AMERICAN UNIVERSITY OF BEIRUT

PARAMETRIC ANALYSIS ON COOLING SET POINT TEMPERATURE IN RESIDENTIAL APARTMENTS IN BEIRUT CITY

by
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Above ground, I am indebted to my family, Mom and Dad, who have been supporting me throughout my life, and pushing me towards my dreams. Without them, none of this would have been possible. I would never be able to thank them enough, and they will always be my role models. I am who I am now because of them. I extend my appreciation to my close friends who have been there for me throughout this journey.

Finally, this research paper is dedicated to my Guardian Angel, my Father in heaven, and to his beautiful soul.

ABSTRACT
OF THE THESIS OF

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Title: Parametric Analysis on Cooling Set Point Temperature in Residential Apartments in Beirut City

This study examines the potential impact of different configurations of building envelope material including external walls and windows on the final cooling energy consumption in a typical residential apartment in Beirut city that uses conventional DX split units in living room and bedroom zones using HAP software. MED-ENEC study is used to benchmark the Business as Usual (BAU) construction scenario of a case study apartment simulated in HAP that uses single walls and single glazing for windows. After the HAP (BAU) model is validated with MED-ENEC at 78 kWh/m^2.year, five different scenarios that include different envelope configurations are simulated to assess possible energy savings, cost savings from EDL and generator subscription, in addition to CO2 emissions reduction.

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CHAPTER I

INTRODUCTION

Energy consumption in residential buildings has been contributing to a large percentage of the global energy consumption, and thus pushed researchers around the world to study energy conservation in the residential sector further (An, Yan, & Hong, 2018). Occupants nowadays spend up to 90% of their time in buildings. Moreover, 60% of the total energy produced in the world is consumed in residential buildings. Hence, huge efforts are needed to reduce residential energy consumption (Itani, Ghali, & Ghaddar, 2015). Recently, the social economic growing standards increased rapidly the total global energy consumption especially the noticeable development in the cooling sector (Gaglia, et al., 2018). It was reported that the total cooling energy consumption in residential and commercial buildings in the world increased from 30% in 2010 to 43% in 2016 (Guo, Yang, Li, Zhang, & Long, 2019). This is due to the fact that the primary energy demand in residential buildings is controlled via the electricity demand for mainly cooling, heating, ventilation and air conditioning (HVAC) (Albayyaa, Dharmappa, & Saha., 2018). Since the building sector has a substantial contribution to peak demand of the continuously increasing usage of HVAC systems, countries who face deficiency in electricity supply and daily power shortages, like Lebanon, adoption of energy efficiency measures in construction material becomes more like a necessity than a choice (Annan, Ghaddar, & Ghali, 2016).

A. Study Objective and Significance

Building envelope material and configuration play a relevant role affecting the cooling energy consumption in residential apartments in Beirut city and should be designed carefully in order to attain both energy and cost savings in addition to reduction in CO2 emissions.

- The primary objective is to illustrate potential energy savings due to the optimization of the building envelope materials used in external walls and windows in residential apartments in Beirut city.
- To present accompanied potential cost savings on EDL and diesel generator subscription bills in addition to reducing CO2 emissions.

B. Thesis Outline

The research starts with a general introduction about the energy consumption in residential buildings followed by literature review in chapter two about energy consumption in Lebanon and the usage of AC split units in most of the residential apartments where business as usual construction is adopted, including single walls and single glazed windows. Chapter three explains the research methodology adopted. HAP software is used to process different simulations for different building envelope configurations in a case study apartment, and compares the output simulate cooling energy consumption with the reference scenario of business-as-usual construction.

Afterwards, chapter four demonstrates the results obtained from the simulation models and validate them with MED-ENEC study to benchmark the business-as-usual scenario. The simulated scenarios with optimized building materials and configurations illustrate the reduction in energy, cost and CO2 emissions.

Finally, chapter five concludes the study with recommendations on upgrading the business-as-usual construction in residential apartment in Beirut city to use extruded polystyrene insulation in double walls along with double glazing for windows.

