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Article

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Reference: Bataineh, Asma' M./Ali, Hikmat H. (2021). Improving energy efficiency of multi-family apartment buildings case of Jordan. In: International Journal of Energy Economics and Policy 11 (5), S. 244 - 254.
https://www.econjournals.com/index.php/ijeep/article/download/11394/6021.
doi:10.32479/ijeep.11394.

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2021, 11(5), 244-254.

Improving Energy Efficiency of Multi-Family Apartment Buildings Case of Jordan

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Received: 15 March 2021 **Accepted:** 03 June 2021 **DOI:** https://doi.org/10.32479/ijeep.11394

ABSTRACT

Saving energy is a high priority in developing countries and several energy-efficient initiatives are being introduced for that purpose. The residential sector is responsible for a big part of the world's energy usage; most of this energy is used in heating, cooling, and artificial ventilation systems. The residential sector in Amman consumes more than 21% of the annual energy consumption, meanwhile multi-family residential apartments occupy more than 60% of that sector. With a view on developing energy-efficient structures, this study provides an overview of building design criteria that can reduce the energy demand for heating and cooling of multi-family apartment residential buildings. These criteria are based on the adoption of suitable parameters for the orientation of the building, shape, envelope system, use of insulation materials, passive heating and cooling mechanisms, setting of cooling and heating thermostat, lighting, and window's ratio and glazing. This experiment measures the effect of these criteria on overall energy demand that reviewed and recommended the best design choices. This is beneficial for professionals in the design phase of energy-efficient multi-family residential buildings and decisions makers. The methodology that is used in the study was represented in field observation and surveys, besides, to use design-builder as a simulation tool to test the assumptions and the design strategies, the results indicate that a 6cm polystyrene insulated walls and roof for a north/west middle floor apartment and WWR ranges from 25 to 30% of double bronze glass will affect greatly in the energy demand.

Keywords: Energy-efficiency, Multi-family Residential Apartment, Design Strategies
JEL Classification: Q20, Q42

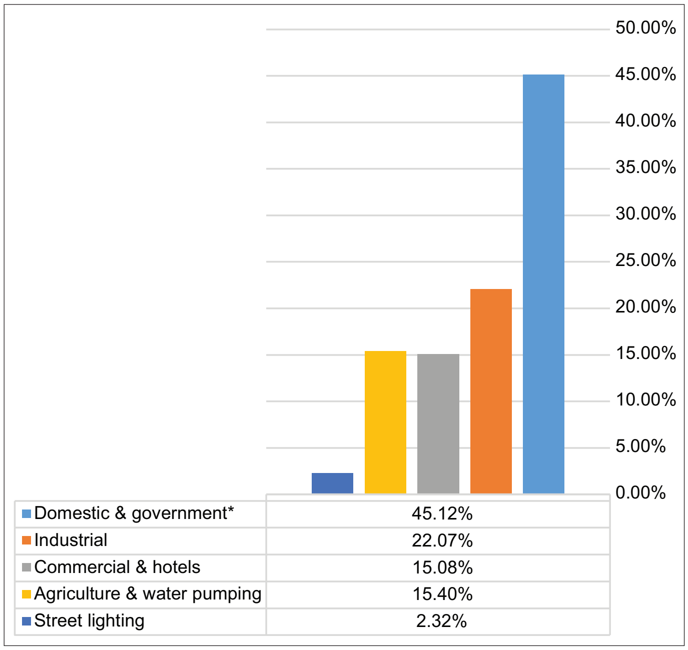
1. INTRODUCTION

The quality of the modern lifestyle depends mainly on modern appliances and electronic devices, which cause an increase in electrical consumption demands (Al-Hinti and Al-Sallami, 2017). Accordingly, Jordan's government realizes the significance of energy conservation and intends to conserve energy in new buildings through building codes (Awadallah et al., 2009).and through the establishment of the Jordan Green Building Council (JGBC) in 2009 (Jordan Green Building Council, 2019). Buildings' energy requirement consumes around 40% of the total energy consumption in the world and the electricity used in buildings produces one-third of the greenhouse gas emissions around the world (Taleb and Sharples, 2011). Energy demand is rising due to population increase, heat increases, and losses that are responsible for high-energy usage in the building envelope (Bataineh and Alrabee, 2018).

Multi-family residential apartment buildings in Jordan account for 21% of overall power generation consumption and 43% of final electricity usage (*Household Survey MEMR*, 2013) as documented in previous studies, more than 60% of household energy consumption is used for space heating and cooling (Al-Hinti and Al-Sallami, 2017) Moreover, Figure 1 illustrate the distribution of electric power consumption in Jordan distributed on the main sectors (Electric et al., 2018).

Reported that urbanization, population growth, and the increase in living conditions all lead to rising residential energy demands

Figure 1: Electrical energy consumption be sector type for the year 2018 as shown at the electrical company report for the year 2018



as reported by Al-Hinti and AL-Sallami, 2017, Besides Al-Ghandoor et al., 2009 found that population is a key factor in energy consumption whereas electricity and fuel prices do not affect the consumption of electricity or fuel. It was found that the urban subsector accounts for approximately 80% of households and 84% of Jordan's residential energy consumption (Akash and Mohsen, 1999), and Jaber et al., 2008 revealed that space heating accounts for 61% of overall household consumption, which constitutes about 14 % of total national energy demand. The cause of this high percentage of consumption is due to the high degrees of temperature during summer, the new style of buildings that include large areas of glasses, and the dependence on imported construction materials that are not compatible with local weather conditions.

The aims of improving energy efficiency in building constructions will result in minimizing energy usage while maintaining comfort levels, energy, and money savings and minimizing harmful emissions (Bataineh and Alrabee, 2018). In terms of thermal wall insulation, it is embedded only in 21% of the overall dwellings while it is used in 32% of the residential building in Amman (*Household Survey MEMR*, 2013) (Mohsen and Akash, 2001), and it was also shown that more than 66% of the total number of multi-family apartments average areas is around 150 m^2 with a small percentage of using thermal insulation and 49% of them have waterproof systems (Swan and Ugursal, 2009).

Jordan's residential sector consumes the most of electrical energy (Bataineh and Alrabee, 2018), and this significant consumption trend raises awareness of this sector at the national level. Many factors influence residential energy use practices, including climatic factors, envelope design factors, and consumer behavior factors. The majority of previous studies have concentrated on climate-related factors such as heating and cooling efficiency (Lahoud, 2018). The form and size of the dwelling, orientation, construction materials, age of the property, number of spaces, and public awareness are all construction-related factors. in addition to Occupant-related factors such as family size, monthly income, average monthly family expenditures, education level, and gender (Chowdhury et al., 2008). The findings indicated that the result of the investigation provided a rebound- effect of about 15 to 30% due to retrofitting of the buildings. The results led to the conclusion that energy savings can be attained in real practical situations and reduction in CO_2 emissions, this is because energy efficiency measures will be lower than those were calculated depending on studies of engineering conservation (Swan and Ugursal, 2009).

