'' energy consumption in in Finland's northern climatic conditions. By using IDA-ICE software, they analyze different factors that affect energy performance, these factors are: combining building's space ventilation system, heat loss between indoors and outdoors and from building to the glazed system, also the air tightness of balcony and its surface absorption coefficient. On the other hand, Hilliaho et al. [15] monitor the temperatures on 22 balconies ,17 are glazed and adjacent in order to adjust the different factors affecting balcony's ability to keep warm. Results show that unglazed balconies have higher temperature than outside air temperature by 2.0 ◦C while glazed ones have an average of 5.0 ◦C higher than the outside air temperature.

V. METHODS

A simulation analysis of balcony design parameters through the building façade will be presented using design builder software to run the required thermal simulations, and quantifies the energy impact of this, and thus propose strategies in order to enhance building energy performance. The various parameters discussed in literature review are applied to the case study building, comparisons between these parameters were conducted to evaluate the effect of balcony design on cooling loads of buildings.
A residential villa was modelled in the Design-Builder simulation program, which uses its climate data from the Energy plus Weather Database, the simulation conducted on bedroom room had an extended balcony with the room's total length with a sliding window. The room was simulated in Cairo city, Egypt, for period between April and September. The weather of Cairo is generally warm or hot in summer with an average temperature reaching (35 °C).

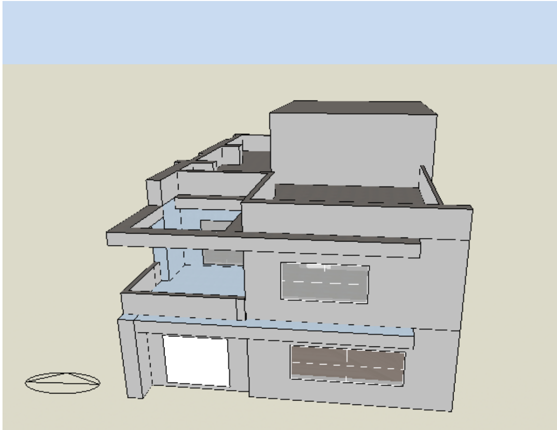

Figure 1. Simulated Model of Residential Villa

Balcony design parameters under investigation:

- Balcony orientation
- Glazing type (single or double)
- Wall thermal insulation
- Balcony slab material

The following cases represent the different proposed case studies of the building:

Case 1-A (base model): Opened balcony with concrete slab, single clear glazed window with no thermal break aluminum frame and no wall insulation, with northeast orientation.
Case 2: Opened balcony with concrete slab, double clear glazed window with thermal break aluminum frame and no wall insulation.
Case 3: Opened balcony with concrete slab, double clear glazed window with thermal break aluminum frame and foam polystyrene wall insulation.
Case 4: Opened balcony with Aerated concrete slab, double clear glazed window with thermal break aluminum frame and foam polystyrene wall insulation
Case 5: Opened balcony with cast foamed concrete slab, double clear glazed window with thermal break aluminum frame and foam polystyrene wall insulation

VI. RESULTS

In Cairo City, it is suggested to give a priority to the indoor energy saving and thermal comfort. This is due to thermal location characteristics and climatic conditions. Balcony orientations in the base model is simulated in two main directions: northeast and southwest. According to the figures 2&3, the lowest cooling loads with 27166 kwh is for the southwest oriented balcony and this orientation is selected for next simulation case studies. Results of the case study (1-B) have shown that September has highest outside dry bulb temperature and relative humidity compared to July and August with no significance difference in radiant and operative temperature (Figure4).

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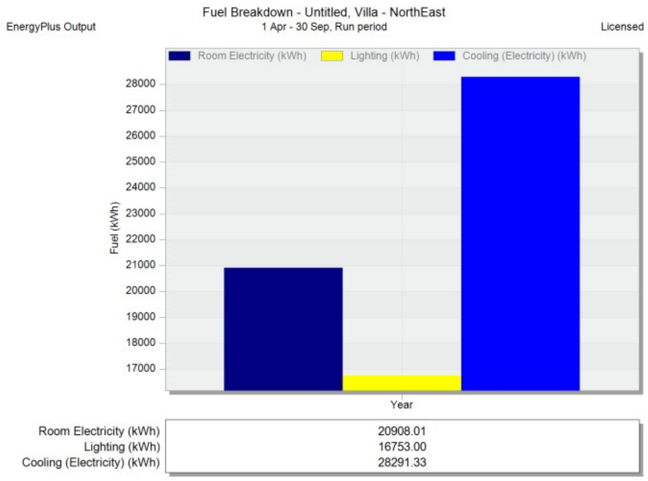