CHAPTER II

LITERATURE REVIEW

Lebanon, as a developing country, has been facing a major problem in the accessibility to a continuous electricity supply over the past years (Bouri & El Assad, 2016). This is because Lebanon is fully dependent on the imported fossil fuels for power generation, and the power production is much lower than the market demand which in turn is in rapid increase (Sabsaby, 2016). However, the importance of having a reliable access supply lies in its role of improving the standards of living of occupants in a more advanced technological and economic society (Gurgul & Lach, 2011). Therefore, self-generation became the alternative solution in Lebanon to support EDL's failure in providing continuous supply. According to the World Bank report, self-generation reached 900 MW which is equivalent to 33%-38% of the total energy consumption in Lebanon (WorldBank, 2008). Diesel generators operators are selling electricity to citizens at a noticeably higher price than EDL's known tariffs, which in turn are highly subsidized; therefore, people end up paying two electricity bills with a huge difference between them (Hamdan, Ghajar, & Chedid, 2012). This gap difference leads to challenges in the occupants' energy consumption habits, which consequently affects the country's economic growth. Moreover, electricity blackout is a current problem in all the regions of Lebanon, and it could easily reach 14 hours per day (Bouri & El Assad, 2016). In central Beirut, which is the focus area in this paper, the majority of people living in Beirut use diesel generators to compensate for the daily cut off hours. Out of the respondents who use diesel generators surveyed by the

CEDRO program, around 10% own their private diesel generators and the remaining 90% have a subscription from either the municipality or the neighborhood generators (Harajli & Chalak, 2019). Being able to save energy and thus reduce personal consumption mainly in residential buildings is quite a must in order to reduce the monthly expensive energy bills.

Currently, the Lebanese energy consumption in buildings has increased remarkably due to the noticeable impact of urbanization, the need for upgrading the living standards and the consequences of climate change (Sabsaby, 2016). In fact, studies showed that Lebanon will achieve 250% energy consumption by 2030 compared to the consumption in 2010 (Jouni & Mourtada, 2011). This exponential growth in energy consumption is due to the inefficient performance of existing buildings especially in cooling systems, mainly small air-conditioning units, and thermal comfort preferences. In Lebanon, the residential sectors accounts for 47% of energy production (Tibi, N., & Ghali, 2012), therefore, any efforts put in achieving possible savings in this sector are essential and contribute heavily to the development of the national economy and the environment. It is then important to focus on energy consumption in existing residential buildings and understand the actual conditions contributing to the current high demand.

According to the Central Administration of Statistics (CAS), 72.6% of Lebanese citizens live in residential apartments in typical residential buildings and the minority do live in households such as dwellings, villas or detached houses (Yaacoub & Badre, 2012). In 2004, the World Bank classified Lebanon as an “upper middle income” country with a gross national income of 4040 USD/capita, and reported that 90% of the total population is urban population, which highlights the importance of conducting further studies in the energy consumption of the residential sector. The frequent electricity cut offs increase mostly in summer where peak demand is present (Houri & Ibrahim-Korfali, 2005).

Moreover, the Lebanese individual household energy consumption ranges between 0.45 and 2.2 MWh (Chaaban & Saifur-Rahman, 1998). Beirut, the capital of Lebanon, contains 50% of the urban population including suburbs. Although Beirut's area is only 0.2% of Lebanon's total area, it shares in consumption 12% of the total energy produced, and the majority of electricity consumption (Krayem, Al-Bitar, Faour, Ahmad, & Najem, 2019), with no surprise, lies in the building sector. Residents of Beirut suffer from 3 hours of electricity blackout daily. This indicates that "Beirut is an energy-starved city!" (Krayem, Al-Bitar, Faour, Ahmad, & Najem, 2019). Essentially, the demand estimates do not reflect the conquered amount of electricity because occupants tend to change their habits and eventually change their energy consumption and modify their preferences during electricity cut-off hours. Consequently, with all the housing problems accompanied with the rapid growth of urbanized population, achieving a thermally comfortable status in residential apartments is a critical parameter to be tackled (Omar & Sabsaby, 2015).

Thermal comfort in residential buildings is directly related to HVAC systems, which in turn account for 40% to 44% of the apartment's energy consumption (Annan, Ghaddar, & Ghali, 2016). In Lebanon, zone 1, the coastal zone, can have a maximum temperature of 24 °C – 32 °C and relative humidity range of 60% to 80% in summer (UNDP, 2005). As commonly known, most of the residential buildings rely on decentralized air-conditioning systems, thus there should be strict standards with temperature setting (Guo, Yang, Li, Zhang, & Long, 2019). Human's behavior has proved its critical impact on the energy use in the residential sector, especially in the operation of air conditioners (ACs). Recent studies showed that air conditioning usage in the summer season is not only dependent on the external weather conditions and the type of the system installed, but is heavily dependent on the envelope material including walls and windows. This boost in energy consumption of residential buildings is not restricted to Lebanon, on the contrary, it is a global trend that attracted researchers from all over the world to combine their efforts in trails to improve building envelope material and HVAC systems.