Numerous studies were conducted on energy conservation and improvement of energy efficiency in residential buildings in different climatic locations. Most of them indicated the high potential for improvement through adapting many sustainable measures and creating a design that is compatible with the environment (Mardookhy et al., 2014). Bataineh and Alrabee, 2018 investigated the impact of various energy conservation measures (ECMs) on residential buildings in Jordan in 2018 and guided to improve the performance of the lighting and HVAC system to minimize the annual consumption of electricity, and to decrease the amount of carbon emission. In another study conducted in Saudi Arabia (Taleb and Sharples, 2011), energy and water consumption patterns were evaluated in a hot-humid region, the study created guidelines and design strategies for delivering sustainable housing by investigating apartment buildings using simulation software packages.

To achieve a reasonable amount of energy efficiency in an apartment, it is crucial to define the indicators that affect energy consumption patterns. In a study conducted in China depended on a literature review and a questionnaire, a set of energy efficiency indicators were proposed and an analytical hierarchical approach was adopted to weigh them. This method was validated by using a consistency estimation procedure (Yang et al., 2010). Another study in China presented the energy efficiency standards and suggested energy efficiency standards be used. Moreover, the study presented constraints and barriers to improving energy-efficient residential buildings and procedures to overcome these barriers (Richerzhagen et al., 2008).

Nevertheless, an Energy efficiency rating is important to manage energy consumption in an existing building. A study conducted by Koo et al., 2014 will help policymakers for an established energy-efficiency rating system for built houses. It is based on data collection and analysis, a correlation between house size and amount of CO_2 pollution, cluster analysis, and develop a new rating system for existing buildings.

The goals of improving energy efficiency in buildings will result in less energy consumption. A previous study in 2017 reviewed several passive measures in the United Arab Emirates (UAE) dedicated to the hot climate, such as construction orientations and thermal insulation that could achieve energy savings of up to 20 % (Friess and Rakhshan, 2017).

One important measure of residential energy efficiency in envelope design and construction, which is considered a key factor of achieving efficiency in the design and construction of the building that uses a limited active air conditioning system. A study conducted in Australia adopted integrated thermal modeling and life cycle approaches in cold-weather regions in Melbourne, Victoria. It concluded that the most cost-effective design is more energy-efficient than the implementation of the national code requirements and the implication of such an approach would be significant policy practices (Morrissey and Horne, 2011).

Insulation of buildings can be considered as one of the major factors in achieving energy efficiency in buildings. It works mainly to deliberate the flow of heat through the envelope building and it seals the envelope by preventing outside air leakage, thus maintaining indoor environmental quality (Al-ajlan, 2006). Al-Homoud, 2014 investigated the influence of thermal insulation on residential and office buildings in Saudi Arabia using the building energy simulation program "EnerWin". The study showed that using walls and roof insulation in hot-dry climates reduced consumption by about 23.69% to 45.51%, and in a hot-humid climate, the reductions ranging from 25.29% to 50.24%.

Wall insulation has been reported to play a major role in reducing energy loss and gain through the building envelope. In Koo et al.'s investigations (Aldiab et al., 2017) it was found that the thermal insulation of residential buildings in the UAE makes 20 % of the energy savings.

Ozel, 2011 studied the effect of wall orientation on the optimal wall thickness, it was considered an acceptable thickness of 5.5 cm for the south-facing wall for the extruded polystyrene, 6 cm was the optimum thickness in the north, east, and west-oriented walls. Cabeza et al. (Ferna, 2010) tested three isolation materials in traditional Mediterranean building materials experimentally, the results showed that the energy consumption of polyurethane is the lowest in comparison with wool and polystyrene, and energy savings in summer can reach up to 64% and in winter 37%.

Another study in china Suggested guidelines for applying insulation to building envelopes, it showed that the thicker insulation used in wall construction, the lower the annual energy usage for cooling and heating, taking into account the climatic region and the orientation of walls (Dongmei et al., 2012).

Window design has a great influence on energy efficiency in apartment buildings. A study conducted in a moderately humid climate in Turkey investigated the effect of window design and its components on energy consumption, different window designs and glazing systems were tested using two apartments, which were identical in construction and operation systems. These systems included smart glass, high-performance glass, clear reflective glass, double glazed windows, heat-reflective glass, and low emissivity glass. The result was obtained using design builder software, which indicated that smart glass with low emissivity glazing is the most efficient choice for energy consumption (Yaşar and Kalfa, 2012).

As a substantial element that affects heat gain or losses of a building, Hee et al. concluded that windows are responsible for nearly 20% to 40% of energy losses (Hee et al., 2015). While a study in Egypt succeeded to minimize energy consumption by 4.3% in residential buildings by reducing the Window to Wall Ratio (WWR) from 40% to 30% and save energy up to 55% by using proper glazing type (Huang et al., 2014).

Studying, analyzing, and evaluating the energy consumption patterns and expenditure among multi-family apartment buildings in the city of Amman which forms 60.3% of its residential sector, and 40.5% of the total residential sector in all Jordan's regions (Nsour and Karmi, 2015), will concern with the following questions: (1) What is the range of energy consumption among multi-family apartment buildings in Amman's climate, which classified as hot dry summers and wet cool winters? (2) What are the factors affecting energy consumption in multi-family apartment buildings? The intent is to develop an efficient model by defining the variables that contribute to residential energy consumption in Amman's climate. To differentiate among different multi-family apartment types in terms of their construction materials, building layout, openings, orientation, location of the apartment within the building complex, and the efficiency of the HVAC system used. The models and the results of this research will be beneficial to energy policymakers, architects, engineers, and researchers who are concerned with residential energy consumption and its relationship with construction factors. Based on the results, conclusions, recommendations, guidelines will be formulated to assist designers in designing energy-efficient multi-family apartment buildings that possibly will improve their energy efficiency in Jordan.

The novelty of this study is that it suggests some important points that should be taken into consideration to reduce the energy consumption of typical multi-family residential buildings under Jordanian climatic conditions. Typical residential buildings represented by multi-family apartment buildings located in Amman are taken as case studies, Energy consumption profiles for each of the proposed measures are determined using dynamic simulation software.

2. METHODOLOGY

A cross-sectional design approach was implemented to attain the research goals and the relevant research context. The research methodology is based on a triangulation approach that used two or more methods of data collection procedures within a single study (Heale and Forbes, 2013) and (Flick, 2009). Quantitative and qualitative methods are combined in the study. The methods used are field observation, occupant's responses through questionnaire, and simulation.