Figure 2. Simulated Model of Residential Villa (Case study 1-A)

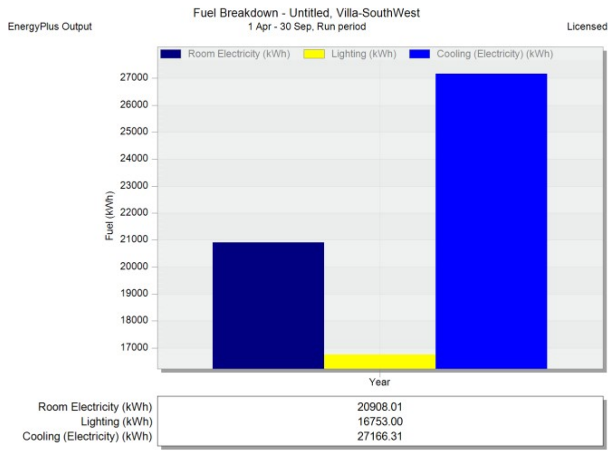


Figure 3. Simulated Model of Residential Villa (Case study 1-B)

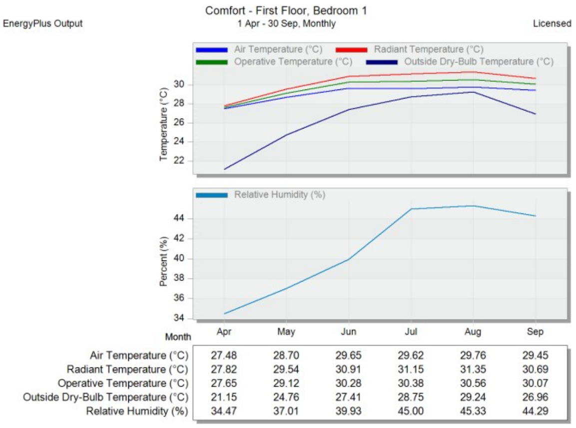


Figure 4. Comfort graphs for Bedroom space in Simulated Residential Villa Case Study (1-B)

Moreover, zone sensible cooling achieved (-452.14 kwh) in August which is more by an approximately (8%) compared to July and by an approximately (25%) compared to September months where cooling loads were (-438.01 kwh) and (-361.73 kwh) respectively (Figure5).

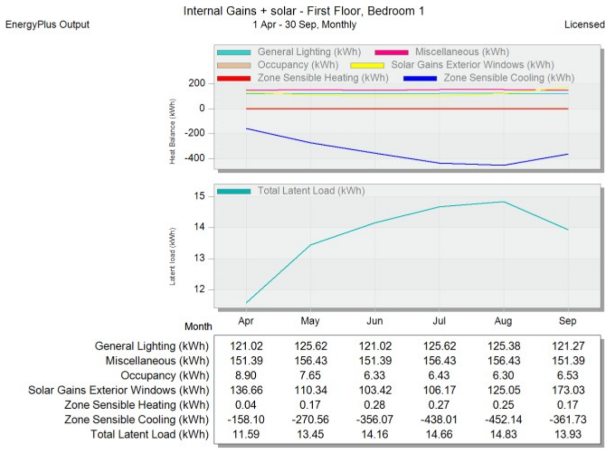
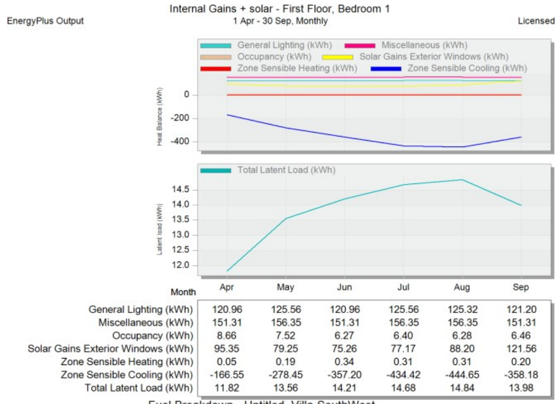


Figure 5. Internal Gains and solar graphs for Bedroom space in Simulated Residential Villa Case Study (1-B)