As mentioned earlier, ACs and electric heaters rank first in energy consumption among the different appliances that occupants use in households. In Beirut city, the cooling season is long while the heating season is much shorter. In addition, as per the survey done through the CEDRO program on energy efficient appliances, 68% of respondents own ACs (Harajli & Chalak, 2019). In the residential sector in Beirut, most people use conventional ACs split units for space cooling. As per a survey done in 2016; 83% of respondents use conventional ACs split units; 62% turn on the ACs system when using private power generation; 84% use valve control (remote control, ON-OFF, Fan Speed, cooling/heating) as the type of thermostat installed in their houses; 87% have only temperature setting features in their thermostat; 20% have humidity control features in their thermostat, and only 5% have home appliances integration control. Moreover, 41% of respondents are satisfied with their thermostat control, but 88% have no idea about the ACs energy consumption and are not aware of its features and the remaining 13% who claimed that they are aware of the ACs consumption gave no reasonable answers (Nicolas, Bitar, Skaf, Al-Moughrabi, & Matta). On the other hand, as per the National Energy Efficiency Action

Plan (2016-2020), NEEAP, the average number of ACs in the households in Lebanon is two. In the conducted study, 36% of the ACs is in the 9,000 BTU category and 98% of the surveyed ACs are split units (LCEC, 2016).

One of the most crucial factors affecting the cooling energy consumption in residential buildings include the thermal conduction gains through the envelope surfaces and glass and thermal radiation gains through glass windows and infiltration (Ghaddar & Bsat, 1998). The contractors going to adopt High Efficiency Non-Certified Buildings through implementing double walls and double-glazing are still few especially in high population urban areas like Beirut City. In fact, social status of citizens is a major factor behind the conventional construction in Beirut and thus a very important aspect in energy consumption. Once developers start adopting double walls with air space or insulation, double-glazing and other possible energy efficiency measures, we will be able to save a percentage of energy and thus this will be reflected on the cost paid by the occupants. The thermal standards for buildings launched in 2005 has set minimum requirements for building envelope measures in terms of their thermal performance in new residential buildings and shares compliance methods with those requirements. This is all to help enhance the overall consumption of buildings. (Schimschar & Assad, 2013)

Beirut, the capital of Lebanon, occupies an area of 20 square kilometers and extends to a 94 km coast on the Mediterranean Sea. Beirut consists of twelve neighborhoods divided into sixty sectors with around 500,000 inhabitants only in the limits of Beirut municipality. The climate of Beirut is by default Mediterranean with hot mild summers which increases energy consumption during the season due to the use of air-conditioning.

This warm season ranges between June 15 and October 12 and attains an average daily temperature above 28 °C. Moreover, August 9 is considered to be the hottest day of the year with a highest average temperature of 31 °C and lowest average temperature of 25 °C (CES-MED, 2010).

Due to urbanization, Beirut became overcrowded with 53.8% of the total Lebanese households, which are equivalent to 50.4% of the Lebanese residents. In addition, Beirut ranked first in higher salaries among other regions of Lebanon, and it was classified as a middle-upper class city (Houri & Ibrahim-Korfali, 2005). One of the major challenges Beirut is currently facing is the limitation in the primary energy resources. Beirut actually depends mostly on imported fuel for purchasing power. In addition, even though the daily blackout period is 3 hours in Central Beirut, this highly dense city is using diesel generators on a daily basis. The residential buildings consume up to 662,890 MWh/year. As previously mentioned, most of the energy consumption in summer time is caused by the heavy use of ACs (CES-MED, 2010) as air-conditioning became a must rather than an option in Beirut city and the majority of residential apartments follow a Business as Usual (BAU) construction. Therefore, due to limitations in time and presence of lockdown due to COVID-19 pandemic, this study analyses the impact of changing the building envelope material on cooling consumption in a residential apartment in Beirut city using HAP software.

CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

In Beirut, typical building envelope material is used in residential building including single walls and single glazing. A base HAP model representing a typical residential apartment in Beirut is adopted to simulate the cooling energy consumption and compare this cooling consumption with the cooling benchmark for business-as-usual residential apartments presented in the MED-ENEC study released in 2013. MED-ENEC relied on HAP software to launch the business-as-usual consumption benchmarks, in order to assess the impact of building envelope material on final cooling consumption in residential apartments.

Carrier's Hourly Analysis Program (HAP) is a simulation tool used for estimating loads and HVAC design systems and simulating energy use in buildings. In this study, HAP software is used to calculate the cooling consumption in the chosen typical apartment.