2.1. Field Observation and Survey

Field observation and a survey was the first step to recognize the physical characteristics of the buildings that help in determining the variables, which will be included within the two other methods, based on a field survey to percept the site, buildings area, use of HVAC systems, and patterns of activities. And determining the thermal comfort zone, and the balance point temperature by analyzing psychometric chat and its strategies, to evaluate roughly building heat efficiency and to investigate the used envelope materials with the use of architectural and construction drawings.

Occupant's surveys were adapted also as self-reported data, to evaluate the perception of building efficiency according to the users, they were asked about definite times and their sensation towards thermal comfort.

2.1.1. Description of the buildings

The study took place in Amman, which is the capital, the largest commercial, the political, and cultural hub of the country with a population of 4,007,526. Different districts were randomly selected and within each district, simple random procedures were conducted and different existing types of buildings were studied in terms of apartment areas, building forms, envelope construction and design, number of units within the building, openings, and orientation.

Topology analyses for selected apartments include several units within the building and the number of floors, around 63% of the selected buildings were three levels buildings with four units on each floor. The envelope of these buildings was varied between; single layer concrete blocks without insulations, a single wall with composite insulation blocks, double walls with insulation, a single wall with composite blocks, and cladded with natural or artificial stone. Other types included more than six units on each floor that account for 16% with a diversity of envelope design. Other types, which are composed of two to three units within the floor and with different envelope designs, were representing 13% of the total selected buildings.

Table 1 shows the attributes of Archetypical Apartment Units in Amman. The selected type for further analysis included the four units, three floors, and different envelope design, the area of each unit was around 113-125 m^2 and the longest side was in different orientations. These units were composed of two bedrooms, a living room, kitchen, guest room, and two bathrooms. The window wall ratio was around 30% of the exterior areas, these windows were composed of an aluminum sliding frame with single pane glass of 6 mm thickness and wall thickness varied between 20 cm to 30 cm with different construction materials. The flooring was ceramic tiles or terrazzo flooring system, and very few had a parquet-flooring system. The internal walls were made of hollow concrete blocks with varies in thickness of 10 cm to 15 cm. There was no heating system installed in most of the apartments because it is occupied by low-income families, in heating days it is handled by kerosene heaters or portable electric heaters. A cooling system was installed in most apartment units, the systems include window type air conditioner or split unite cooling system. Each apartment includes one to two cooling units in the living room and sometimes in the master bedroom, Figure 2 shows the plan of the considered base case in the study.

Table 1: Attributes of archetypal apartment units in Amman

Number of Floors	3
Number of Apartment per Building	12
Total Building Area	1286.72 m^2
Area of Apartment	113.49 m^2
Number of Bedrooms in Apartment	2
Number of Bathrooms in Apartment	2
Height	3.0 m
Exterior wall Area	1090 m^2
Area of Windows	230.73
Window to Wall Ratio	30%
Cooling System	Window Unit, split Unit
Number of Cooling Units in Apartment	2

2.1.2. Climate in Amman

The predominant feature of Jordan's climate is the Mediterranean; it is characterized by hot dry summers and wet cool winters. Jordan is located 80 km to the East of the Mediterranean Sea (Al-qinna, 2018). Jordan is divided into three main climatic regions; the Ghor Region (lowlands), the Badia or Desert region, and the Highlands, which includes Amman the city (Hassouneh et al., 2015).

The Latitude of Amman is 32.1 N and the longitude is 35.52 E (Hassouneh et al., 2015), the following table shows the climatic data for the city of Amman as recorded by Jordan's Meteorological Department.

Table 2 shows that the maximum temperature during summer is approaching 43.4°C, which is extremely hot, where it reaches around –4.4°C in winter. Several weather indicators were studied and analyzed using climate consultant software (Jordan Meteorological Department, n.d.), as shown in Figure 3. It shows dry bulb temperature, wet bulb temperature, comfort zone as well as radiation for the 12 months. It is clear that around 9 months the temperatures exceed the thermal comfort level; this means that the cooling strategy is the most required for three quarters of the year.

2.2. Building Simulation

The study was adopted Design Builder software as one of the powerful energy simulation programs. A three-dimensional model for the case study was created based on prototype building drawings, and several models have been developed and assessed according to an intensive review of the building configurations and attributes. The input of the program is the description of the building including lighting, equipment, thermostat settings, and the activities of the occupants. A clear schedule of operation for the

Figure 2: The plan shows a typical floor plan for apartment buildings and archetypical units

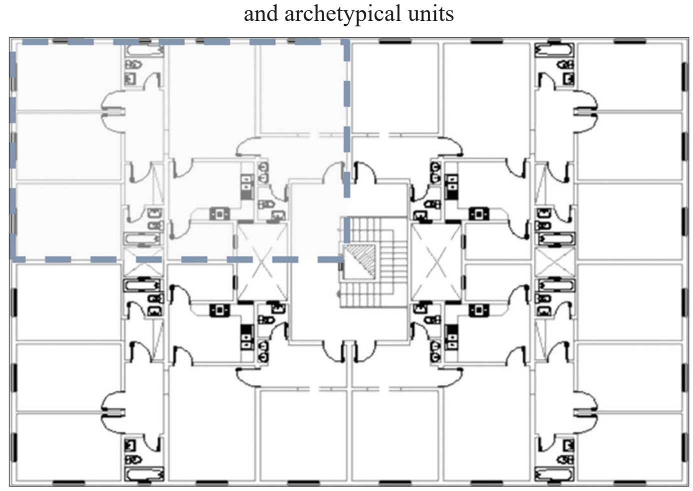


Figure 3: Monthly weather data for the city of Amman (created by using climate consultant 5.5)

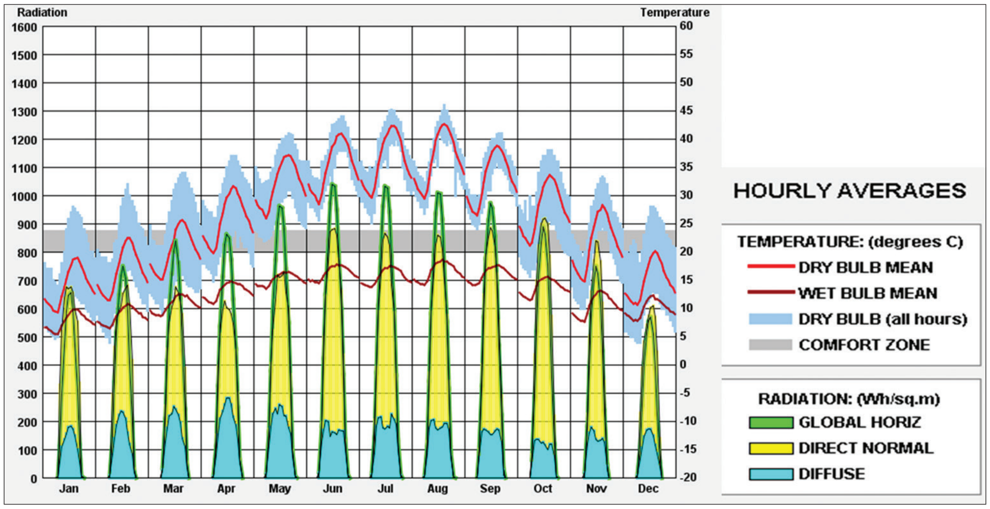


Table 2: Climatic data of Amman (Jordan Meteorological Department, n.d.)

