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Assessment of Retrofitting Old Residential Buildings in Urban Districts: Expected Performance of Selected Energy Efficiency Measures

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Abstract

Developing solutions to face the climate crisis is becoming a challenge not to local and national governments but also to researchers and modern societies. Of these, energy efficiency of buildings is a key topic to control carbon emissions and enhance sustainability. This study contributes to the very limited literature on energy efficiency retrofitting of old buildings in urban areas, in Jordan as well as the neighboring Arab countries. The considered case study is the capital city of Jordan, Amman, with the aim of investigating possibilities and economics of selected retrofitting energy efficiency measures in old residential buildings. The analysis presents the thermal performance of different types of dwellings and energy demand based on real data obtained from official surveys and statistical reports. The developed simulation model examined the impact of each of the studied energy efficiency measures on different types and sizes of housing units under same operating conditions and comparing results with the base case. The adopted retrofitting technique of existing envelops, i.e. external walls and final roofs, depends on boosting thermal resistance, thus, the overall heat transmission coefficient will be reduced. In case of windows, the new double-glazed windows should decrease heat losses as well as the solar heat gain coefficient under different conditions. The maximum savings could be generated in small housing units, in a multi-family building, which represent the major fraction of dwellings, in Amman. This group is the most attractive and challenging due to poor performance of existing envelops and being occupied by low-income families. The stimulated results suggest that such group of houses have remarkable potential of energy savings, of about 22%, resulting from insulating external walls and replacing old inefficient windows. Unfortunately, final roof insulation and replacement of basic appliances, i.e. washing machine and the fridge, would have relatively long payback periods, which made such options not very attractive from the economic point of view. To conclude, there are good opportunities to more green residential buildings through retrofitting programs aiming to control energy demand and expansion in using available renewable energy systems.

Keywords: Energy Efficiency, Retrofitting, Old Buildings, Sustainability, Residential Sector.

1. Introduction

1.1. Background

The government of Jordan (GoJ) has recently given energy efficiency a major weight when taking decisions that may result in a net increase of future energy demand in the country. To achieve such a strategic goal, long list of energy efficiency acts and by-laws, standards and specs have been introduced, during the last ten years, with the aim to control the increasing national energy consumption and reducing carbon emissions by promoting energy efficiency and renewable energy technologies in all sectors including buildings. In this regard, the GoJ has signed and adopted almost all the international and regional conventions relating to environmental protections. Among these are the Biological Diversity (1992), Climate Change (1992), Desertification (1994), Stockholm (2009), and Paris Convention on Climate Change in 2016. Although, Jordan, as a non-Annex I country with low annual GHG emissions, has no commitments for GHG emission reduction targets, the GoJ believes that there is a good potential for mitigation. During the last few years, there were excellent developments regarding Renewable Energy (RE) and Energy Efficiency (EE) policies, strategies, laws and by-laws formulation. As a result, there are now ongoing activities related to implementation of RE projects, especially for central and distributed power generation. Private sector engagement in climate change activities is still not at the expectation level but slowly improving, and good progress is taking place in investment in RE in particular. However, the overwhelming majority of climate initiatives and projects in Jordan are still donor-driven, especially under the prevailing economic conditions and the increasing problem of refugees as well as high concerns regarding security and stability.

The construction and building sector is one of major sectors in Jordan from the economy and financing point of views, in

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addition to its social dimension as main absorber of jobs and work in the country. The buildings and public works, including the property services sector contributed to the Gross Domestic Product (GDP) by 20% in 2021 [1], which is equivalent to an added value of JD 4,500 million (the fixed exchange rate is One USD=0.7085 JD). Thus, the building and construction activities contribute directly to the economy and development of the private sector in the country. In this study, a straightforward evaluation of some energy efficiency measures for existing buildings is considered to assess the potential of reducing annual energy consumption and resulting emissions from retrofitting old residential buildings in urban areas. The research paper is presented in five sections, including the previous short introduction and problem definition, which represents 1st section. The 2nd section contained literature review, while in section 3, the data sources and adopted methodology are outlined. Followed by detailed presentation of energy consumption and building stock in Amman in section 4. The technical and economic analysis and of the selected retrofit energy efficiency measures in old buildings, as well as the environmental dimension, are discussed in section 5. Finally, conclusions and recommendations are presented in section 6.

1.2. The Problem

The Hashemite Kingdom of Jordan witnessed a rapid population growth, since its independence and the unification with the West Bank in early 1950s. Since 1967 and the occupation of the West Bank by the Israeli forces, more floods of refugees into the country were seeking for safety. Followed by the civilian war in Lebanon, then the Iraqi conflict which ended by the invasion in 2003 by US troops and recently the Syrian war, all these have led to unplanned increase in population especially in main cities. In addition to a gradual shift of the population from rural to urban areas. For example in 1952, the total population of West and East banks was 586 thousand, of which more than 50% living in rural areas and small villages. Forty years later and after the invasion of Kuwait, in 1990, the population jumped to 3.5 million with 70% as urban population. The recent statistical book, in 2021 [1], showed that population touched 11 million and most of them (90.3%) are living in urban areas, putting the kingdom on top of the list of most urbanized countries in Asia and the world. About 5 million, or slightly more, are living in Amman, the capital city. In the near future, the country is still open and exposed to the political and social conflicts in the region, which may involve new waves of refugees into Jordan. Thus, the country, and in particular main cities including Amman, will experience growing strains due to continuous degradation of agricultural land because of informal settlements, improper and low quality urban services, overcrowding and traffic congestions as well as lack of green space and recreation facilities. Such challenges will require careful policies and additional resources to deal with and correct such up normal urban changes successfully. This requires the involvement of the government to empower and enhance the capabilities of local authorities to respond quickly and effectively to such urban changes immediately. According to the latest study about population and residents in the Kingdom, the estimated total population would be close to 13 and 19 million in 2030 and 2050, respectively [2]. The key issues resulting from increased population and urbanization are the shift of large proportions of the population to modern centers with high incomes, requiring new residence and higher rates of water and energy consumption to sustain their new urban life. Under such conditions, it was almost impossible to create an energy-sustainable community or even address the impacts of energy poverty and unaffordability of poor households' experience on their daily living difficulties. The low-income families, in urban areas, are more vulnerable to the negative impacts of global warming effects and the associated natural disasters.

Based on the Ministry of Energy and Mineral Resources statistics, most (99.9%) of the population has access to the electrical grid, including refugee camps. The major consumer of electrical power, in Jordan, is the residential sector with a sharing ratio of more than 46% of total electricity consumption in the country during the last five years: in 2021, such ratio exceeded 48%. It consumed 25% of the total final energy consumption in the country [3]. Traditionally, the industrial sector was the largest consumer until late 1990s, and since then the residential sector jumped on the top of the list. Such shift in the consumption pattern was due to the structural changes in the economy and unexpected increase in the population because of sequential breaks of refugees from neighboring countries: Jordan is still considered as a destination for forced waves of migrants from the nearby-prolonged conflict areas. The latter was directly reflected on the number of annual permits for new constructions and/or adding new dwellings to the existing buildings to absorb the increasing numbers of residence and refugees, especially in main cities, including the capital city of Amman. However, large number of added dwellings, during the last forty or fifty years, on old buildings and refugee camps, in main cities, were built illegally: without obtaining the required permits from local authorities. More importantly, they lack energy efficiency measures and are characterized by poor thermal insulation and low quality windows and doors, which contributed indirectly to the increase in energy demand [4], In addition to the prevailed low energy prices in the past century and hot and dry climate in summer. Therefore, improving energy efficiency of old and low-income households is considered a crucial move in developing a more sustainable system.

1.3. The Local Climate

Although, Jordan has no shore on the Mediterranean Sea, it enjoys the Mediterranean weather: cold and wet winter, dry and hot long summers. However, there are three different climatic regions:

- The western mountains, where Amman and other main cities are located, and the majority of the population live, have moderate weather conditions prevailing around the year: cold (-2 ºC to 5 ºC) and rainy winters with occasional snowstorms, but pleasant summers and relatively acceptable temperatures (25 ºC to 35 ºC).
- The eastern plateau, or the desert, which is the vast majority of the country but low population density, has a mild weather: extremely hot (35 ºC to 45 ºC) and dry summers, and experience very cold (-4 ºC to 4 ºC) winters with rare or little rain and large variation in temperature between day and night. Most of the population, in this region, are working as cattle ranchers and/or farmers especially in the north close to the Syrian border and the south east towards the border with Saudi Arabia.
- The Jordan valley and Aqaba Gulf, which extends from north to the south of the country on the western region, i.e. Jordan Rift Valley below sea level down to the Red Sea. This region is unique since the lowest point on earth exists, i.e. the Dead Sea, with an altitude of about 400 m below sea level. The weather conditions in this region are different: very hot (35 ºC to 48ºC) and dry summers but warm (8 ºC

to 20 °C) winters, with fertile soil, and the eastern water canal represents the agricultural basket in Jordan. Most of population in this region are farmers and/or post-harvest chain. While Aqaba is the only seaport, in Jordan, on the Red Sea.