HAP takes several inputs illustrated in the diagram shown in Figure 1. The model is developed by creating the spaces of the living room and bedroom, where the AC split unit is used, including floors, external walls, partitions and roofs, and assigning their construction material and U-values, in addition to the orientation and dimensions. Windows are constructed as single glazed with specifications and U-values. Moreover, more simulation inputs include the AC schedule, and occupancy schedule, number of occupants, lighting schedule, equipment, internal gains and weather conditions.

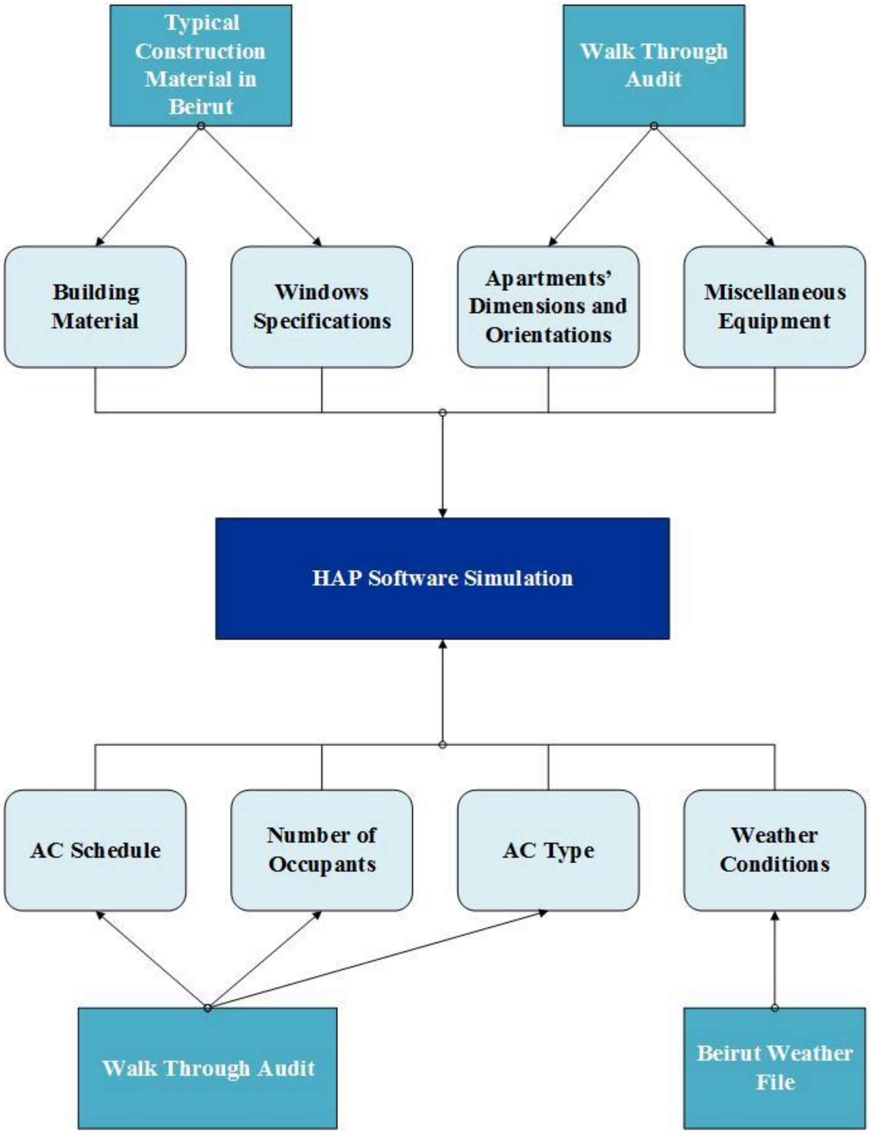

Figure 1. Inputs of HAP Software

The Beirut weather file in HAP version 5.1 is from ASHRAE date base, which imports the weather data from Beirut airport weather station.

In the case study apartment, conventional DX split units are used for cooling in living room and bedroom zones. HAP software is used to display different building envelope materials scenarios and reflect on cooling energy consumption while using AC split units.

The different scenarios inputs into HAP are the following:

A. Scenario 1: Business as Usual (BAU) with Single Walls and Single Glazing:

This is the existing BAU construction of our case study residential apartment.

Table 1 shows the construction materials used in external single walls. The single glazing used has a U-value of 6.195 W/m2.K.