Climatic data for Amman												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Record high °C	23.0	27.3	32.6	37.0	38.7	40.6	43.4	43.2	40.0	37.6	31.0	27.5
Average high °C	12.7	13.9	17.6	23.3	27.9	30.9	32.5	32.7	30.8	26.8	20.1	14.6
Daily mean °C	8.5	9.4	12.4	17.1	21.4	24.6	26.5	26.6	24.6	21.0	15.0	10.2
Average low °C	4.2	4.8	7.2	10.9	14.8	18.3	20.5	20.4	18.3	15.1	9.8	5.8
Record low °C	-4.5	-4.4	-3.0	-3.0	3.9	8.9	11.0	11.0	10.0	5.0	0.0	-2.6
Average precipitation mm	60.6	62.8	34.1	7.1	3.2	0.0	0.0	0.0	0.1	7.1	23.7	46.3
Average precipitation day	11.0	10.9	8.0	4.0	1.6	0.1	0.0	0.0	0.1	2.3	5.3	8.4
Mean monthly sunshine hours	179.8	182.0	226.3	266.6	328.6	369.0	387.5	365.8	312.0	275.9	225.0	179.8

building is needed including information about occupancy of the building (times, days of the week, and seasonal variations), HVAC, and internal equipment operations schedules. It also required building envelope configurations including materials, structure, and building shell, in addition to the geometry (dimensions) of the building, its construction materials, glass properties, windows, dimensions, and window shades (overhangs or fins). For the accuracy of any energy simulation of buildings, it is important to have information about HVAC equipment efficiency and utility data; such as hourly electricity demand, as well as economic parameters.

Modeling of typical apartment buildings (Base Case) with the identified parameters was developed to quantify the energy consumption by energy simulation program Design-Builder. The results of the base-case were calibrated with the real-time consumption obtained from the utility bills. Moreover, investigations were conducted to identify the critical parameters of building parameters that affect energy efficiency in apartment buildings. Consequently, the outcome identified the appropriate building components that improve the energy efficiency of a typical apartment building in Amman.

3. RESULTS AND ANALYSIS

The analysis of the study was conducted based on field survey and archival analysis, self-reported questionnaires, and simulation of selected buildings.

3.1. Monthly Electric Bill Data

To get insight into the electricity consumption of the selected multi-family apartments, electric bills were collected for the years 2017, 2018, and 2019 from Jordanian electric power Co. [34], by providing them with apartment account numbers.

Figure 4 shows the mean monthly energy consumption patterns for 76 selected units. These units have an average area of around 113 m^2. The consumption patterns indicated a huge amount of usage for cooling during the harsh weather season. The total average consumption per meter square is 22.93 KWh/m^2/year, and the highest average annual consumption is 47.8 KWh/m^2/year and the lowest is 15.0 $KW/h/m^2$/year.

The utility data can be considered as a tool for evaluating and calibrating the base case simulation results. However, it does not give detailed information about subcategories of usage such as cooling, lighting, appliances, and domestic hot water.

3.2. Occupants Responses

The questionnaire survey was conducted during June. Seventy-six multi-family apartment residents were chosen to fill the questionnaire. The purpose was to assess their perception of indoor environmental factors and to define their comfort levels. Several questions were prepared to seek information about the resident's social and economic variables. The questions were aimed to get information about the size of the family, age, education, and economic status.

The surveyed occupants were asked to express their feeling at the time the questionnaire was delivered, toward indoor environmental situations. The analysis was carried out based on ASHRAE thermal sensation scale (55-2010, 2010). The scale is from -3 as (feeling cold) and +3 as (feeling hot). The data were categorized based on floor level and orientation of the apartment.

Figure 5 indicates the response of occupants in different floor levels. It shows that the residents of the first floor, which is protected from above and below, are more comfortable than residents of the second and ground floor. They tend to feel cold with the same cooling systems. Figure 6 also indicated the responses of south and west-facing units. It is shown that east and north residents feel more comfortable than west and south. The best situation is fulfilled a good thermal comfort level is the first-floor level that is oriented east and north.

3.3. Simulation of the Base Case

The building, which consists of three floors and four multi-family apartments on each floor, was drawn in design-builder. The geometry of the building, as shown in Figure 7, was conducted for energy modeling. It is understood as a concept of a 3-dimensional object, which is constructed as planes of a 3D grid. The simulation program defines the surfaces as a group of vertices; with x, y, and z coordinates, composing it with other surfaces that make up design drawing.

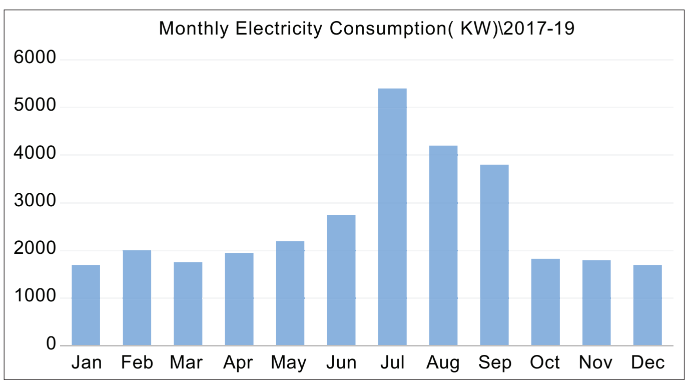


Figure 4: Monthly electricity consumption of selected apartments based on utility bills

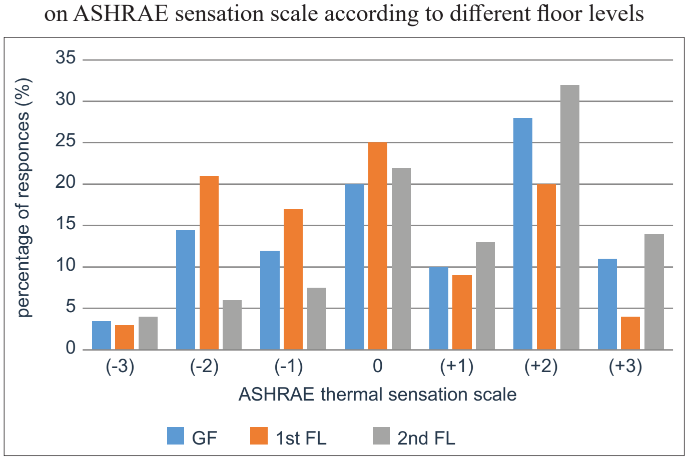


Figure 5: Thermal comfort assessment of apartment buildings based on ASHRAE sensation scale according to different floor levels

The thermal zones of the building were defined as a single apartment unit. It was hypothesized that each apartment behaves as homogeneous on its thermal performance. The separation of each thermal zone was assigned based on occupancy and similarities in thermal gains and losses, equipment usage, and orientation. The area for each apartment (Thermal zone) is 113.49 m^2 and the total area of the building is 1361.88 m^2 (113.49*12 = 1361.88 m^2).