Such differences in climatic conditions have a significant influence on type of building and used materials in these regions. Consequently, energy demand and consumption in the residential sector is greatly affected. For example, in the western mountains, space and domestic-water heating is required during winter, while in Jordan Valley and Aqaba, space cooling in summer needed to overcome high ambient temperatures. The average solar radiation, around the year, is about 5 to 7 kWh/m^2 day and about 3,000 hours per annum [5]. In this research, the focus will be on the housing sector in Amman with some emphasis on old buildings and retrofitting effects on energy consumption.

2. Literature Review

Renovation of old buildings, from energy efficiency point of view, is considered as an inter-disciplinary assignment that requires a comprehensive investigation covering the building conditions, environmental, and societal context. Previous research papers mentioned different aspects and effects of various key factors throughout the consequent phases of buildings renovation. By implementing energy efficiency retrofits on existing old residential buildings, there are some challenges in applying suitable methods to convert an existing building to low or zero-energy consumption. Currently, there is no national regulation or building code that defines or describes buildings energy retrofitting in Jordan. Thus, more efforts are still needed to develop such regulations or construction codes which should address the necessity of applying retrofitting options as measures to enhance energy efficiency and cut GHG emissions. Such desired new codes should integrate buildings' retrofitting with new and renewable energy systems as well as encourage innovation to achieve sustainability [6,7]. However, these codes will be effective only when enforced and executed by the local governments, municipalities and concerned institutions, including but not limited to Jordan Building Council, Jordan Engineers Association and the Contractors Association. It was reported that different countries have enforced building energy directives which led to a net decrease in buildings' energy consumption rates, e.g. in China savings of between 13-22%, in India about 17-42% and in the European Countries 6-22% [8].

As the building sector is a major contributor to GHG emissions, with about 33% global energy final consumption, there is an increasing attention among researchers and politicians, in both of developed and developing countries, to understand the impacts of building energy regulations on the performance of buildings. Researchers have investigated the progress in the development of regulation of energy in developing countries and its consequences on energy efficiency through a comprehensive survey, which covered 95 countries, and reported that 42% of developing countries lack existence of energy standards [9]. While most of the European countries have mandatory energy standards for new constructions and renovation of existing buildings. New buildings energy standards exist in various countries in the Middle East and North African, including Saudi Arabia, Jordan, Egypt, Algeria and Morocco [10,11]. Nevertheless, energy regulations for existing buildings are still as proposals describing minimum requirements for different types of building envelopes, natural lighting and minimum performance rates for air conditioning systems. Other researchers examined the impact of applying building regulations on energy consumption rates for new residential buildings in Gainesville, Florida - USA, and they found that by increasing the strictness of applying the building regulations, energy consumption decreased by 4% and the payback period was about 6 years [12]. Hanna, 2010, has conducted a study that covered most of Arab Countries to assess the impact of energy codes on various building elements such as walls and roof materials, window size and glazing type, etc. The results confirmed that by applying code requirements on wall and roof insulation, shading device and glazing type; the rate of energy consumption could be reduced by 60% [13]. The economic and environmental impacts of energy efficiency programs associated with new and existing buildings were evaluated in the Kingdom of Saudi Arabia [10]. It was concluded that an energy efficiency retrofit program targeting only the existing residential buildings could reduce electricity consumption significantly.

Apart from energy regulation and plans to cut emissions, improving energy efficiency of poor households that would help breaking the cycle of poverty, gained increased interest during the last decades. Some researchers reported that low-income families often forgo some life necessities, such as medical treatment and foodstuff; to cover the increased cost of energy bills [14-17]. Other researchers studied economics and reasons behind low adoption of energy efficiency retrofits, including modern and efficient appliances, in poor households [18-20]. They concluded that vital macroeconomic benefits flowing from the energy efficiency scenario, including higher GDP and employment and the main obstacles are classified into three groups. These are (i) economic, (ii) administrative and (iii) behavioral barriers; including lack of savings and inability to obtain a loan or credit to finance the needed upgrade. In addition, the low-income people are uncertain of future earnings [21]. To overcome such difficulty, some European countries, developed and implemented subsidy programs, e.g. special grants and soft loans, for the adoption of energy saving measures in vulnerable households [22-24].

As the buildings sector, in Jordan, is a major contributor to GHG emissions due to heavy dependence on fossil sources, the adopted governmental plans aimed at increasing utilization of low-cost and less polluting renewable energy sources as well as enhance energy efficiency in various sectors of the economy [25,26]. These will ensure avoiding burning further fossil fuels in the future to satisfy the increasing energy demand. In previous papers, as stated earlier, the researcher investigated the relationship between poverty, energy consumption and environment as well as prospects of energy savings in the residential sector [27-30]. Unfortunately, the local research activity related to energy efficiency in buildings is not strong enough and few research papers were spotted in open literature. Most of these research papers were based on simulation of new buildings in Jordan. Hassouneh et al., studied the effect of glazing types and orientation on energy demand of new apartment buildings in Amman, Jordan [31]. Jaber and Ajib also discussed the optimum window type and its size, from both heating and cooling loads points of view in different climate zones: two in Jordan (Amman and Aqaba) and the 3rd in Germany (Berlin) [32]. They reported that the most widely used type of windows, in Jordan, is the single-glazed with hallow aluminum frame. Hee et al., discussed the role of window glazing on the energy and daylighting performances of building and concluded that selecting a glazing for window system is still a crucial issue since it should balance visual and energy aspects [33]. Goussous et al., studied heat gain and losses through the roofs, in Jordan, and concluded that a green roof consisting of clay and grass has better thermal performance than a conventional roof [34]. Al-Hinti and Al-Sallami H [35] studied the potentials and barriers of energy saving in Jordan's residential sector through thermal insulation and reported that complete absence of serious enforcement of building codes is a major barrier. Alshorman et al., investigated the validation of Jordanian green building model based on Leadership in Energy and Environmental Design (LEED) and reported that higher efficiency could be achieved when considering thermal efficiency and double glazed windows from the early beginning of construction [36]. Bataineh and Alrabee analyzed the impact of some energy efficiency measures on the energy performance of different types of residential buildings and reported that the payback period of the selected measure is encouraging [37]. Hikmat et al., [38] inspected the economic and computational potential of various integrated passive and active design systems, for a building in the northern region of Jordan, using a dynamic building energy modeling and simulation software under local climatic conditions. Abu Qadourah at el., studied improving the energy performance of the typical multi-family buildings utilizing passive design strategies [39]. The simulation results proved that it is possible to reduce the annual energy demand significantly by introducing passive design strategies. All published work, in Jordan, discussed energy efficiency in new constructions. However, the study in hand is the first attempt to study the impacts of retrofitting of old buildings in the country. It aimed to fill partially the gap of information pertinent to the feasibility of selected energy efficiency retrofitting measures of old residential buildings within the capital city of Amman. Such measures include envelope thermal insulation, window(s) replacement, and employing modern high efficiency appliances such as refrigerators, washing machines instead of the existing obsolete units.

3. Data Sources and Methodology

This research study was conducted based on official reports and data published by concerned governmental institutions. Energy and electricity consumptions were obtained from the Ministry of Energy and Mineral Resources (MEMR), National Electric Power Company and Energy and Minerals Regulatory Commission. Population and housing details were taken from official reports that were published by the Department of Statistics (DOS), in particular the Annual Statistical Book, 2021 [1], the recent field survey of housing in Jordan and the population and residents analysis during 2015-2050 [40], in addition to the latest information pertinent to the residential sector within the Greater Amman Municipality [41].

To examine the impact of a specific energy efficiency option or a certain technology on the energy performance of an existing building, a top-down or bottom-up engineering modeling analysis is used in many countries around the world [42]. In several countries, large-scale building energy efficiency programs have utilized the bottom-up approach [43-47]. The study in hand will be based on simulating the existing condition, in Amman city, to perform the bottom-up analysis of selected retrofitting alternatives and check their influence on energy efficiency of existing old buildings. The first step was defining the renovation item or scenario, then discuss possibilities and assess the potential savings and involved costs on sample basis. Each of the selected measures tested individually to assess the possible reduction of annual energy consumption. Finally, the best combinations that will ensure minimizing the costs and reducing consumption of the residential sector in Amman are discussed. Again, this study is intended to assess the impact of selected retrofitting energy efficiency measures and technologies on old building's energy performance using a straightforward and detailed simulation taking into account local climatic conditions prevailing in the city of Amman. The evaluation includes potential impacts on energy and/or electricity consumption and possible reduction of GHG emissions. Moreover, a life cycle cost analysis is carried out to determine the most suitable option of energy efficiency measures that can be implemented to improve the energy performance of existing buildings. The analysis is limited to old buildings that were built more than 20 years ago (i.e. before the year 2000) within the city of Amman. It should be remembered that the aim of this investigation is not to re-design or propose a new design for energy efficient buildings.