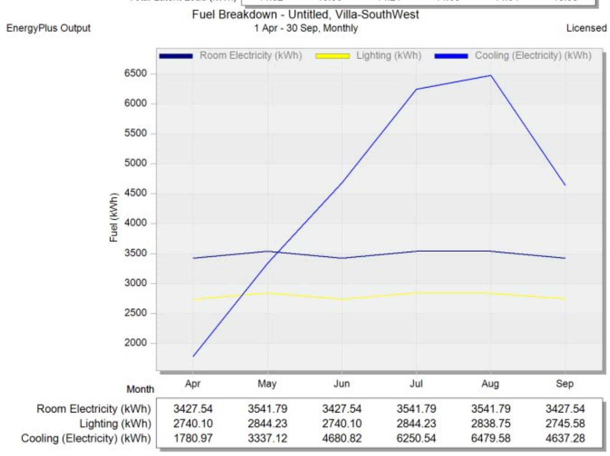


Figure 6. Fuel Breakdown for Simulated Residential Villa Case Study (1-B)

Figure (6) shows that the August has highest cooling loads with an amount of (6479.58 kwh) which are increased by almost 40 % compared to September with an amount of (4637.28 kwh) and are increased by almost 5 % compared to July an amount of (6250.54 kwh).

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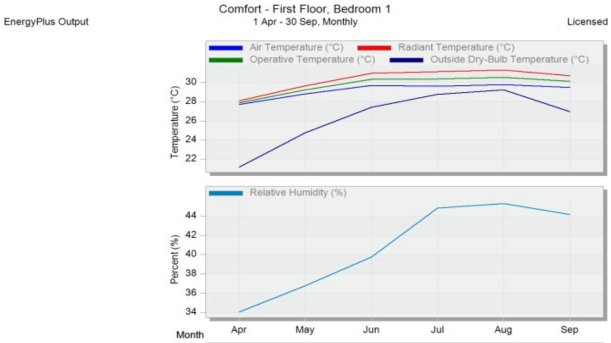
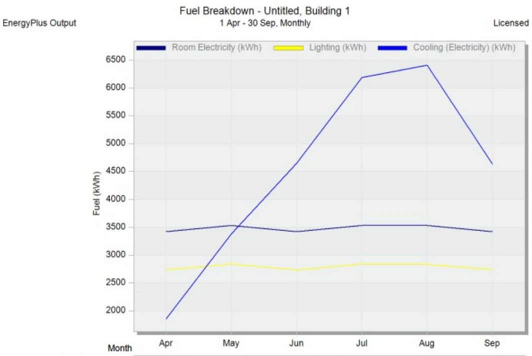


Month	Apr	May	Jun	Jul	Aug	Sep
Air Temperature (°C)	27.69	28.79	29.69	29.63	29.78	29.50
Radiant Temperature (°C)	28.07	29.67	30.95	31.14	31.32	30.71
Operative Temperature (°C)	27.88	29.23	30.32	30.39	30.55	30.10
Outside Dry-Bulb Temperature (°C)	21.15	24.76	27.41	28.75	29.24	26.96
Relative Humidity (%)	34.05	36.79	39.75	44.85	45.31	44.16

Figure 7. Comfort graphs for Bedroom space in Simulated Residential Villa Case Study (2)

According to (Figures 7&8), it can be recognized that there is no significance difference in comfort results of Case study (2) compared to base model, however there is an obvious decrease in solar gain exterior windows by approximately (27 %), this is due to the usage of double glass low-e window. However, cooling loads have decreased by only (2 %) compared to base model (Figure 9). This is may be due to effect of other balcony parameters so, it is important to take into considerations other parameters along with window glazing type in order to decrease cooling loads significantly.

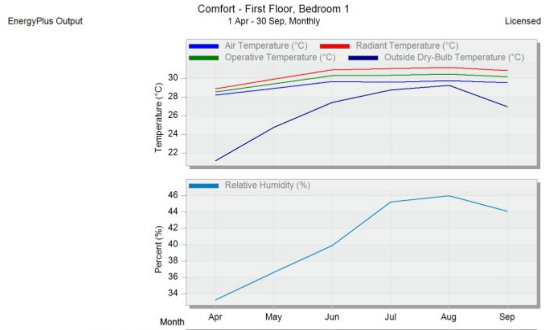
Figure 8. Internal Gains and solar graphs for Bedroom space in Simulated Residential Villa Case Study (2)