The Opaque construction of the building and the material specifications were defined base on field survey and archival data. The construction set of a collection of materials was specified. It included many different construction materials types for different surface types, such as exterior walls, internal walls, windows, doors, partitions, etc. Design builder provides many default construction and materials that comply with code performance values.

The construction of the exterior walls was constructed of five layers as shown in Figure 8. The outer layer was stone, with a conductivity of 2.15 w/m.k and density of 2320 kg/m^3, thermal absorbance was 0.9, visible absorbance was 0.58 and roughness was 3-rough. The second layer was 7 cm concrete with conductivity

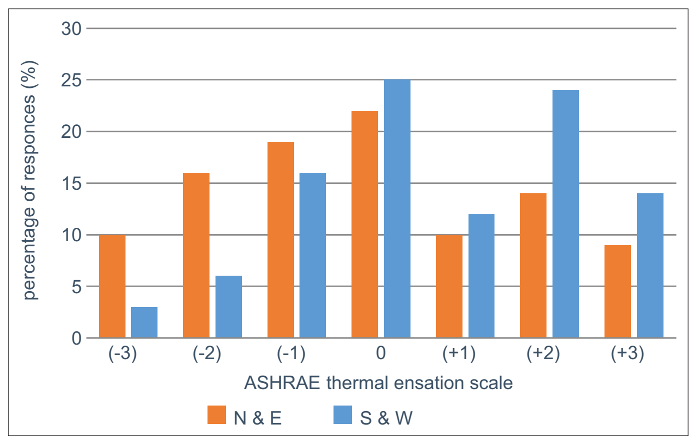


Figure 6: Thermal comfort assessment of apartment buildings based on ASHRAE sensation scale according to different orientations (south/west) and (north/east)

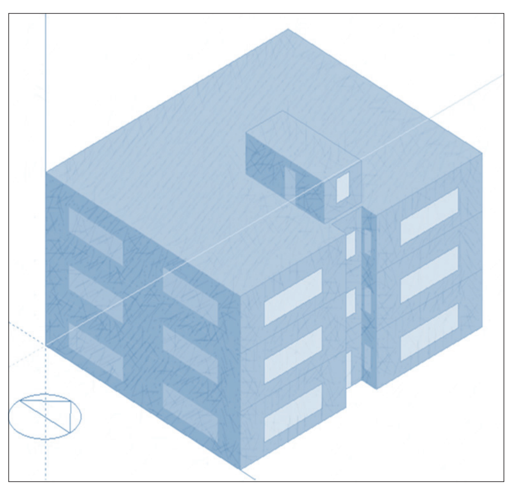


Figure 7: The geometry of the selected prototypical building is used for simulation

0.165 w/m.k, density 500 kg/m³, thermal absorbance 0.900, visible absorbance 0.600 and roughness was 3-rough. An air gap of 2 cm was the third layer. The fourth layer was a concrete block of 15 cm with a conductivity of 0.5105 w/m.k and a density of 1400 kg/m³. The internal layer was cement plaster of 3 cm with a conductivity of 0.725 w/m.k, density of 1760 kg/m³, thermal absorbance 0.900, visible absorbance 0.600 and roughness was 3-rough.

The roof construction, which was composed of six layers; the outer layer was 2.5 terrazzo floor with a conductivity of 1.8, density of 2560 kg/m³, thermal absorbance was 0.9, solar absorbance was 0.7. The second layer was a concrete screed of 7cm with a conductivity value of 0.7, and a density of 2100 kg/m³, thermal absorbance 0.9, and solar absorbance 0.85. A layer of 0.5 cm asphalt was used for the third layer and a layer of 5 cm of dense concrete was the fourth layer. The fifth layer was a hollow block with a conductivity of 0.19, density of 600 kg/m³, thermal absorbance was 0.9, and solar absorbance was 0.6. The internal layer was a dense plaster of 2 cm with a conductivity of 0.16, density of 600 kg/m³, thermal absorbance was 0.9, and solar absorbance was 0.5.

The window ratio to wall area was set as 30%. The glazing of the window was set as a single pane glass window with 6 mm thickness. The window height was1m, 1.5 m in width, and the sill height was 0.8 m. The construction of the window was painted aluminum frame of 5 cm thickness.

The lighting was set as the default generic lighting system with a suspended luminaire type with a radiant fraction of 0.420, a visible fraction of 0.180, and a convective faction of 0.400. It was assumed no lighting control was applied. The highest temperature approached 45°C between 2 and 3 pm on the selected date which is July, 15th. A big drop in temperature is after 8 pm, with 50.5% average annual relative humidity, which ranges from 36% in June to 69% in January.

Table 3 shows the simulation results of different blocks (floor levels) with different zones (apartment units). The table indicated the variation of energy consumption with the different situations of each apartment. The middle floor that has a northeast orientation required less energy consumption, while the unit in the upper floor facing south and west required the highest energy consumption. This is normal because of the exposure to the sun.

The location of each multi-family apartment within the building has a major effect on energy usage. All units have two shared walls and two exposed to outside conditions. The variability in consumption patterns depends on the level of exposure. The units in the upper level have direct exposure to the sun from two walls and the roof, while the units on the ground floor have exposure from two walls and the ground. On the other hand, units on the middle floor are protected from the upper floor and ground floor and take the benefit of cooling from both levels. This was presented clearly on electricity monthly and annually consumption, as well as the cooling usage. Table 3 and Figures 9 and 10 present these findings for the base case.

Table 3: Monthly energy consumption (KWh\m²) for different floor levels and different multi-family apartment orientations

	Ground floor	Middle floor	Upper floor
APT (N/E)	23.6	19.8	26.78
APT (N/W)	24.1	20.7	27.7
APT (E/S)	24.9	22.1	28.5
APT (W/S)	25.3	22.7	31.2

4. MEASURES AFFECTING ENERGY EFFICIENCY

There are several building configurations and measures that can be adopted to minimize energy consumption and improve the efficiency of building [35], these include:

- Orientation of building
- External wall construction
- Roof construction
- Window design and construction
- Lighting
- Cooling thermostat setting.

The procedure used was to take one factor as influential in energy saving while blocking other factors. This procedure would define the influential factors without considering the interaction effect among different factors.