Table 1: External Single Walls

Layers: Inside to Outside	Thickness (mm)	Density (kg/m3)	Specific Heat (kJ/kg.K)	R-Value (m2.K/kW)	Weight (kg/m2)
Inside Surface Resistance	0.00	0.00	0.00	0.12064	0.00
Plaster	10.00	1400.00	0.84	0.01430	14.00
20 cm Hollow Block Concrete	200.00	1600.00	0.84	0.18000	320.00
Plaster	10.00	1400.00	0.84	0.01430	14.00
Outside Surface Resistance	0.00	0.00	0.00	0.05863	0.00
Totals	220.00			0.39000	428.00
Overall U-Value	2.578 W/m2.K				

B. Scenario 2: Single Walls and Double Glazing:

In the second scenario, single walls are maintained as in Table 1 while upgrading to single glazing to Clear Low E double-glazing having a U-Value of 1.6 W/m2.K.

C. Scenario 3: Double Wall with 2 cm air space and 3 cm extruded polystyrene and Single Glazing:

In the third scenario, single walls are upgraded to double walls with 2 cm air space and 3 cm of extruded polystyrene, as shown in Table 2 and using single glazing with a U-value of 6.195 W/m2.K.

Table 2: External Double Wall with 2 cm air space and 3 cm extruded polystyrene

Layers: Inside to Outside	Thickness (mm)	Density (kg/m3)	Specific Heat (kJ/kg.K)	R-Value (m2.K/kW)	Weight (kg/m2)
Inside Surface Resistance	0.00	0.00	0.00	0.12064	0.00
Plaster	10.00	1400.00	0.84	0.01430	14.00
10 cm Hollow Block Concrete	100.00	1600.00	0.84	0.13000	160.00
Air Space	20.00	0.00	0.00	0.16026	0.00
Extruded Polystyrene	30.00	30.00	0.30	0.69400	0.90
20 cm Hollow Block Concrete	200.00	1600.00	0.84	0.13000	320.00
Plaster	10.00	1400.00	0.84	0.01430	14.00
Outside Surface Resistance	0.00	0.00	0.00	0.05863	0.00
Totals	370.00			1.32	508.9
Overall U-Value	0.757 W/m2.K				

D. Scenario 4: Double Wall with 5 cm air space and Double Glazing:

In the fourth scenario, single walls are upgraded to double walls with 5 cm air space as shown in Table 3 and using Clear Low E double-glazing with a U-value of 1.6 W/m2.K.

Table 3: External Double Walls with 5 cm air space

Layers: Inside to Outside	**Thickness (mm)**	**Density (kg/m3)**	**Specific Heat (kJ/kg.K)**	**R-Value (m2.K/kW)**	**Weight (kg/m2)**
Inside Surface Resistance	0.00	0.00	0.00	0.12064	0.00
Plaster	10.00	1400.00	0.84	0.01430	14.00
10 cm Hollow Block Concrete	100.00	1600.00	0.84	0.13000	160.00
Air Space	50.00	0.00	0.00	0.16026	0.00
20 cm Hollow Block Concrete	200.00	1600.00	0.84	0.13000	320.00
Plaster	10.00	1400.00	0.84	0.01430	14.00
Outside Surface Resistance	0.00	0.00	0.00	0.05863	0.00
Totals	370.00			0.63	508.9
Overall U-Value	1.593 W/m2.K				

E. Scenario 5: Double Wall with 2 cm air space and 3 cm extruded polystyrene and Double Glazing:

In the fifth scenario, single walls are upgraded to double walls with 2 cm air space and 3 cm of extruded polystyrene, as shown in Table 2 and using Clear Low E double-glazing with a U-value of 1.6 W/m2.K.

F. Scenario 6: Double Wall with 5 cm extruded polystyrene and Double Glazing:

In the fifth scenario, single walls are upgraded to double walls with 5 cm of extruded polystyrene, as shown in Table 4 and using Clear Low E double-glazing with a U-value of 1.6 W/m2.K.

Table 4: External Double Walls with 5 cm extruded polystyrene

Layers: Inside to Outside	**Thickness (mm)**	**Density (kg/m3)**	**Specific Heat (kJ/kg.K)**	**R-Value (m2.K/kW)**	**Weight (kg/m2)**
Inside Surface Resistance	0.00	0.00	0.00	0.12064	0.00
Plaster	10.00	1400.00	0.84	0.01430	14.00
10 cm Hollow Block Concrete	100.00	1600.00	0.84	0.13000	160.00
Extruded Polysttrene	50.00	30.00	0.30	1.78500	1.50
20 cm Hollow Block Concrete	200.00	1600.00	0.84	0.13000	320.00
Plaster	10.00	1400.00	0.84	0.01430	14.00
Outside Surface Resistance	0.00	0.00	0.00	0.05863	0.00
Totals	370.00			2.25	509.5
Overall U-Value	0.444W/m2.K				