4. Energy and Buildings

4.1. Energy Consumption in Households

Historically, the growing population, urbanization, and direct and indirect subsidies have contributed to the continuous increase in energy and water demands. The high-energy bills, in the residential sector, could be attributed to excessive consumption or inefficient energy use. The latter is completely true in the case of low energy efficiency buildings which involves many factors including but not limited to type of building and its material, roof insulation, air leakage, type and quality of home appliances, etc., as well as consumers' energy use habits. Altering consumption behaviors towards a more sustainable lifestyle needs continued public awareness and training programs by all concerned stakeholders, including governmental agencies, professional associations and non-governmental organizations, suppliers, vendors and academic institutions. In the current research, more focus on existing buildings and possible energy efficiency retrofitting options is carried with the prime aim of reducing energy poverty problem and improving the in-door environment, health and welfare by consuming required amount of energy but in a more efficient way. However, discussing the reasons behind hidden energy poverty is out of the scope of the study in hand since these are more related to socio-economics, but not to the physical housing conditions, e.g. building envelop which is examined in the current analysis.

According to the published recent statistics by the Ministry of Energy and Mineral Resources, in 2021, the buildings sector is the 2nd largest single consumer of energy in Jordan, with a sharing ratio of around 25% of the national energy consumption, after the transport sector [48].This is due to the rapid development in the country during the last few decades. Thus, the buildings sector could be considered as the single largest contributor, after transport, to GHG emissions, with approximately 30% of the national emissions [49]. In addition, the construction sector is responsible for a large proportion of natural resources consumption, including fresh water and building materials, and producing large volumes of solid wastes during the construction phase and later when occupied by people. Therefore, the building sector should be in the center of any plan aiming to enhance sustainability and efficiency of resources utilization in the country.

Since 1990, the rate of new added buildings, including residential, commercial and office blocks, was about 18,000 per year during 1990-1999, then slowed down during 2000-2010 to about 12,000 building per year and in the last decade raised up again to the previous rate [50]. Currently the average annual growth rate of number of buildings is about 1%, bearing in mind that each residential building consists of at least 8 apartments. The increasing tendency of building construction can be seen in Fig. 1, classified according to number of housing units in a building. It is clear that after 1980, the trend moved from single house towards multi-apartments buildings, especially in Amman. This is mainly due to the high increase in the price of organized land and specified for residential purposes within the municipal boundaries. More importantly is that more than 60% of building stock classified as old constructions since these were built before the year 2000 and about 200 thousand (i.e. 20%) buildings with an average age of 50 years or more [40]. Almost half of these are single houses, i.e. known locally as local old-style house called dar or traditional single-family house.

The average growth ratio of residential buildings during the period 2016-2020 was 2.2% with an annual construction cost of about US$ 3.0 billion [1]. Assuming the business as usual scenario, without alteration of prevailing conditions, the country will need an additional new 150,000 housing units to be constructed over the next seven years, until 2030, to accommodate the projected growth and urbanization. Furthermore, increasing wealth would lead to higher space requirement, consequently the escalation in the number of household appliances, with implications for future energy consumption. Such development had a significant impact on the consumed energy, which is in a rising trend since 1970s. The energy consumed in the residential sector could be distributed according to final use as shown in the following Table 1. Others include, but not limited to, water pumping, reverse osmoses (RO) units, irrigation and elevators, etc.

Table 1. Distribution of energy consumption in households

Final use	Ratio (%)
Heating domestic water	15.0
Household appliances	19.0
Lighting and TV	12.0
Cocking	6.0
Space heating and cooling	45.0
Others	3.0

In previous work, the researcher investigated the relationship between poverty, energy consumption and environment [51], prospects of energy savings in residential space heating [52], possibility of using renewable energy sources for space heating in the household sector [53] and the potential of energy savings in the residential sector [54]. This work is oriented to investigate the impact of retrofitting of old residential buildings on energy consumption within the capital city of Amman.

4.2. Building Stock

Amman is an old city, established in the stone-age before 8,000 years B.C. In 1921, it became the capital of the newly established state, i.e. Emirate of East Jordan, then the Hashemite Kingdom of Jordan. The city witnessed up-normal growth, during the past century, due to the political and armed conflicts in the region, which led to waves of refugees into the city. The 1st influx was in late 19th century by Qajaqs and Chechens before the 1st World War and followed by the Palestinians after the 2nd World War. Then waves from nearby Arab countries flooded the city: Iraqis in 1990s, Syrians in 2011 and from Yamen and others. Thus, the population of the city jumped from less than 200 thousand inhabitants, in early 1950s to about 5.5 million, in 2021 [2], and its area was increased from less than 50 km^2 to approximately 800 km^2 [55]. In other words, almost 50% of the Kingdom's population live in Amman, with a high density of about 7,000 inhabitant per km^2 compared with other cities, where the population density is far less reaching one hundred per a square kilometer in the southern regions. Although, the Greater Amman Municipality (GAM) management is working towards achieving sustainable development and managing urban growth development. Nevertheless, several gaps still exist, including but not limited to the lack of policies for urban design and evaluation criteria for such policies, poor public participation at all levels and the institutional challenges represented by human, financial and technological resources [56]. Such obstacles will diminish the ability of the local authority to improve living standards and quality of life as well as providing the basic urban services effectively.

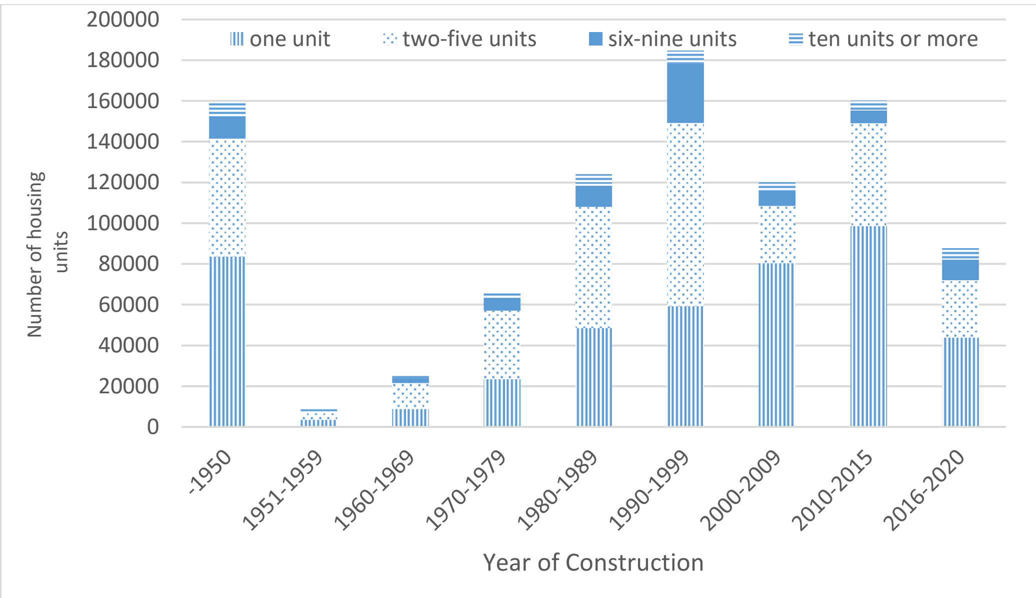

Figure 1. Housing stock classified according to year of construction and number of units in each building

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According to the recent census, conducted in 2015 by the Department of Statistics [40], and published annual data concerning new buildings and occupancy permits up-to 2020 [57], Jordan had 937 thousand buildings. Of which the large segment (81.2%) in urban districts and the remaining (18.8%) in rural areas. The residential buildings form the major fraction of about 85% of total buildings and the residual includes office, governmental and municipal, commercial and services, warship, cultural and sports buildings. About 42.4% of the total building stock in Amman. The vacant buildings represents low percentage of less than 3.0% of the building stock in Jordan and most of these are residential apartments and houses in main cities. As shown in Fig. 1, multi-apartment buildings represent the major fraction of newly added constructions since the year 2000, especially in Amman, i.e. the capital city of Jordan. The total number of dwellings, for living, in Amman city is around 1.15 million, representing almost 59% from the total housing units in Jordan. The composition of the building stock, during the period 1950-2020 in Amman distributed according to the year of construction is shown in Fig. 2. As can be seen clearly that old buildings, with an average age of more than 20 years, forms the major fraction of about 60%. While those built before 1970, in the old districts of Amman, still account for more than 40% of the building stock in the city.