Figure 8: Wall construction materials

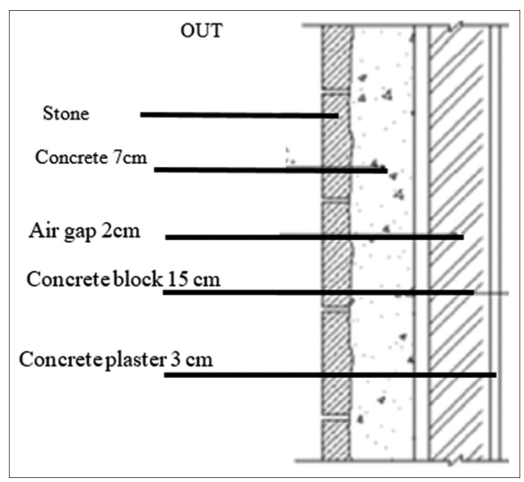


Figure 9: Monthly cooling load for different floor levels and different multi-family apartment orientations during July

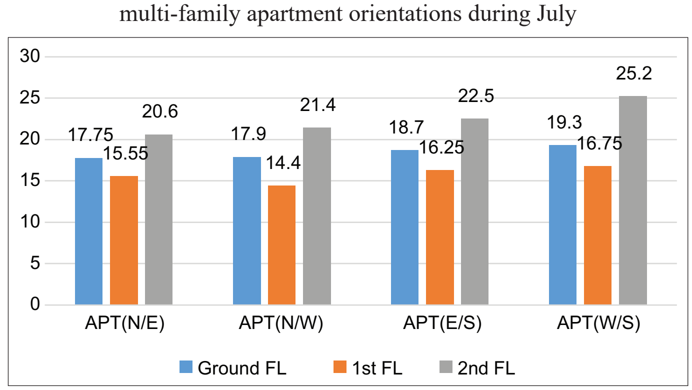
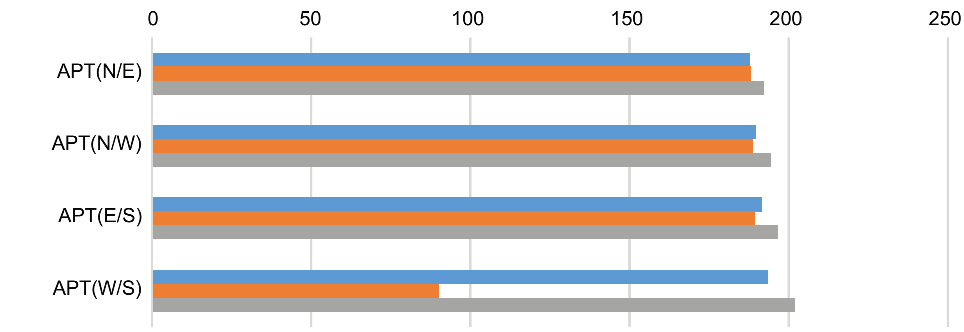


Figure 10: Annual energy consumption (KWh/m^2) for different floor levels and different apartment orientations



	APT(W/S)	APT(E/S)	APT(N/W)	APT(N/E)
Ground FL	193.5	191.7	189.7	187.9
1st FL	90.3	189.3	188.8	188.1
2nd FL	201.8	196.5	194.6	192.1

Ground FL 1st FL 2nd FL

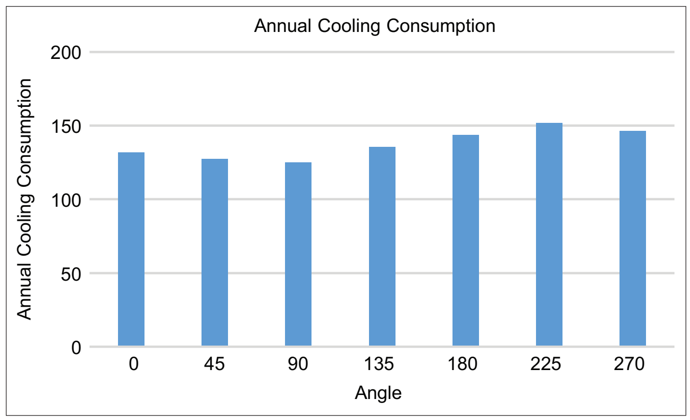
4.1. Orientation of Building

Orientation has a significant effect on building performance, the site orientation is the site plan view relative to North. Several orientation options were considered as shown in Figure 11; (0, 45, 90, 135, 180, 225, and 270). For the same multi-family apartment unit, these seven directions were applied to set the best performance in association with the best orientation.

The multi-family apartment, which is located on the middle floor and the longest façade facing the west direction, was selected to test the influence of different orientation angels on cooling loads. The results as follows:

It is noticed from the graph that angle 90 is the best performance for the selected apartment. This means that the longest wall faces the north and the shortest wall faces the east.

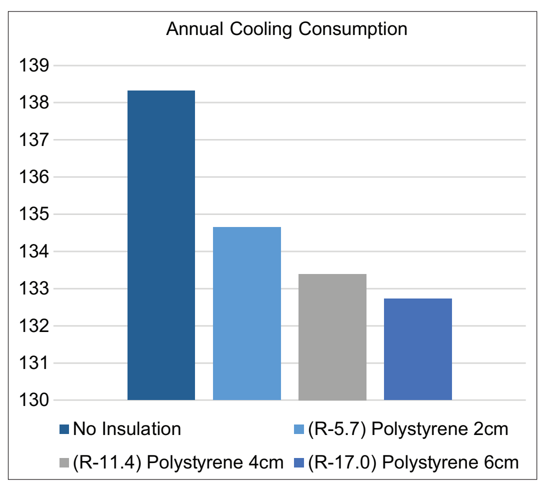
Figure 11: Annual cooling load per floor area with different orientations



4.2. External Wall Construction

The external wall construction which is in direct contact with the outdoor environment has an important role in the efficiency of the building i.e. the main cause for heat transfer resulting from outdoor-indoor temperature difference occurs through the building skin. The base case wall construction was described previously, while the modification in wall construction was on insulation thickness, which is because the more heat flow resistance the lower energy consumption and cost, and the best to improve comfort. Four scenarios were adopted: first with no insulation, second with RSI-1.0 (R-5.7) Polystyrene (2 cm thickness), third with RSI-2.0 (R-11.4) Polystyrene (4 cm thickness), fourth with RSI-3.0 (R-17.0) Polystyrene (6 cm thickness) [35]. The results showed that adding 6 cm Polystyrene will improve the efficiency of the building by 3.66%. As shown in Figure 12.