Other relevant inputs in HAP are:

Table 5: Building Infiltration Rates

Building Type	**Infiltration rate (L/s/m²)**
Apartment Building	0.33

Table 6: Air Conditioning Set Point Temperatures

Temperature required for simulation (°C)		
Mode	Occupied space	Unoccupied Space
Cooling	24	27

Table 7: Apartment Ventilation Rates

Outdoor Air Ventilation Requirements		
Space Usage	Ventilation Rate*	
	L/s/person	L/s/m²
Residential: Dwelling Unit	2.5	0.3

*Ventilation rates depending on each type of room are as per ASHRAE Standards 62.1 (Ventilation for Acceptable indoor Air Quality)

Table 8: Summary of schedules table

Occupancy, Thermostat, & Lighting Schedules	
Residential Apartments	
Type	**Hours per day**
Living Room	16:00 pm to 11:00 pm
Bedroom	21:00 pm to 7:00 am

CHAPTER IV

RESULTS AND DISCUSSION

The final energy consumption in any building sector is a critical indicator for both economy and environment. (Schimschar & Assad, 2013) Therefore, it is very important to reduce the final energy consumption in any way possible especially cooling consumption.

According to MED-ENEC study, the final cooling consumption in Business as Usual (BAU) residential buildings is 78 kWh/m^2.year, where it relies on HAP software models to simulate energy consumption in different building type. MED-ENEC takes into account that in practice, not all the rooms in the apartment are conditioned. Usually, living room and bedroom zones are conditioned as in our case study apartment with a total conditioned area of 35 m^2.

In our case study apartment, the HAP simulation results for the different scenarios presented in the below bar graph:

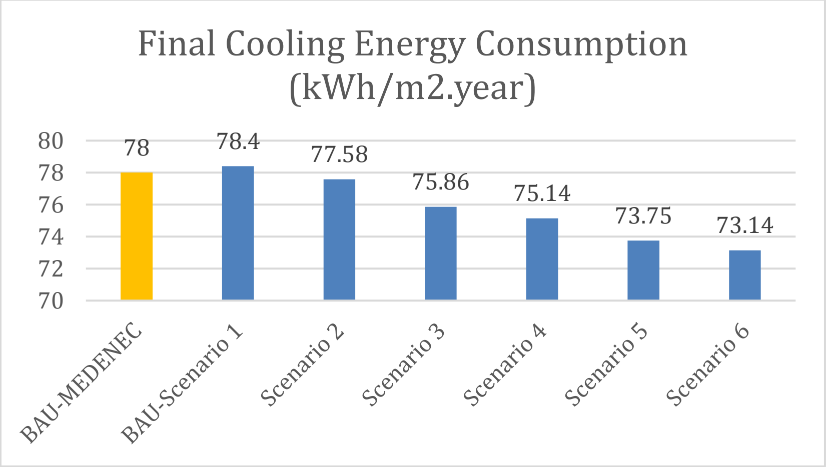

Figure 2. Final Cooling Energy Consumption in MED-ENEC and in different HAP scenarios

In Figure 2, we notice that the final cooling energy consumption in BAU construction, which is simulated over the cooling season from June to October, is 78.4 kWh/ m^2.year whereas the reference in MED-ENEC study for BAU construction is 78 kWh/m^2.year. This means that our BAU HAP Model (Scenario 1) is validated.

Cooling consumption is affected by many factors including the physical quality of the building and building envelope material which is the factor assessed in our study. By changing the envelope characteristic in six different scenarios, cooling consumption dropped with ever enhancement done. As noticed in Figure 2, upgrading to double-glazing, while keeping single walls in scenario 2, barely showed any reduction in consumption that reached only 77.58 kWh/ m^2.year. This is due to the window to wall ration in bedroom is 0.2 and that in the living room is 0.4. Therefore, the influence of changing from single wall to double wall is higher in our case study. As seen in scenario 3, changing from single wall to double wall, while keeping the single glazing, result in higher reduction that reaches 75.14 kWh/ m^2.year.

Consequently, changing the specifications of the double wall while having double-glazing windows will lead to the optimum combination in reducing cooling energy consumption. Scenarios 4, 5 and 6 use double-glazing for windows but different double wall specifications. The cooling energy consumption drops from 75.14 kWh/ m^2.year while using double wall with 5 cm air space to 73.75 kWh/ m^2.year while using double wall with 2 cm air space and 3 cm extruded polystyrene insulation. However, increasing the insulation to 5 cm extruded polystyrene insulation with no air space barely showed a reduction of 0.61 kWh/

m^2.year. Therefore, adopting a double wall with less insulation thickness and air space could provide the optimal solution regarding both energy and cost savings.

