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Life Cycle Assessment of Energy Retrofit Measures in Existing Healthcare Facility Buildings: The case of Developing Countries

Shouib Mabdeh*, Hikmat Ali, Magd Al-Momani

College of Architecture and Design, Jordan University of Science and Technology, Irbid 3030, Jordan. *Email: snmabdeh@just.edu.jo

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ABSTRACT

Although retrofitting existing buildings is an important step toward sustainability, most research has concentrated on the sustainability of new structures. Existing buildings retrofit is being questioned, particularly in terms of selecting the optimal solution. Additionally, thermal comfort is crucial for patient satisfaction in healthcare facilities, but enhancing this factor increases energy use. However, envelope retrofitting of healthcare facilities buildings stock provides a high potential for energy savings. Consequently, this study aims to develop envelope retrofitting guidelines for uninsulated healthcare buildings in Jordan and to propose locally available retrofit measures. The difference in the building performance before and after retrofit is used to assess potential energy savings. Next, this outcome is used in a life cycle assessment (LCA) to examine the economic and environmental feasibility of the proposed retrofit measures using life cycle cost and life cycle CO_2. This procedure combines the best economic and environmental measures available to create a comprehensive retrofit strategy. Thus, this study adopts a mixed-method design combining quantitative and qualitative methods, including physical analysis, national archives, and questionnaires. The results show that all proposed measures are economically and environmentally feasible, and the combination of two or more measures could produce up to 33% energy savings. Finally, the holistic approach strategy is investigated with various healthcare facilities' life cycle.

Keywords: Envelope Energy Retrofit, Life Cycle Assessment, Life-cycle Cost Analysis, Life Cycle CO_2, Healthcare Facilities
JEL Classifications: Q41, Q50, Q55, Q56, Q59

1. INTRODUCTION

Sustainability's main aim involves enhancing the human quality of life, allowing people to live in a healthy environment while improving social, economic, and environmental conditions (Ortiz et al., 2009). Thus, making every new building sustainable is a step forward in the right direction but would have a negligible impact on sustainability for some time (Wood, 2006). Consequently, to achieve sustainable development, existing buildings must be adequately treated (Husin et al., 2019). Existing buildings consume about 40% of global energy and emit 1/3 of all greenhouse gas (GHG) emissions (Ruparathna et al., 2016). Yet, the percentage of the existing buildings annually retrofitted does not exceed 1–3%. For such reasons, building retrofit plays a vital role in improving the sustainability of existing buildings. Retrofitting a building involves physical or operational changes in a building's fabric, its energy-consuming equipment, or its occupants' behavior (Jafari and Valentin, 2017) without impacting the health and comfort of its occupants (Akadiri et al., 2012). The selection process of the retrofit measures significantly impacts the success and efficiency of the energy upgrade process (Benzar et al., 2020), which is complex and represents one of the main challenges for owners and building managers. The optimal solution to this issue involves various energy-related and non-energy-related factors. Most building owners, managers, researchers, and scientists recognize that energy-efficient retrofits can yield ample savings on building operation costs and reduce negative environmental impact.

Generally, retrofit measures are proposed without examining a building's life cycle or its embodied resources (Asdrubali and

Grazieschi, 2020). Currently, a life cycle assessment (LCA) tool is used as an analytical evaluation tool to measure a building's performance throughout its lifetime. It helps decision makers compare several options of retrofit measures that vary according to the building type (Vilches et al., 2017). However, simplified LCA methodologies were proposed by Oregi et al. (2015) to make a well-structured decision on building energy retrofits.

The building envelope profoundly impacts a building's thermo-energy performance because it serves as a physical barrier between the outer and inner environments (Kumar and Raheja, 2016). This element consists of opaque parts (walls, roof, ceiling, and floors) and fenestrations (windows and doors), and foundations and landscape in some studies (Pratt, 2006). In terms of energy, the building envelope is defined as the interface of energy losses that transfer heat to or from the surrounding environment, causing heat gains or losses (Başarır et al., 2012). These processes cause energy losses of up to 50% of the total energy consumed for heating and cooling (Fan and Xia, 2015). Consequently, the building envelope is given the priority in many energy retrofit researches (Hong et al., 2019).