Figure 12: Annual cooling load per floor area (KWh/m^2) with insulation thickness of the external wall



4.3. Roof Construction

Roof construction is an essential part that has a great responsibility on annual energy usage and comfort level. After examining The base case of roof construction, cooling loads were calculated under different scenarios for several options of insulation were used: No insulation, RSI-1.0 (R-5.7) Polystyrene (2 cm thickness), RSI-2.0 (R-11.4) Polystyrene (4 cm thickness), and RSI-3.0 (R-17.0) Polystyrene (6 cm thickness) [35]. The results indicate in Figure 13 the saving of using 6 cm insulation for the roof will reduce the annual energy usage by 5.31% of total consumption while implementing 6 cm polystyrene insulation for both wall

Figure 13: Annual cooling load per floor area (KWh/m^2) with insulation thickness of the

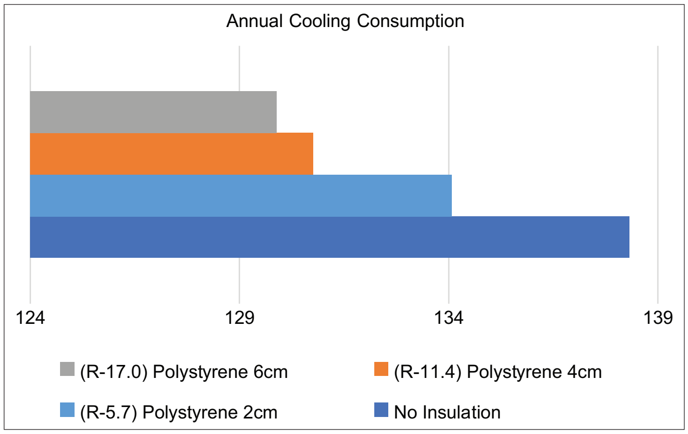
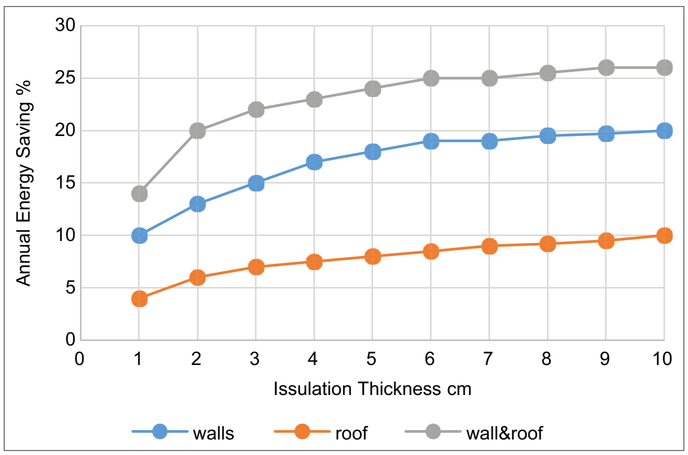


Figure 14: The percentage of annual energy saving by changing the insulation thickness for wall, roof, and wall and roof



and roof will enhance the annual energy saving to 25% based on the results in Figure 14.

4.4. Window Design and Construction

The window ratio to wall area (WWR) was set as 30%. Heating and cooling load can be reduced by changing the type of window glass and its ratio to the wall (WWR). The glazing of the window was set as single pane glass with 6mm thickness. Several scenarios were adapted to the possibility of saving by changing window configurations [36]. Window wall ratio was set as 10%, 20%, 25%, 30%, and 40% respectively. The design of the window was Single Clear (6 mm), as the base case, Single Bronze (6 mm), Single Low-e (6 mm), Double Bronze (6/6/6 mm), and Double Low-e (6/12/6 mm).

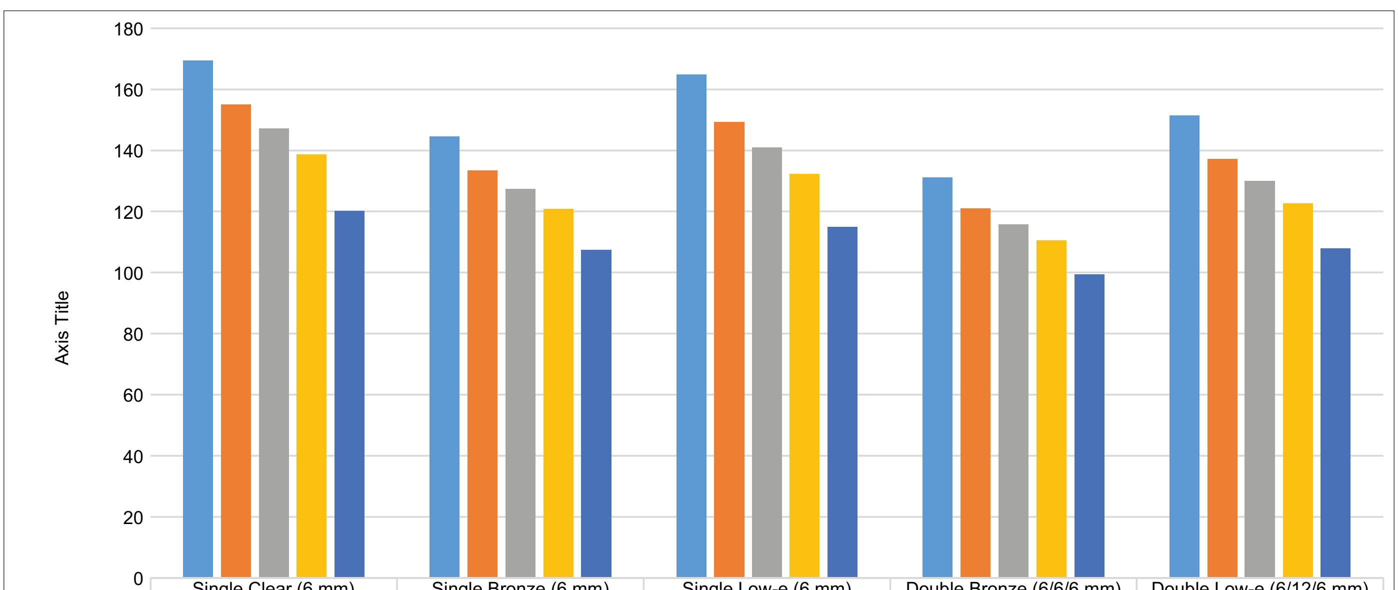
As shown in Figure 15 the best combination to achieve the best performance of the building, is to use double bronze glass with a thickness of 6/6/6 mm. The annual cooling consumption for this combination is 99.33 w/m^2. By using this type of design and construction of the window, it will save around 41.34% of total cooling consumption.

4.5. Lighting

The energy used for lighting inside the building is high, replacing traditional lighting fixtures and lambs with more effective ones will help to reduce the running costs and the overall impact of producing electricity on the atmosphere. Moreover, it decreases the heat produced within the main spaces, which will help to obtain thermal comfort easily in addition to other strategies.