Traditionally, the most common construction in the wealthy districts was based on stones and concrete, but the low-income areas used brick walls and concrete without roof thermal insulation. A small fraction of buildings had water insulation for the final roof in order to prevent water penetration into houses during winter months. Most of new buildings have a reinforced concrete structure and walls made of local stones (3-5 cm), concrete (10-15 cm) and hallow bricks (10 cm). However, in low income districts, such as eastern and southern parts of Amman, and rural areas, the cement-brick walls are still used as the main method of building construction. The recent field survey showed that the most widely used material in building construction for external walls is the stone cuts, i.e. natural calcium carbonate rocks from local quarries, as shown in Table 2. Temporary structures such as caravans, hangers, tents and marginal erections are not included since these did not exist within the boundaries of GAM. As illustrated in Fig. 2, the largest portion of the building stock was built during the last four decades without taking into account energy efficient measures. Thus, there is a genuine need of intervention to make these buildings complying with the national codes and regulations through introducing and implementing some energy efficient measures. Recently the GoJ, represented by the National Building Council, developed and launched the Green Building Guide in 2015, as none-compulsory code,and only for new buildings[58]. This guidance code focuses on energy and water efficiency, comfortable and healthy indoor environment and best practices of building management, but will not lead to real savings in the near future due to its none-obligatory status.

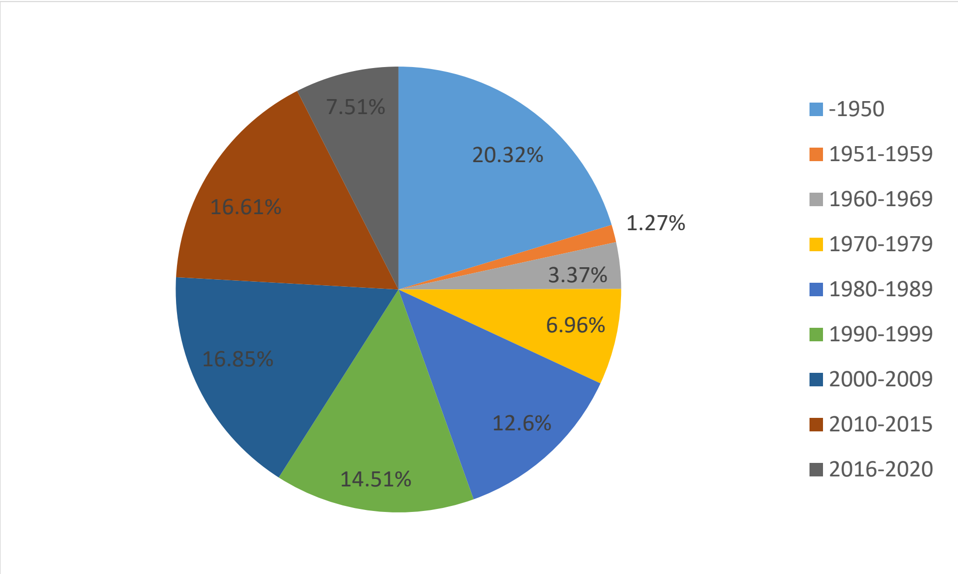


Figure 2. Distribution of housing stock according to the year of construction

Table 2. Distribution of existing buildings stock in Jordan and Amman according to the type of material used in the construction of external walls (%)

Type of Material	Stone		Stone & Reinforced Concrete		Concrete		Cement Bricks		Mud Bricks		Others	
Type of Building	J	A	J	A	J	A	J	A	J	A	J	A
Multi-Floors	30.8	51.5	16.8	15.2	24.5	22.9	27.3	10.1	0.0	0.0	0.6	0.3
Dar	11.2	32.9	8.9	11.4	27.9	34.3	50.0	20.9	0.5	0.3	1.5	0.2
Villa	91.5	96.6	4.0	1.8	1.7	0.9	2.7	0.7	0.0	0.0	0.1	0.0
Enterprise	16.3	32.6	9.8	10.3	26.5	26.2	38.9	18.5	0.7	0.6	7.7	11.8
Hotel	52.9	79.0	13.3	8.7	13.5	7.6	16.5	1.8	0.0	0.0	3.8	2.9

J: Jordan, A: Amman, Dar: Independent conventional house, Villa: Consists of two floors and basement, Enterprise: Includes institutions, hospitals, cultural buildings, sport facilities, establishments, fire-brigades, etc.

However, this is true in case of multi-floor buildings, villas, enterprises and hotels but in independent single-family houses, i.e. dar (a detached house) consists only of one floor, the story is different. Cement hallow and/or solid bricks, with a standard thickness of 10 or 15 cm, are used as main material for external walls. About 50% of these houses were built with external walls made of cement bricks in Jordan, while such ratio is much less in Amman (20.9%). This could be attributed to many reasons, the most important one is that the buildings follow regulation within GAM and being the relatively higher income of people living in Amman. Equally important, is the price of land in Amman which equal almost tens folds compared with other parts of the country that does not encourage building simple small houses as in rural areas. Mud bricks are rarely used in urban areas and limited to a minor fraction of small conventional houses in the open suburbs. These are common in agricultural and cattle raising areas, usually out of the municipal boundaries built as individual rooms with mud roofs reinforced by branches from trees. Usually the mud bricks and roofs is made of local clay mixed with straw to provide needed firmness and solidity. Others include curtain systems or (i.e. glazing); metal cladding (i.e. alucobond); steel structure; pre-fab or pre-casted; etc., in commercial and office buildings envelop. It can be said that, new buildings in Jordan and Amman, external walls are built as sandwich using stone from outside, with an average thickness of 3 cm, then a layer of concrete mix of about 10-15 cm and a 10 cm hallow cement-brick from the inside. A thin layer of about 2 cm of cement plaster used to cover the internal side of cement-bricks. Thermal insulation for external walls and roofs are still not widely used, although local building codes made it mandatory for all types of buildings including individual houses since late1980s. On the contrary of the private sector, all state buildings and governmental large residential projects, i.e. Abu Nusair City (late 1980s) and the Generous Residential Project commissioned in 2010, developed and executed by the Ministry of Public Works and Housing were thermally insulated. According to recent field survey, only 21% of all residential buildings employed thermal insulation for external walls, mainly in urban areas [40]. Unfortunately, roofs are not insulated with relatively high all overall heat transfer coefficient of about 2.2 W/m^2 C, or even more (3.0 W/m^2 C) in the case of a reinforced concrete slap with an average thickness of 12-15 cm. While such coefficient should not exceed 0.56 W/m^2 C for the building or house envelop, including the final roof [59]. Currently, less than 15% of the building stock in Jordan is energy efficient, based on estimates by experts in this field, with almost zero renovation efforts to improve the efficiency of existing buildings. There is a misunderstanding among public about roof thermal-insulation, since large number of people still consider cement tile or screed to slope, i.e. a cement-mix layer to create slope to the drain, on the roof as sufficient insulation. As a waterproof or insulation, it prevents water accumulation on the roof, but cannot be considered as a method of thermal insulation because the overall heat transfer coefficient of such layer is very high and does not help to prevent or reduce heat transfer through the roof. Thus, it would be impossible to reach the desired thermal comfort for the residence in summer or winter. It can be said that currently using roof thermal insulation is on a narrow scale and mainly found in public and commercial buildings. Hence, the majority of existing old residential buildings, in Jordan, are characterized by low energy performance and high heating and cooling demands [53,60]. In this research work, some energy efficiency retrofitting measures of old houses aiming to enhance performance and consequently reducing consumption and the resultant emissions will be discussed in the next section.

5. Retrofitting of Old Houses

5.1. Energy Efficiency in Households

Housing or adequate shelter is not just a roof over someone's head. It should provide enough space; security and privacy; structural stability and reliability; space heating and ventilation; lighting; and needed basic infrastructure. These include access to potable water supply, sewage network and solid waste-management facilities; electrical grid; acceptable and healthy environment; and adequate and accessible location with regard to work and basic facilities. All of these should be available continuously and at reasonable and fair cost, especially electrical power and clean fuels as main sources of energy in urban areas. Without the availability of these resources, the existing dwellings, in poor urban districts, will pose a range of severe and long lasting humanitarian and environmental difficulties not only for the present residence but also for future generations. Therefore, the provision or availability of appropriate and affordable housing units will remain a key issue for the GoJ.

Energy consumption intensity in the residential sector is greatly influenced by the individuals' daily energy-related behavior, available appliances and technology, socio-economic aspects and housing characteristics. Thus, reducing energy consumption in the residential sector, require addressing all these issues in addition to paying special attention to energy poverty among low-income households. Usually, high-income families enjoy living in large dwellings, which are equipped with latest technologies and efficient appliances, while on the contrary; low-income families live in leakier apartments, flats or houses and use old-fashioned home appliances with low energy efficiency [61]. Thus, poor households are more likely to be involved in risky behaviors inside their houses since they cannot afford to pay bills for utilities. Different researchers have examined the use of low quality energy sources, for space and water heating, by poor families. They reported that such sources could threaten the health and life of occupants, especially children and women, by causing lung and respiratory diseases and cancer due to the indoor air pollution and/or misuse of energy sources [51,62,63]. Thus, the low penetration of advanced technologies and absence of building energy efficiency among low-income households reflects energy inequality issues in the society, which is a serious and annoying problem that should be on the top of politicians' agenda. There is no doubt that energy efficiency improvements can potentially help reduce rates of consumption and the need for energy resource development as well as cut the associated carbon emissions at relatively low cost.