2. PURPOSE OF HEALTHCARE FACILITIES

Healthcare facilities differ from commercial buildings because they provide constant patient care while serving visitors and staff. Thus, energy efficiency is always challenging in healthcare facilities due to sensitive thermal comfort requirements. The latter is complicated in developing countries with the broader scale factor as catastrophic pressures, including fatal conditions such as population growth, refugee exodus, and COVID-19. These factors have created new special places, including medical staff and vaccination sites in the public health center, and low-scale factors such as local conditions, including MOH budget and the different climatic zones in the country.

In Jordan, healthcare facilities represent approximately 6% of total energy consumption in the utility buildings sector. Heating, ventilation, and air conditioning (HVAC) systems are the major sources of electrical energy consumption. A building's air conditioning system is responsible for around 70% of that building's total electricity consumption. Electric motors and lighting systems represent approximately 19% and 21% of this total energy consumption, respectively. Although such facilities require special indoor conditions (Anwer et al., 2020), no construction regulations have been established regarding the used envelope by the Jordanian Ministry of Health (MOH). As a result, based on a local survey of the MOH database, 85% of the existing facilities had a thermally poor envelope design (MOH, 2020), resulting in high HVAC energy consumption, especially in Jordan's mixed climate (Ergin and Tekce, 2020b; William et al., 2020). Consequently, it is essential to retrofit the existing healthcare facility buildings in a limited energy-source country such as Jordan.

This research aims to propose a retrofitting process for Jordan's existing healthcare facilities to provide comfortable, healthy spaces with the lowest feasible energy consumption, cost, and carbon dioxide emissions across the life cycle of the existing structures. To achieve these objectives, locally available retrofit methods are presented and examined in terms of potential energy savings strategies, initial costs, and embodied CO_2 emissions. Following that, the best economic and environmental measures in each envelope part (wall, window, and ceiling) are combined to produce a holistic approach for the entire existing building. The holistic approach was adopted to upgrade energy efficiency with maximum economic and environmental benefits under the limited budget of MOH, in Jordan's mixed climate. As a result, this study investigates the possibility of retrofitting existing healthcare facilities through several life cycles, and then compares this approach to the construction of new healthcare buildings in terms of potential energy, initial cost, and CO_2 emissions reduction.

3. RELATED WORK

This work focuses on healthcare facilities in a mixed climate where cooling and heating are required. Energy consumption in such buildings attributed to heating, cooling, and ventilation constitutes the major operating expenditures (Anwer et al., 2020; William et al., 2019).Furthermore, indoor air quality, thermal comfort, and energy efficiency affect healthcare buildings' environments, medical staff productivity, and patient satisfaction. Thus, these elements should be considered during retrofitting (Ergin and Tekce, 2020b; Zuo and Zhao, 2014).

Many experts assume that the high annual energy consumption rate in healthcare facilities is connected to achieving the proper level of thermal comfort. Healthcare facility buildings in the United States accounted for 10.3% of total commercial building area. They consumed 210.42 billion kWh of energy, with heating and cooling accounting for 61.5 billion kWh and 23.15 billion kWh, respectively, accounting for more than 40% of total energy consumption (Bawaneh et al., 2019). In Spain, the tertiary sector consumes 20% of overall energy consumption, with HVAC systems accounting for 40% of hospital energy usage (González et al., 2017). Space heating accounted for 44% of total energy consumption in healthcare buildings in the United Kingdom (Fifield et al., 2018). HVAC systems consume a significant amount of energy (30-65%) in India (Franco et al., 2017). HVAC systems in Thailand accounted for 51.36% of total energy consumption in 210 understudy hospitals (Thinate et al., 2017).

According to Husin et al. 2019 (Husin et al., 2019) building age, size, design, building envelope, materials used, and occupant behavior are all influential factors in building energy use. Moreover, several studies have shown that retrofitting the envelopes of existing buildings is an effective method of achieving sustainability. Further research used the DesignBuilder simulation program to assess the environmental effect of healthcare facility energy retrofits in Egypt's hot-arid areas. This research reveals that integrating energy design strategies resulted in 50% energy savings (William et al., 2019). Another research investigated thermal upgrading of walls and roofs using different types of thermal insulation to reduce energy usage (Khoukhi et al., 2020). In contrast, (Lucero-Álvarez et al., 2016) revealed that thermal insulation for all opaque envelope components increased energy consumption. This gap was explained by climates with relatively low heating and cooling needs, such as Mexico City and Pachuca, as explored in (Lucero-Álvarez et al., 2016),where the best alternative is to insulate the roof because it was the only economically viable approach to retrofit in such conditions.