The base case of lighting was set as the default generic lighting system with suspended luminaire type with a radiant fraction of

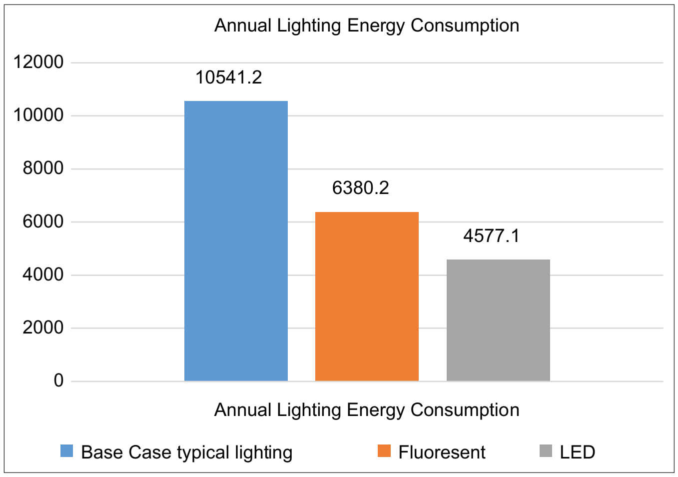
Figure 15: Annual energy consumption of building under different design and construction strategies of the window



	Single Clear (6 mm)	Single Bronze (6 mm)	Single Low-e (6 mm)	Double Bronze (6/6/6 mm)	Double Low-e (6/12/6 mm)
WWR = 40%	169.33	144.55	164.81	131.04	151.34
WWR =30%	154.9	133.47	149.17	120.89	137.06
WWR = 25%	147.01	127.36	140.8	115.78	129.87
WWR = 20%	138.57	120.87	132.18	110.48	122.61
WWR = 10%	120.16	107.37	114.88	99.33	107.8

0.420, a visible fraction of 0.180, and a convective faction of 0.400. It was assumed no lighting control was applied. Different options of lighting densities were suggested; the base case was Typical (7.6 W/m^2), improvement suggestions included; usage of fluorescent compact with lighting energy equal to 4.6 w/m^2 -100lux, radiant fraction equal to 0.42, and visible fraction equal to 0.180. The second strategy is using LED lighting system; lighting energy equal to 3,40 w/m2-100lux, and radiant fraction equal to 0.370, and visible fraction equal to 0.180. The findings are shown in Figure 16.

Figure 16: Annual lighting consumption with different light systems



The reduction of lighting consumption could save more energy by replacing the typical lighting system by using an energy-efficient system such as fluorescent and LED systems. The efficiency could be around 56.6%.

4.6. Cooling Thermostat Setting

Cooling setpoint temperature is considered the acceptable temperature to be used as a limit of comfort level for occupants. The evaluation of setpoint temperatures was based on 24°C, 25°C, and 26°C. The potential of saving is acceptable by raising the temperature by 2 degrees. It is around 18%. The finding is shown in Figure 17.

Figure 17: Annual cooling consumption with different set points temperature

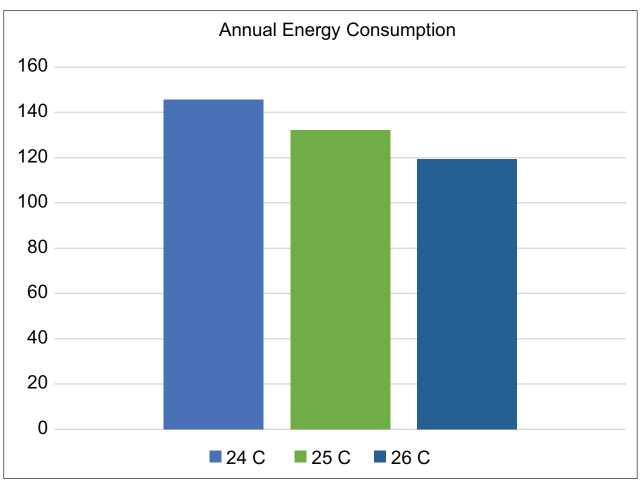
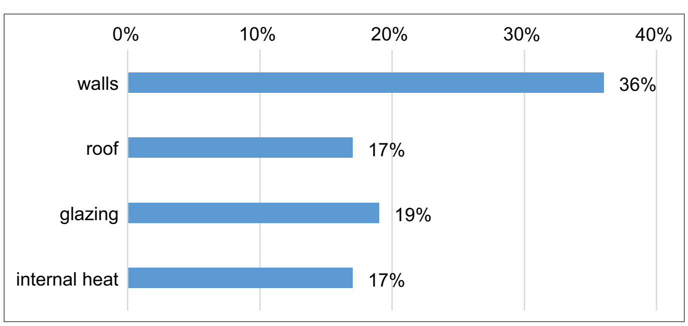


Figure 18: Percentages of Fabric components on total energy cooling loads



5. CONCLUSION

The contribution of each apartment's components in heat gain during the whole day is shown in Figure 18. It shows that glazing has a significant impact with fluctuation in day and night and sun movement. The building performance of the different multi-family apartment components varies for different floor levels (ground, middle and upper floor). It indicates the contribution in terms of heat gain for the glazing, external walls, roof, and floor.

The thermal performance of the selected apartment on the first floor varies with different orientations. It indicates that there is a difference in thermal behavior between southwest facing apartment and northeast facing unit.

There are several efficiency potentials to be used in newly constructed apartments. These include the adaptation of environmentally responsive design through careful adjustments of the location of the building. Good orientation will reduce the demands. Moreover, using appropriate building layout and geometry has a significant effect.

Designing and constructing the exterior wall is one of the major factors for saving energy. Using insulations with appropriate type and thickness will contribute to the reduction of energy use. Besides, the shape of windows and their size will affect energy efficiency. The size and type of glazing influence efficiency measures. A double or triple glazed system will reduce heat gain with a significant high percentage.

The use of efficient HVAC systems and appliances, as well as efficient types of lighting, will have significant effects on building performance. Also, an occupant's adoption of an energy-conserving attitude can improve energy efficiency and behavior changes such as adjusting thermostat settings and controlling appliances, devices, and lighting.

Comprehensive studies to retrofit and modify the existing multi-family apartment buildings is a persistent need, to enhance their energy consumption and performance, by using energy conservation methods (i.e. thermal insulation, double glazing windows, WWR, thermostat setting, with choosing the best geometry and orientation for the unit … etc.), with the need to include in future studies the act of applying appropriate shading devices and designing the surrounding landscape that will affect solar radiation. Appropriate painting of exterior walls and roofs with light colors will reflect solar radiation. Periodic maintenance for these layers is important as it affects the performance of walls and roofs.

This study is intended to serve as a foundation or guide for energy researchers, architects, and policymakers to fully understand the current state of multi-family residential apartments. And it is strongly recommended to focus on the rigorous need to rewrite building codes including energy consumption and performance as the main variable in design and to incorporate these studies and results into academic curriculums in Jordanian architectural design schools to avoid repeating the mistakes with the future architects.

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