5.2. Retrofitting Energy-Efficiency Measures

There is no doubt that high-energy efficiency measures are the straightforward answer to relieve the deteriorating energy misfortune, in Jordan, and to reduce pollution intensity, represented by GHG emissions. As stated earlier, to reduce consumption and improve energy performance of old buildings of more than 20 years, in the city of Amman before the year 2000 A.C., the most common two different building types are studied and simulated. These are the single-family house (Dar) and the multi-family building, which includes two to five housing units. The selected retrofitting options, as 1st phase or level, in this study are:

- Adding a layer of thermal insulation to external walls and final roof.
- Replacing old windows.
- Replacement of obsolete home appliances (refrigerator, washing machine and A/C units).

It is assumed that in practice, such measures could be split into different programs individually or any combination, e.g. (i) thermal insulation and windows replacement and (ii) changing main home appliances, such as fridge and washing machine, and implemented or supported by MEMR, i.e. Renewable Energy and Energy Efficiency Fund. Such future could be coordinated with GAM as part of its plan to enhance the sustainability of the city. The idea behind dividing these measures into separate packages is to study the impact of each level individually and use the saved money from one measure to cover a portion from the cost of another measure and so on. In this study cost energy efficiency measures, such as reducing inside heating temperature in winter, or increasing cooling set point temperature in summer and using weatherization tapes to reduce air infiltration are not discussed. These may be considered as supportive items during the project implementation to assist the funding process of the ruminated retrofitting measures. The basic assumptions considered in the current study are:

- No physical changes to the orientation, shading or external design of existing old buildings.
- All operating conditions kept unchanged, including ambient temperature, air change rates, furniture, inside and outside paints, curtains, outdoors, operating time and residents' behaviors, etc.
- The studied old housing units are located in urban areas and within the same climatic zone.
- Family size, influence of guests, type of space heating and cooling system, lighting, cocking, water pumping, etc., are not taken as key variables.

The simulation analysis is the first of its kind since it discusses old building retrofitting and carrying out for the considered different types of houses, i.e. dar or traditional single-family house, villa and a multi-family building. The proposed retrofitting measures are modeled and evaluated separately in the following section. The simulation models are developed for two types of existing old residential dwellings, taking into account the construction details and different materials used in external walls and the roof, types of windows, and the average annual electricity consumption of employed old and new high efficiency home appliances. The distribution of housing units in Amman according to the construction material used in external walls is shown in Table 3. Buildings classified under mixed use, e.g. residential and commercial, are ignored in the current study since these are located down town and usually occupied by foreigners as well as represent very small fraction of the building stock in the city.

The old method of roof construction in old houses was based on a concrete slab, reinforced by steel bars with an average density of about 25-30 kg steel per square meter, of about 12-15 cm thick. The new method was introduced in early 1980s, by using hallow cement blocks of about 18 cm height and reinforced ribs with a total thickness of approximately 25 cm, without the additional screed to ensure slop to the drain. The average area of roof and external walls, excluding windows, area of different types of housing units in Jordan are as shown in Table 4.

Based on the conducted field survey, early 2023, of a random sample of about 100 old housing units covering different districts, in Amman, the specs and thermal characteristics of the existing old buildings' envelop are summarized in Table 5. Bearing in mind that out-doors and other items of the building's envelop are not included in the current study. The average values of the overall heat transfer coefficient (U) are calculated using published data pertinent to local construction materials and methods.

Table 3. Number of housing units in Amman according to type of building and construction material of external walls

Type		Stone& Concrete	Stone & Reinforced Concrete	Concrete	Cement Block	Total
Housing unit in building		326130	96140	145165	64078	631513
Independent house	Traditional house	132193	45909	137555	83895	399552
	Villa	53134	969	489	409	55001
Total		511457	143018	283209	148382	1086066

Table 4. Average area of roof, external walls and windows

Type		Roof (m^2)	External Walls (m^2)	Windows Area (m^2)
Housing unit in building		100	30	9
Independent house	Traditional house	160	120	20
	Villa	350	250	32

Table 5. Existing old building materials and thermal characteristics

Item	U (W/m^2 C)
1-External Wall a-15cm stone, 15cm concrete & 2cm mortar b-7cm stone, 15cm reinforced concrete & 2cm mortar c-2cm mortar, 20cm concrete & 2cm mortar d-2 cm mortar, 15 cement bricks & 2cm mortar	 2.85 3.33 3.05 2.75
2-Final Roof -15 to 18 cm hallow ribs, 12 cm heavy concrete, 10 cm screed to drain & 2 cm mortar	3.77
3-Windows, single glaze (6 mm thick) with hallow aluminum or 90° angle steel frame, no integrated shading device	5.68

The average annual energy consumption, on site, of each type of housing units in Amman is obtained from the recent household surveys conducted by MEMR and DOS as well as the mini field survey [1,40,64]. Nevertheless, the needed primary energy to generate, transmit and distribute electrical power as well as energy consumed in the refinery are not considered in the current analysis. The central heating systems, fired by diesel fuel, are used only in villas and a very small fraction of traditional houses, while kerosene and LPG stoves are widely used in the residential sector as shown in Table 6. LPG is used for cocking, space, and water heating. In this study, it is assumed here that on average each family, regardless of its size, about 16-18 cylinders per year are used for cocking and the remaining for space heating using portable LPG heaters or modern fireplaces fueled by LPG. The latter is mainly used by high-income families living in villas or independent house, while mobile stoves by poor households. However, there is an overlap between the employed heating systems, i.e. two sources, or more, used for space heating in different types of houses in Jordan [53]. Central-heating systems, firing diesel fuel or bulk LPG, are used by wealthy families and housing units that equipped with such schemes represent less than 10% of the total housing stock [12]. Recently, there was a significant increase in using A/C units for space cooling and heating and the most widely used sizes are one and one and half ton refrigeration. While the majority of middle and low-income households rely on traditional portable un-vented kerosene and/or LPG stoves. Poor households do prefer kerosene heaters since these could be used simultaneously for space heating and cooking as well as heating water. Nevertheless, it should be remembered that such unvented domestic devices discharge combustion gases within the closed space causing direct exposure to toxic gases such as carbon monoxide.

The relatively low rates of annual fuel (Diesel, LPG & Kerosene) consumption are due to the fact that households do not heat all spaces in the house and for the limited use-time. In other words, space heating is not used around the clock except in villas and houses that equipped with central or under-floor heating systems. It is a common practice, among middle and low-income households in Jordan, to heat one or two rooms, while the rest of the house kept unheated. Such practice is attributed to the high cost of energy compared with the degrading monthly income [40,53]. In case that all spaces in the house would be heated, then fuel consumption should be doubled or tripled compared with the reported average figures in Table 6. The ratio of energy used for space heating to the total annual energy consumption is around 36% and 39% in multi-family buildings and traditional houses, respectively. While such ratio jumps to about 50%, or more, in villas due to larger heated spaces and for longer periods. Although the average annual energy consumption is higher in old traditional houses and villas, but the calculated energy intensity (kWh/m^2 yr) is much higher in housing units in multi-family buildings. This could be attributed to the low quality of the building envelop and low efficiency of the employed appliances as well as the lack of awareness. In the current investigation, regardless of the employed space heating and/or cooling system, the reduction in heating/cooling load was based on adding a new layer of insulation material to external walls and the final roof as well as replacing existing old windows and main home appliances (i.e. refrigerator and washing machine). This was accomplished through answering a key question: what is the typical annual energy consumption of each category of the studied houses and the expected reduction in consumption when applying the proposed retrofitting measures? The anticipated annual energy savings, of each of the proposed measures, are evaluated taking into account different types of residential buildings in Jordan and an implementation program over a period of six years (2024-2030) to cover at least 10% of the existing old buildings stock, i.e. about 10,000 housing unit per annum. The adopted model considers the following key retrofitting activities:

1. Heating/cooling load difference due to the installation of a new layer of suitable thermal insulation material on external walls and the final roof,
2. Replacing single glazed windows,
3. Substituting the old fridge and washing machine by efficient appliances, with rating of A^+, or higher, according to the local energy efficiency standards (Jordanian Technical Regulation for Washing Machines 2104:2013; Air Conditioners 2108:2013; Refrigeration appliances 2101:2013), which are solely based on energy directives issued by the European Council, i.e. European Standard: EN 14511 & EN 14825.