Month	Apr	May	Jun	Jul	Aug	Sep
Room Electricity (kWh)	3421.54	3535.59	3421.54	3535.59	3535.59	3421.54
Lighting (kWh)	2735.31	2839.25	2735.31	2839.25	2833.78	2740.78
Cooling (Electricity) (kWh)	1857.02	3382.04	4651.48	6187.51	6407.91	4636.32

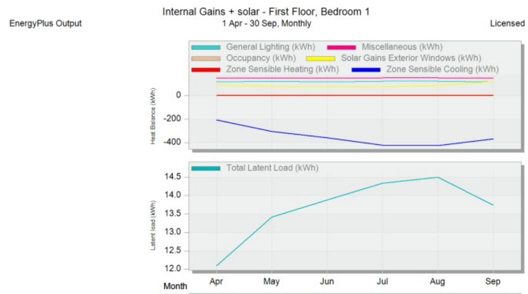
Figure 9. Fuel Breakdown for Simulated Residential Villa Case Study (2)

Results for the case study (3) have shown that by increasing thermal conductivity wall material by adding polystyrene foam insulation layer the cooling loads have decreased by (8%) compared to base model, however there is no significance difference in outside dry bulb temperature and relative humidity, but the solar gains exterior windows have decreased by almost (6%) due to usage of clear double glazed window (Figures 10,11&12).



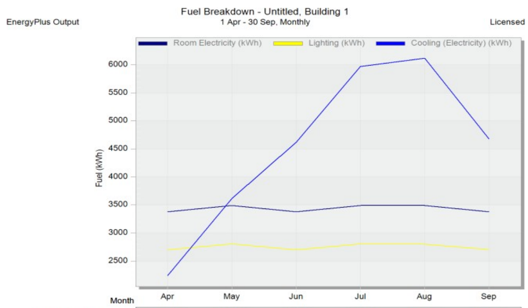
Month	Apr	May	Jun	Jul	Aug	Sep
Air Temperature (°C)	28.18	28.89	29.65	29.59	29.74	29.52
Radiant Temperature (°C)	28.88	29.92	30.92	31.03	31.17	30.81
Operative Temperature (°C)	28.53	29.40	30.28	30.31	30.45	30.16
Outside Dry-Bulb Temperature (°C)	21.15	24.76	27.41	28.75	29.24	26.96
Relative Humidity (%)	33.23	36.60	39.91	45.26	46.02	44.10

Figure 10. Comfort graphs for Bedroom space in Simulated Residential Villa Case Study (3)



Month	Apr	May	Jun	Jul	Aug	Sep
General Lighting (kWh)	118.70	123.21	118.70	123.21	122.97	118.94
Miscellaneous (kWh)	148.48	153.43	148.48	153.43	153.43	148.48
Occupancy (kWh)	8.00	7.27	6.21	6.35	6.22	6.32
Solar Gains Exterior Windows (kWh)	95.35	79.25	75.26	77.17	88.20	121.56
Zone Sensible Heating (kWh)	0.05	0.19	0.34	0.31	0.35	0.21
Zone Sensible Cooling (kWh)	-206.69	-302.22	-356.16	-421.34	-425.26	-368.40
Total Latent Load (kWh)	12.10	13.42	13.89	14.34	14.50	13.74

Figure 11. Internal Gains and solar graphs for Bedroom space in Simulated Residential Villa Case Study (3)



Month	Apr	May	Jun	Jul	Aug	Sep
Room Electricity (kWh)	3379.58	3492.23	3379.58	3492.23	3492.23	3379.58
Lighting (kWh)	2701.76	2804.43	2701.76	2804.43	2799.02	2707.16
Cooling (Electricity) (kWh)	2240.36	3616.91	4616.01	5971.97	6116.28	4679.28

Figure 12. Fuel Breakdown for Simulated Residential Villa Case Study (3)

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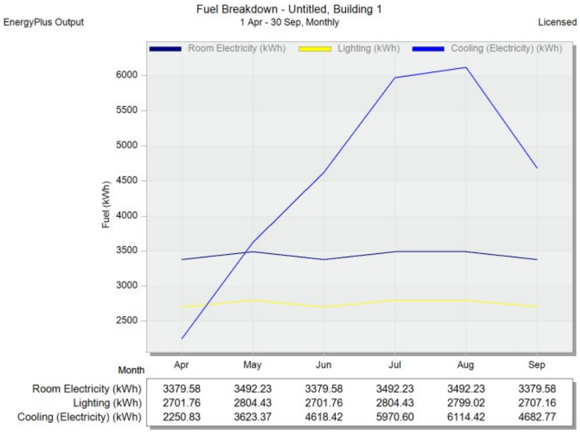