Digging deeper in energy and cost savings achieved, Figure 3 shows the total cooling energy consumption in kWh between the different HAP scenarios.

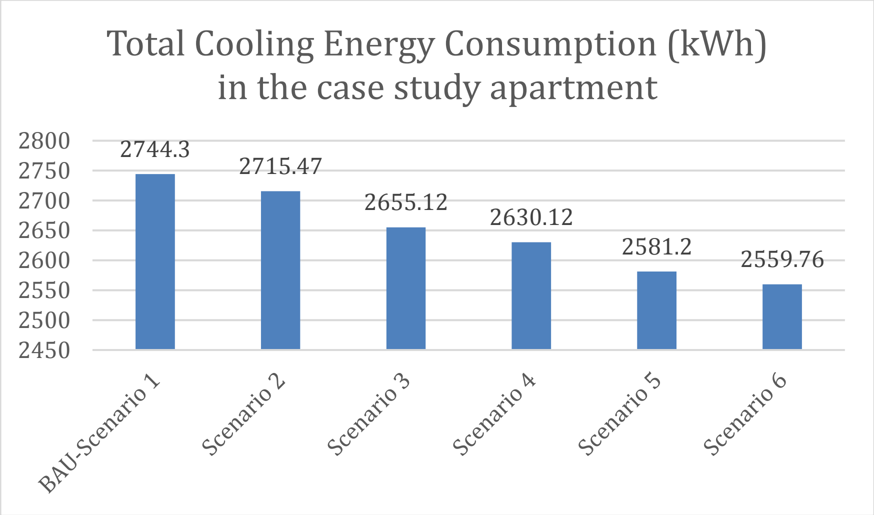

Figure 3. Total Cooling Energy Consumption (kWh) in the case study apartment

In Lebanon, the most important energy carrier is electricity (Schimschar & Assad, 2013). We have two sources of electricity: EDL and diesel generators that are used to supply independent electricity during the times of cut offs in the grid. Out of the 24 hours electricity supply in Beirut, the three hours electricity cut off are compensated by generator subscriptions. Cooling consumption is the most relevant aspect in residential building consumption, and therefore Figure 4 shows the cost savings that could be achieved by the occupants when upgrading the envelope materials in the different scenarios presented earlier in reference with the (BAU) scenario.

Assuming that occupants do turn their ACs on during the 3 hours cut offs, then 12.5% of cooling energy consumption is paid by the diesel generator rate at 30 US cents/kWh, while the rate of EDL is 9.6 US cents/kWh. (Ahamd, 2020)

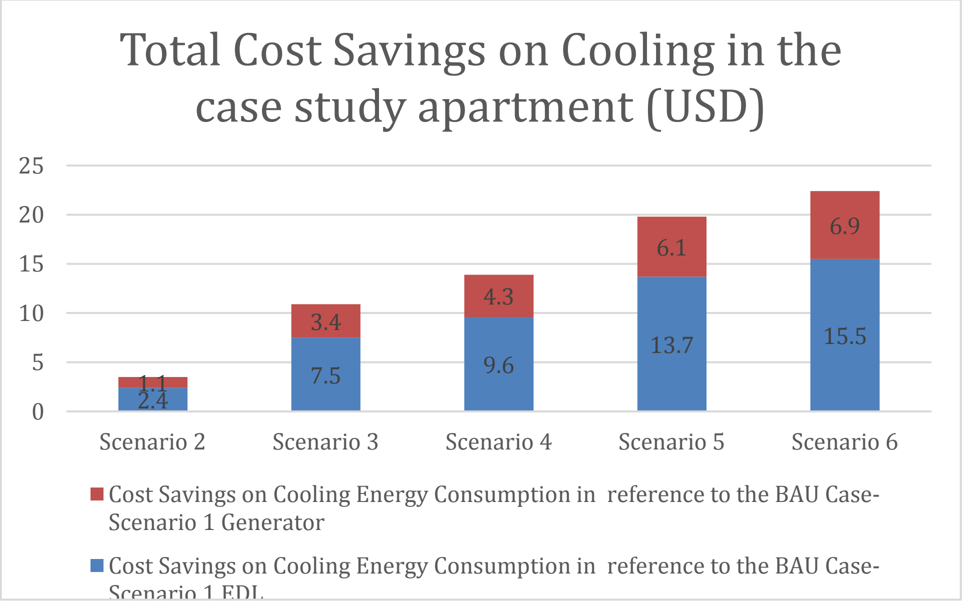

Figure 4. Total Cost Savings in the case study apartment (USD)