In the future, installing a single PV module, of about 500-600 W, on the external wall to support the operation of the electric water heater, specifically for multi-housing buildings where no enough space available on the roof to install solar water heaters, or a sharing PV system should be discussed. The annual energy consumption is computed based on average consumption per type of the studied houses excluding energy consumed in cocking, lighting, ventilation, ironing, dish washing machines and dryers. Then a simple economic assessment is conducted, assuming soft or green financing made available for low-income households by the concerned governmental agencies. Thus, simple payback period (SPBP) is presumed, without taking into account the interest and inflation rates.The adopted work procedure, in the study in hand, is shown in Fig. 3.

$$EC = \sum_{k=1}^{3}(NH * AVC) \quad (1)$$

$$ES = (EC)existing - (EC)retrofiting \quad (2)$$

$$GHG = \sum_{k=1}^{3} NH * EF \quad (3)$$

$$SPBP = \frac{ES}{CC} \quad (4)$$

Where EC: Energy Consumption (kWh/yr); k: Building Type; NH: Number of Houses, AVC: Annual Average Energy Consumption (kWh/yr); ES: Energy Savings (kWh/yr); GHG: Green House Gas Emissions (ton CO_2/yr); EF: Emission Factor (kg CO_2); CC: Capital Cost (US$)

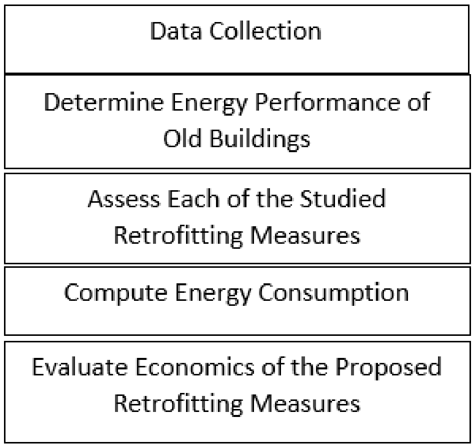


Figure 3. Summary of adopted work procedure

5.2.1. Thermal Insulation

The practical experience with low-energy houses revealed that the desired comfort room temperature is attained by using highly efficient components and systems. For example, good levels of insulation of the building envelop, windows, waste heat recovery for heating and/or cooling and integration of renewable energy sources, etc. In this section, insulation of external walls and final roofs of old buildings is examined. As discussed previously, most of old buildings, in Amman, are classified as high thermal mass structure due to the fact that envelop consists of heavy materials such as stone and high density concrete, with framing structure creating thermal bridges without proper insulation. Thus, adding a layer of thermal insulation is a necessity to achieve minimum comfort level and sustainability of housing. In theory, there are two options to install the required thermal insulation: externally or internally. From the thermal resistance point of view, fixing new insulation on the outside of external walls is much better than having the insulation on the inner side. Because of keeping the internal thermal mass of walls, reducing heat losses and at the same time eliminating solar gains through walls. However, adding an extra layer to the outside façade of walls may require special permit from the concerned department at GAM since it will affect the external view of the building and diminish the minimum allowed legal distance/space between buildings, in addition to low resistivity to harsh climatic conditions and possible damages due to unexpected human activities, unless made of hard materials such as metal cladding and thermal insulation or low-density cement hallow bricks or any similar stuff having low thermal conductivity. Additionally, it demands higher costs of installation compared with fixing insulation internally due to interference with existing openings, extensions and cantilevers.

Previous studies have shown different types of insulation materials that are employed in various parts of buildings' construction, such as fiberglass blankets, low-density cement bricks, foam materials, extruded polystyrene, biomass based materials and structural insulated panels. All of these having almost similar thermal conductivity factor with slight differences, but each insulating material has specific characteristics and is applied differently. The most widely used, in external walls of new buildings in Jordan, is the extruded polystyrene at different densities and thicknesses, as a sandwich between the layers of concrete and hallow cement bricks [37,52]. This is due to good features with respect to its thermal (0.9 – 1.5 m^2 C/W) and moisture resistance and good durability as well as relatively low cost. In addition to the complexity of insulating all outer walls in one operation, which requires approvals and participation of all tenants and/or occupants of the residential building. To avoid such complications and the needed legal authorization as well as minimizing the implementation cost, fixing the insulation material on the inner side of the external walls and final roof is assumed in this study. Equally important is the flexibility of implementation, especially in multi-families buildings, since each family-house has the choice to install the recommended new insulation or not. While in the case of external insulation, all outer walls should be insulated in one operation. Table 7 summarizes available various options of insulating external walls and the final roof internally. Using light density blocks, i.e. thermos-bricks, with low thermal conductivity, is excluded here, to insulate the external walls, since it requires a lot of work inside the house, reduce the internal space significantly and high cost.

As can be seen that the overall heat transfer coefficient (U), for both of external walls and the final roof, could be reduced significantly by adding proper insulation material on the internal side with a maximum thickness of 6 cm at a reasonable cost. Consequently, the heating and/or cooling loads would be less; thereby the annual energy consumption is reduced as well as the resultant emissions. The major disadvantage is the slight loss of internal space, which is estimated to be around 2% and 4% of the room area in case of one wall and two walls in a single room, respectively. The average cost of each type of insulation appeared in Table 7 includes the cost of material, preparing the site and installation excluding finishing and painting as well as governmental taxes, i.e. sales tax which equals to 16% of the cost. The average cost of painting the newly installed sheet of thermal insulation is about 5.0 US$ per m^2 which should be added to the listed costs to obtain the final cost. However, in the case of using the decorative wood boards to insulate external walls, there is no need for painting and the cost remains as shown in Table 7. The calculated annual energy savings for different options of installing new layer of thermal insulation in old housing are summarized in Fig. 4 (a-Multi houses, b-Traditional house & c-Villa) according to the type of existing external wall and the adopted insulation material. As can be clearly seen that options 2 (1.2 cm gypsum board, 3 cm polystyrene & 2 cm cavity) & 3 (1.8 cm MDF wood board & 2 cm cavity) are the best since these would generate the highest annual savings compared with other studied options. However, the relatively high cost of option 3, will have a negative impact on the computed payback period, i.e. 2.5 to 3 times that of option 2 of around 4 years. Unfortunately, other options have very long payback periods, of more than 15 years, which would make such choices as unattractive for retrofitting the studied old houses.

Table 6. Average annual energy consumption in old households

Type		Electricity (kWh/yr)	Diesel Fuel (Lit/yr)	LPG* (Cyl/yr)	Kerosene (Lit/yr)	Total Energy (kWh/yr)	Energy Intensity (kWh/m^2 yr)
Housing unit in building		6,500	-	36	265	14,895	149
Independent house	Traditional house	9,650	-	45	360	20,420	128
	Villa	12,900	1650	36	-	34,595	99

*LPG cylinder contains 12.5 kg of butane/propane used for cocking, space and/or water heating

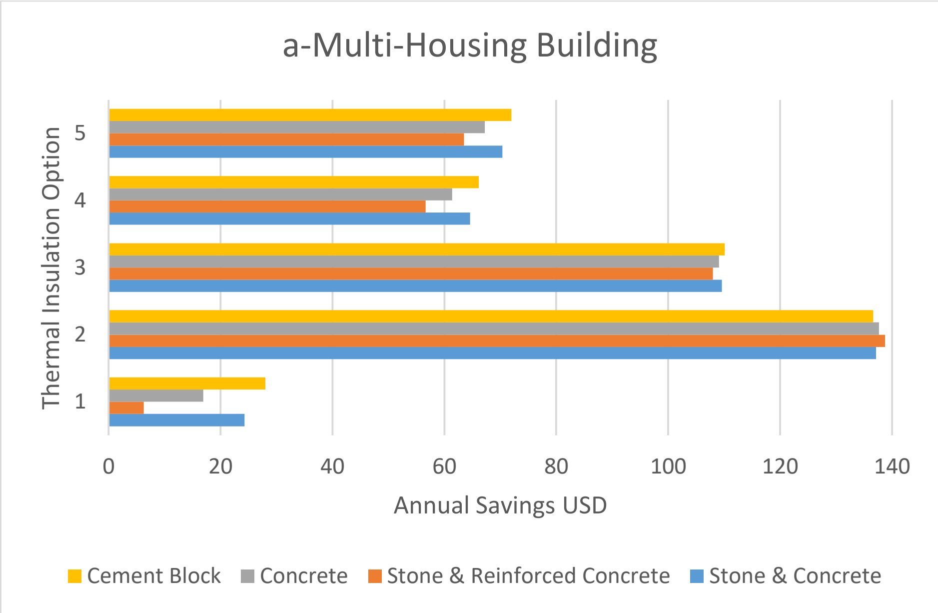
Table 7. Thermal characteristics of new inner insulation material and costs