Figure15. Fuel Breakdown for Bedroom space in Simulated Residential Villa Case Study (5)

The results show that the role of using aerated concrete in case study (4) is not effective as one would consider, although it is known for its heat preservation, heat insulation and sound absorption properties, there is no significance effect on cooling loads. Referring to (Figures 13,14& 15), cast foamed concrete used in case study (5) with lower thermal conductivity, like the aerated concrete ones, decrease the cooling loads, but can hardly be considered as effective as expected. According to the study, balcony design parameters can contribute in decreasing heat flows through the building.

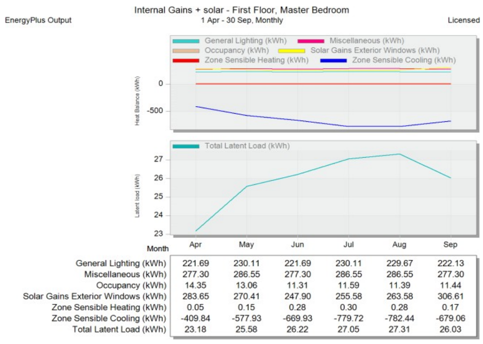

Figure 13. Comfort graphs for Bedroom space in Simulated Residential Villa Case Study (5)

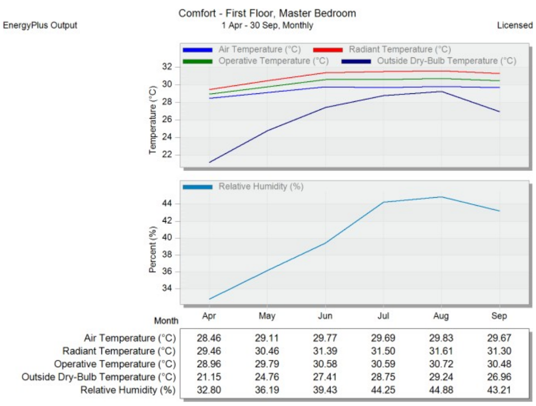

Figure14. Internal Gains for Bedroom space in Simulated Residential Villa Case Study (5)

According to the findings of this study:

- Balcony Orientation is one of the effective parameters on energy consumption where southwest has better thermal performance than northeast one with (4%) decrease in annual cooling loads.
- Wall thermal insulation material can significantly affect heat flows and thus cooling loads.
- Double clear glazing windows present better behavior than single ones

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TABLE 1: EFFECT OF DIFFERENT PARAMETERES ON SOLAR GAINS AND COOLING LOADS WITHINSIMULATED RESIDENTAIL VILLA (FROM APRIL TO SEPTEMBER)

Case Studies	Parameters			Simulation Data		
	External Windows	External Walls	Balcony Slab	Solar Gains (KWh)	Zone Sensible Cooling (KWh)	Cooling (Electricity) (KWh)
Base Model (1-B)	Single Clear Glass with no thermal break aluminum frame	Without insulation	Concrete	173.03	-452.14	6479.58
Case 2	Double clear Glass (6mm/13mm) with thermal break aluminum frame	Without insulation	Concrete	121.56	-444.65	6187.51
Case 3	Double clear Glass (6mm/13mm) with thermal break aluminum frame	Without insulation	Concrete	121.56	-425.26	6116.28
Case 4	Double clear Glass (6mm/13mm) with thermal break aluminum frame	With insulation	Aerated Concrete	121.56	-425.22	6115.61
Case 5	Double clear Glass (6mm/13mm) with thermal break aluminum frame	With insulation	Cast Foamed Concrete	121.56	-425.22	6114.42

The material of the balcony is also a parameter that should be taken into consideration with other requirements, but can hardly be considered as an effective measure to the heat flows within building.

It was noticed from table 1 that cooling loads has been decreased in case of using double clear glass with wall insulation by 7% which is more effectively than in case of using double clear glass without wall insulation where cooling loads has been decreased by 5%. This is due to the higher thermal resistance of polystyrene insulation since heat flow through them are reduced compared to the uninsulated one. Moreover, by increasing both thermal conductivity of the wall material by using polystyrene foam insulation and using aerated concrete (which known for its thermal and acoustical insulation properties), and double glass window, cooling loads in case (5) decreased by almost 8% than base model cooling loads (Table 1).