The most achieved cost savings on cooling energy consumption is in Scenario 6 where 5 cm extruded polystyrene insulation is used in double walls. However, we notice that the reduction in cost between Scenario 5, which uses 3 cm extruded polystyrene insulation is much less than that in other scenarios. Therefore, taking into consideration the minimal final energy consumption presented earlier between Scenario 5 and 6, in addition to the achieved cost savings in Figure 4, Scenario 5 could act as the optimal scenario in terms of energy and cost savings.

Moreover, the environmental impact attained with the enhancement of building envelope material should not be neglected. Figure 5 shows the reduction in CO2 emissions in the different HAP scenarios adopted in this study.

As per the International Energy Agency (IEA), the average emission of C02 for electric grid generation is 0.638 kg/kWh.

As for diesel generators, with a diesel average density of 832 g/L, the combustion of 1 liter of diesel fuel will generate 2591.7 grams of CO2 then with average consumption of 0.273 L/kWh, the diesel generator will produce 708.35 grams of CO2 for each kWh generated.

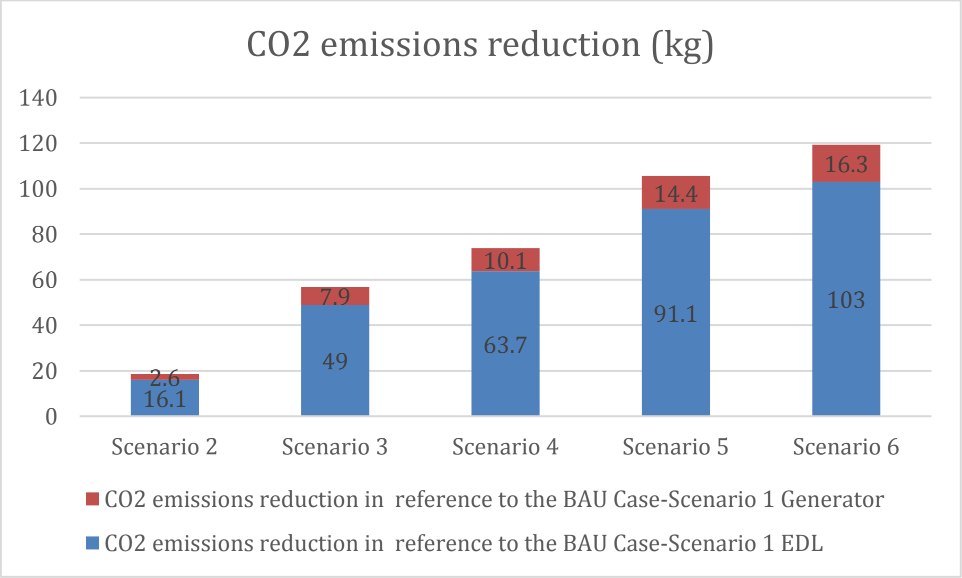

Figure 5. CO2 emissions reduction in the case study apartment

CHAPTER V

CONCLUSION AND RECOMMENDATION

This study illustrates the impact of building envelope material on cooling energy consumption in a typical residential apartment in Beirut city that uses conventional DX split units. A case study apartment is modeled using HAP software using six different scenarios of building envelope configurations of external walls and windows. HAP takes envelope materials, orientations, areas, AC schedule, occupancy lighting and other factors when processing the simulations.

In order to validate the Business as Usual (BAU) scenario we modeled in HAP, MED-ENEC study is used to benchmark the HAP simulation results with cooling consumption in BAU residential buildings of 78 kWh/m^2.year.

Different wall configurations are modeled where the reduction in cooling energy consumption increased with increasing the insulation thickness in the external walls while implementing double-glazed windows. However, the energy simulations showed lower reduction percentage when increasing the thickness of extruded polystyrene insulation from 3 cm to 5 cm. In addition, this minimal reduction is reflected in cost savings on EDL and generator subscriptions. The cooling energy consumption drops from 78 kWh/m^2.year to 73.75 kWh/m^2.year when using double wall with 2 cm air space and 3 cm extruded polystyrene with double glazed windows and to 73.14 kWh/m^2.year when using double wall with 5 cm extruded polystyrene with double glazed windows. Finally, CO2 emission reduction shows that we are able to go down by 105.53 kg when using 3 cm extruded polystyrene in external walls.

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