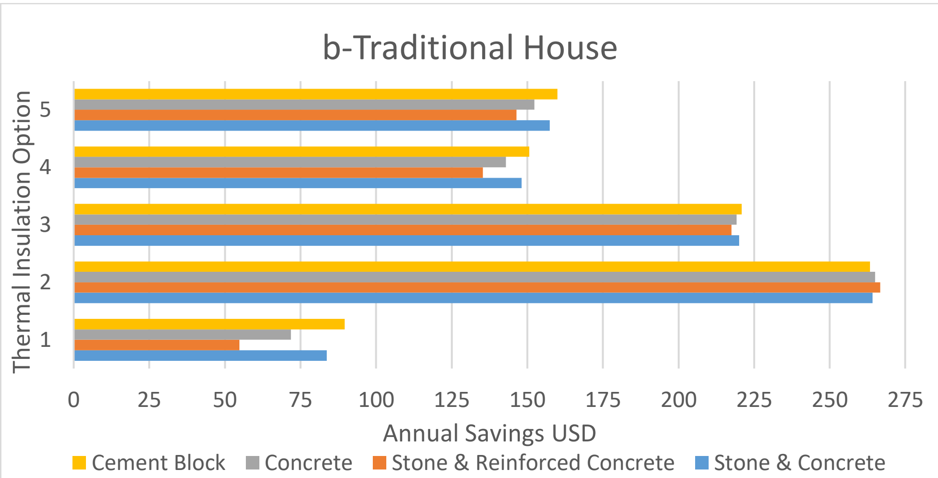
Item	U (W/m^2 C)					Average Cost** (US$/$m^2$)
Existing Wall Type	a	b	c	d	Average	
1-External Wall						
-1.2 cm gypsum board attached directly to the inner surface	2.39	2.73	2.53	2.32	2.49	11.0
-1.2 cm gypsum board, 3 cm polystyrene & 2 cm cavity	0.26	0.23	0.25	0.27	0.25	14.0
-1.8 cm MDF wood board & 2 cm cavity*	0.78	0.81	0.79	0.77	0.79	34.0
-1.5 cm cement board & 2 cm cavity	1.63	1.78	1.69	1.60	1.68	25.0
-Decorative wood board including air cells of 2x2 cm	1.52	1.65	1.58	1.49	1.56	20.0
2-Final Roof						
-1.2 cm gypsum board attached directly to the inner surface					3.01	11.0
-1.2 cm gypsum board, 3 cm polystyrene & 2 cm cavity					0.73	14.0
-1.8 cm MDF wood board attached directly to the inner surface*					1.75	34.0
-1.8 cm MDF wood board and 3 cm polystyrene*					1.02	37.0
-1.5 cm cement board & 2 cm cavity					1.89	25.0

*MDF wood board should be resistive to dampness and anti-fungus
**excluding the cost of final finishing and painting as well as the sales tax

Due to the relatively long payback periods, the Net Present Value (NPV) is introduced here as a tool to assess the economics of the studied measure, assuming zero inflation and energy prices remains as prevailing in 2023, interest rate is 4% and the lifetime of new internal walls around 15 years. The results showed that the NPV of insulating external walls equals approximately US$ 6,000; 2,000&16,800 for a house in multi-housing building, traditional house and villa, respectively. Similar analysis applies to the final roof, as condensed in Fig. 5. Again option 2 will produce the highest annual savings, but with longer payback periods, of more than 10 years for multi-housing buildings and reaching 45 years, or more, in case of traditional houses and villas. The NPV of roof insulation is negative in all cases, including option 2. Such results, i.e. the negative NPV and extreme long payback periods, will not be abided by any financial institution since these exceeding all limits. In case of a commercial loan, at a higher interest rate of 8%, is arranged by the concerned governmental institutions through commercial banks for public to insulate houses and replace windows, the results of NPV are not encouraging. Because all values became negative except insulating the external walls remained positive under same operating conditions, i.e. US$ 4,000; 295 & 8,900 for a house in multi-housing building, traditional house and villa, respectively. From a commercial point of view, it is practical to concentrate on the insulation of external walls of multi-housing buildings since pertinent economics are more attractive.

Although, insulation of final roofs is important, but economics are not in favor of such a retrofitting measure. Thus, in case there are some funds made available in the future, as grants or soft loans to enhance sustainability, by JREEEF and/or GAM, it is recommended to start a project aiming to insulate external walls of multi-housing buildings in Amman due to the involved low cost and reasonable payback period. Equally important is that such project may be considered as indirect support to the low-income families living in old buildings. In addition, such a program will help in creating new jobs for young engineers and technicians, which will have a positive impact on the increasing unemployment in the country.





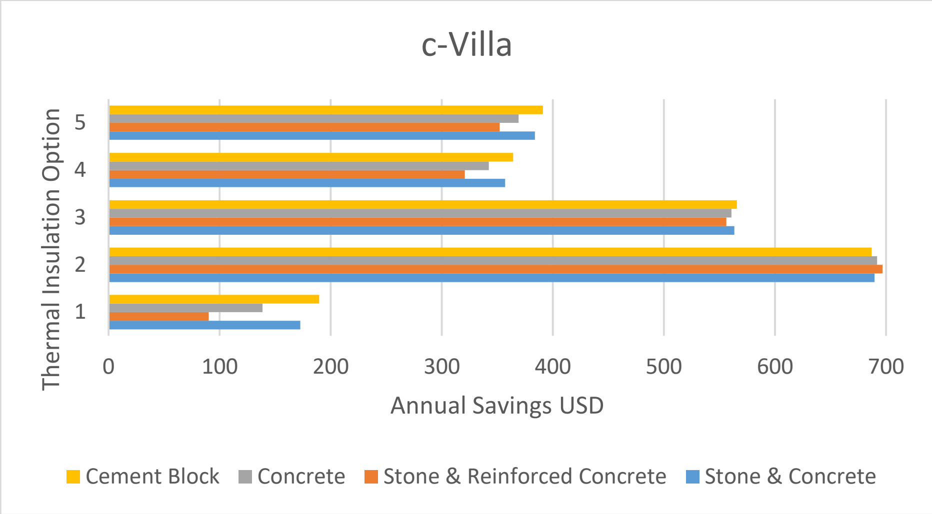


Figure 4. Calculated annual energy savings for external walls

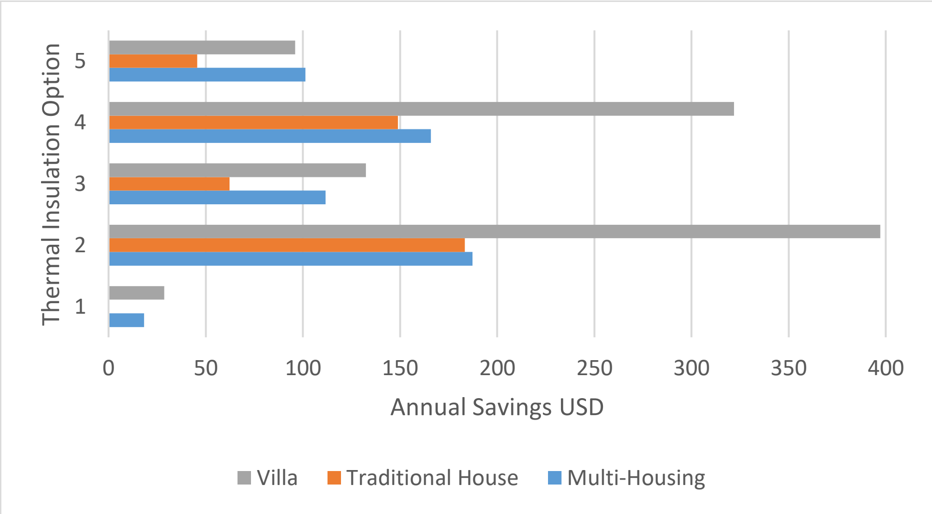


Figure 5. Calculated annual savings for final roofs

5.2.2. Windows Replacement

The energy performance of a commercial or residential buildings are very dependent on its envelop, particularly the windows which are responsible of 20-40% of wasted energy in the building [65]. To reduce heat losses and/or heat gains, windows area, in a building, should be minimized depending on the orientation and region. Taking into account, allowing the penetration of natural light into different spaces of the building. A study conducted by Jaber and Ajib in 2011 [32], showed that most windows of old and new residential buildings, in Amman, are single glazing with standard sliding rectangular hollow aluminum frame. Such window characterized by its high ratio of air infiltration and low energy performance, e.g. high U-value of about 5.6 W/m^2 K, especially when a thin glass of 3 mm used. Replacing the existing single glazed, aluminum framed window by a PVC low-energy double glazed window, of 6/12/6 mm, filled with Air or Argon, will enhance windows performance and reduce heat losses and solar gains, regardless of direction, bearing in mind that the maximum heating demand occurred at the northern windows, due to low solar incident radiation at this direction. While the southern direction induced the lowest heating energy as being the recipient of high solar incident radiations. In the market, there are several types of glazing such as selective coating, tinted, reflective and low-emissivity (low-E). The latter is clear, moderate or low solar gain and heat loss and is suitable for different seasons and directions. Triple-glazed widows allow less solar gain and reduce the thermal transmittance; however, the cost is much higher than double glazed windows. The thermal characteristics of the existing and double glazing widows are summarized in Table 8 [33].

Table 8. Characteristic of windows

Item	Single Glazed	Double Glazed	
U-Value	5.68	2.83	1.4
SHGC	0.855	0.775	0.589
Gas Fill	-	Air	Argon

SHGC: Solar Heat Gain Coefficient

The computed savings of windows replacement, under same operating conditions irrespective of orientation and the ratio of windows-to-floor area, are based on standard double glazed filled with air as summarized in Fig. 6. As can be seen that the SPBP in the case of multi-housing building is encouraging compared with the other two types of buildings.