VII. Conclusions

The paper highlights the importance of reducing or cooling loads and heat flow resulting from balcony in order to reduce energy consumption in buildings. According to the study, balcony design parameters can contribute to a relatively large portion of heat flows through the building.

In this paper, various parameters related to the balconies in several simulations were examined and their impacts on energy consumption were analyzed (Table 1). With the obtained analysis from the simulations in, it was found out that for southwest oriented balcony with double clear glazing and wall thermal insulation had the best performance with up to 27% decrease in annual energy consumption. It can be concluded that balcony material had a small impact on annual energy consumption.

Future research on effect of other balcony design parameters, like geometry, shape of the balcony and whether it is closed or opened balcony seems to be an interesting research challenge in order to decrease cooling loads.

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REFERENCES

[1] Sbci, U. "Buildings and climate change: summary for decision-makers," United Nations Environmental Programme - Sustainable Buildings and Climate Initiative: Paris, France, pp. 1-62, 2009. https://wedocs.unep.org/20.500.11822/32152

[2] Moussa, R.R., and Elsawaf, L.A., "Using Anaerobic Digesters as a Sustainable Approach in Creating Sustainable Cities in Egypt, " Environment and Ecology Research, vol. 10, no. 2, pp. 314-323, 2022. DOI: 10.13189/eer.2022.100222

[3] C. Rhodes, "Construction industry: statistics and policy," House of Commons Library, no. 01432, pp. 3-7, 2019. https://commonslibrary.parliament.uk/research-briefings/sn01432/

[4] Moussa, R.R., Ismaeel, W.S.E., Solban, M.M., "Energy generation in public buildings using piezoelectric flooring tiles; case study of a metro station, " Sustainable city and society, vol. 77, 2022. DOI:10.1016/j.scs.2021.103555

[5] S. B. Sadineni, T. M. France, and R. F. Boehm, "Economic feasibility of energy efficiency measures in residential buildings," Renewable Energy, vol. 36, no. 11, pp. 2925-2931, 2011. DOI: 10.1016/j.renene.2011.04.006

[6] Smusz R., Korzeniowski M, "Experimental investigation of thermal bridges in building at real conditions," E3S Web of Conferences 70,03013, 2018. DOI: 10.1051/e3sconf/20187003013

[7] Ribeiro, C., Ramos, N. M. M., and Flores-Colen, I. A review of balcony impacts on the indoor environmental quality of dwellings.

[8] Sustain. Switz. 12, 2020, 6453.doi:10.3390/su12166453

[9] Wing Chau, K., Kei Wong, S., and Yim Yiu, C. The value of the provision of a balcony in apartments in Hong Kong. Prop. Manag. 22, 2004, 250–264. doi:10.1108/ 02637470410545020

[10] Kennedy, R., Buys, L., and Miller, E. Residents' experiences of privacy and comfort in multi-storey apartment dwellings in subtropical Brisbane. Sustain. Switz.7, 2015, 7741–7761. doi:10.3390/su7067741

[11] L. Sierra, J.L. Zamora, Balconies. Analysis of constructive technology current state and foresight of new industrial development structures and architecture: concepts,2013, Appl.Challenges 636–643.

[12] J. Slusarek, A. Szymanowska-Gwizdz, P. Krause. Damage to historical balconies in view of building, Phys. IOP Conf. Ser.: Mater. Sci. Eng. Pap, 2019.

[13] A. Shamseldin, Adaptation opportunities for balconies to achieve continuity of their environmental functions, Alexandria Engineering Journal,Volume 67, 2023, PP. 287-299, ISSN

[14] 1110-0168,

[15] E. Mirabi, N. Nasrollahi. Providing optimal balcony typology with energy management approach in residential buildings, case study: Tehran, In.t J. Eng. Tech. Res. 9, 2019,18–22.

[16] Hilliaho K,Makitalo E, Lahdensivu J.Energy saving potential of glazed space: Senstivity analysis. Energy Build 2015, PP.99:87-97.

[17] Hilliaho K, K¨oli¨o A, Pakkala T, Lahdensivu J, Vinha J. Effects of added glazing on Balcony indoor temperatures: Field measurements. Energy Build, 2015, PP.128: 458–72