The calculated NPV for windows replacement of a house in a multi-family building is about US$ 1,500, while having negative values in the case of traditional house and villa. Such results are not encouraging and simply attributed to the needed high costs that are almost twice that of insulating external walls. Argon filled windows will generate more savings; however, the cost is higher and double-glazed is more available and affordable. Further savings in lighting, cooling and energy could be obtained when using the insulated glazing with low-E coatings, especially in commercial and office buildings. This is because the accomplished energy savings through small cooling equipment may be sufficient to meet the required high installation costs.

5.2.3. Replacement of Home Appliances

Previous studies showed that the Jordanian market is flooded with different types of electrical appliances, especially the inefficient ones since these usually offered at lower price. Poor households, living in old multi-housing buildings rely on second-hand and outdated, inefficient appliances. Thus, the monthly electricity bills are relatively high and exceeds the tight energy budget due to excessive consumption by the basic old and deteriorating appliances. Hence, low-income families are indeed the ideal recipient of new and efficient appliances with low consumption rates. In one hand, they really in need of a single dollar generated from energy savings, but on the other hand cannot afford to pay more for buying energy efficient appliances. The higher cost of efficient appliances is a major obstacle and remains as a challenge to provide funds or subsidies in order to encourage costumers purchasing more energy efficient home machines. To overcome such serious difficulty and find possible solutions, future research may be oriented to study and analyze different thinkable options, including the market and vendors as well as supporting the local home appliances industry to acquire advanced technologies.

In the current study, two home devices are considered the fridge and washing machine to be replaced by highly efficient appliances of Grade A$^+$ or higher. The energy efficiency level of a washing machine and the refrigerator are taken from the local market for tested appliances according to the Jordanian technical regulations (washing machine 2104:2013 and the refrigeration unit 2101:2013) as shown in Table 9.

Table 9. Energy efficiency of main home appliances

Item	Old	New	Annual Savings
Washing Machine			
- Load (kg)	8	8	-
- Water Consumption (Lit/yr)	5750	2500	3250
- Electricity Consumption (kWh/yr)	500	260	240
- Average Purchase Price (US$)	265	350	-
Refrigerator			
- Capacity (Lit)	329	329	-
- Electricity Consumption (kWh/yr)	585	306	279
- Average Purchase Price (US$)	585	725	-

Real consumption will vary according to the family size, daily usage, etc., and will be slightly higher than the rated values. Assuming same conditions including equipment size and the daily operating schedule, the annual generated savings in each house could reach 500 kWh, i.e. at least US$ 70.0 per year. In addition to about 3.0 m^3 per year, or more, of potable water and peak demand shaving, which are not assessed in the current study. From a pure economic point of view, financing the replacement of old home appliances may not be attractive. However, when considering the social factors and other benefits, such as required investments to upgrade the distribution grid and reduce the peak demand, the program could be more likeable. Future research should investigate ways to increase the availability of advanced technologies, in the market, at reasonable costs and the behavior of households with respect to acquiring energy efficiency retrofitting measures. Again, this requires the development of governmental support programs and further improvement of regulations and enforcement of codes related to energy efficiency in buildings.

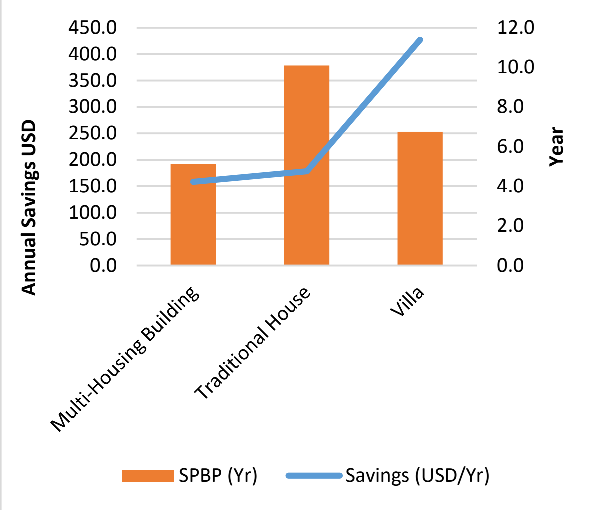


Figure 6. Economics of windows replacement

5.2.4. Avoided GHG Emissions

The calculated annual possible avoided GHG emissions resulting from the implementation of the feasible energy efficiency retrofitting measures in different types of dwellings are summarized in Table 10. The average yearly reduction per house, in a multi-family building, would reach 850 kg CO_2/yr, without taking into account energy savings of water pumping due to the reduced water consumption in highly efficient washing machines.

Table 10. Associated reduction of GHG emissions

Item	GHG Reduction (kg CO_2/yr)
Insulation of External Walls	
- Housing Unit	300
- Traditional House	560
- Villa	1,500
Windows Replacement	
- Housing Unit	345
Efficient Home Appliances	225

To sum up what was discussed in this research that insulating external walls of housing units represents the first option in a retrofitting plan of old houses. Such measure is promising, easy to implement and enjoys good economics compared with other studied options having relatively long payback periods. The obtained saving results are in agreement with reported figures by other researches [36,66,67]. However, in practice such results may not be achieved 100% due to some limitations and barriers. The most important barriers that may retard the implementation of reported retrofitting energy efficiency measures are the availability of detailed data and information regarding the general condition of old houses, existing neighborhood, knowledge about the existing building stock, lack of retrofitting codes and the existing legal gaps in housing rental and talents regulations. The latter is extremely important in the case of rented houses due to the fact that the talent-law forces the talents to obtain approvals from owners or landlords before conducting any major change in the housing unit. Bearing in mind that, in Amman, more than 35% of housing units are not owned by occupants' and rented on monthly basis, with an average monthly charge of US$ 200-350, without furniture [2]. Most of these dwellings (98%) are apartments or small housing units, consisting of two or three rooms, in multi-family buildings [10]. Equally important is that significant fraction of multi-family buildings is shared by the father and his son(s) and their families, which is a local custom in Jordan to expand the building vertically by sons. Thus, before starting any renovation program of old houses, all legal obstacles should be eased and removed by the concerned governmental institutions, including GAM, to allow successful implementation of energy efficiency retrofitting measures aiming to enhance efficiency and sustainability as well as integration of renewable energy systems within envelops of residential and office buildings. Finally, as stated earlier, there is a good fraction of houses not used by owners since they live permanently outside Jordan, and they rather consider the place, in Amman, as vacation home. Such segment of the community should be considered and separate these houses when implementing a retrofitting program of old houses.

6. Conclusions

Energy in buildings is a hot subject due to the increasing pressure on politicians and scientists in order to reduce energy usage and consequently GHG emission rates. Thus, new building regulations consider aspects pertaining to energy monitoring and efficiency in both of new and existing buildings. However, in Jordan, as other developing countries, regulations and codes of energy efficiency retrofitting of old buildings are still absent and there is a real need to work hard towards developing and enforcing such standards and rules very soon. This research examined the impact of applying a set of selected energy efficiency retrofitting measures on the performance of old buildings in Amman as possible solutions to reduce consumption as well as emissions to the environment. Different types of existing residential buildings are studied with the prime aim to enhance efficiency and sustainability of old housing buildings under the prevailing conditions in Amman. The selected retrofitting techniques includes enhancing thermal resistance of the building envelop, replace old single-glazed windows and introduce highly efficient home appliances, mainly in low-income housing units. The simulation was applied to all types of buildings and the stimulated results confirmed that economics of selected measures are not inspiring except the case of small housing units in residential buildings. About 22% of annual energy usage in an old housing unit could be saved, in existing buildings, by insulating external walls internally, replacing windows and main home appliances, in addition to the associated GHG emission reduction and creation of new jobs as well as peak demand shaving. However, the actual savings depend not only on the selected retrofitting method, but more on the acceptance of residents to participate in such program and developing clear procedures to overcome the existing legal issues. It is recommended to expand this study on a real sample of old houses, in different districts, in order to evaluate all aspects of retrofitting measures and possible difficulties taking into account the financial ability of low-income families to apply such measures. Future research work may study adequate energy policies that would encourage the retrofitting process in old houses and the essential modification on regulations to control such new activities and maintain the identity of old houses as well as the cultural image of the city. Integration of renewable energy systems into new and old buildings and possible use of biomass based insulation materials are important subjects and must be addressed and assessed soon. Equally important, the implementation of different retrofitting techniques and materials as well as response and behavior of families to achieve the desired national goals of enhancing energy efficiency and sustainability of urban districts should be investigated. Finally it is believed that the concerned governmental institutions are highly advised to study the possibility of introducing an energy performance benchmarking scheme for houses and/or buildings similar to the energy star program in other countries, e.g. Energy Star in USA [68].

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