Using the OneClick LCA tool, one study assessed embodied and operational emissions of different building retrofitting scenarios. This research concluded that it was more environmentally friendly to insulate the building envelope than the ground floor due to the insulating of the building envelope significant embodied emissions (Rabani et al., 2021). Gangolells et al. 2020 (Gangolells, et al., 2020) indicated that the most successful sustainable retrofitting solutions collected energy, economic, or environmental factors, and 99.5% of cost-effective measures also reduced emissions over the life cycle. This research involved building envelope energy retrofit measures related to envelope components (opaque parts [walls, roof, and floors] and fenestrations [windows and doors]) (El-Darwish and Gomaa, 2017). Additionally, this work was based on control single or a combination of the thermal characteristics: reduction of transmission, reduction of infiltration and ventilation losses, or decreased or increased solar gains through the envelope (Güçyeter and Günaydın, 2012). In this vein, (Karmany et al., 2016) used DesignBuilder modeling software to explore the influence of wall and roof insulation on energy utilization and CO_2 reduction in Egyptian residential buildings. This process produced 40% less energy consumption by the HVAC when using thermal insulation in exterior walls and roofs, significantly reducing operating costs.

Energy retrofitting can have environmental, economic, and social benefits in addition to reducing energy demand. For instance, a building retrofit promotes and protects biodiversity and ecosystems by reducing air emissions (Ergin and Tekce, 2020a). Beyond that, direct economic adaptability is achieved by decreasing the energy and maintenance costs of a building service (Fan and Xia, 2015). Furthermore, by preserving the social and cultural values embodied in the existing built environment, building retrofitting can aid in social sustainability (Bullen, 2007). The LCA technique promotes the long-term sustainability of buildings (Ingrao et al., 2018), allowing designers and practitioners to avoid influencing or misleading outcomes. A building's life cycle energy can be divided into embodied and operational energy. Embodied energy is the energy sequestered in buildings and building materials during all production processes. In contrast, operational energy is the energy expended to maintain the indoor environment, including heating, cooling, and lighting (Dixit et al., 2012). Both energies must be considered when performing life cycle energy and environmental assessments of buildings (Kovacic et al., 2018). Therefore, this paper uses LCA to examine the economic and environmental feasibility of the proposed retrofit measures using life cycle costs and life cycle CO_2 methods.

This research focused at Jordanian healthcare centers that offer vaccination, maternity care, childcare, and chronic disease management services in both urban and rural areas. These centers range in size from small individual clinics to comprehensive, multi-clinic centers, depending on location and population serviced (MOH, 2020). Most comprehensive centers operate 24/7 to cover 90% of patients' needs, and plans are in the works to create all comprehensive health centers 24/7 operating systems in the next years (MOH, 2020). Because of the poor thermal characteristics of their envelopes, many existing healthcare facilities constructed before to the energy efficiency building code are inefficient. Despite its importance to the indoor environment quality, the building prototypes in these regions that used by the MOH lack to any type of envelope installation (MOH, 2020). In terms of energy consumption (fuel and electricity), the absence of energy-saving measures for the healthcare facility envelope explains the occupation of health centers after hospitals in energy consumption (Jaber et al., 2003), where most of these energies are wasted owing to a lack of thermal insulation.

Energy-efficiency research, according to the literature, is vital. To the best of these researchers' knowledge, there is a gap in the literature regarding energy retrofits in developing countries' healthcare facilities in mixed climatological zones such as Amman, Jordan. Thus, by addressing this issue in primary healthcare centers, this paper aims to fill that gap using economic and environmental analysis. Another gap in previous studies is that they have exclusively relied on global standards to establish economic efficiency, neglecting local constraints. The strategies used to evaluate economic efficiency were based on the impartiality of the MOH's priorities, making their application questionable if budget constraints are not considered. Consequently, this study establishes economic feasibility criteria that overlap between international strategies and local priorities to select the optimal retrofit strategy within the building life cycle.

4. METHODOLOGY

4.1. Selection of Representative Buildings

Because of the heterogeneous nature of the construction sector, it is difficult to identify single, environmental, and cost-feasible energy retrofit measures in this field (Gangolells, et al., 2020). For this reason, a reference building is an effective tool for evaluating the energy efficiency of the entire building stock (Pistore et al., 2019). To identify representative buildings (RB's), a multi-stage criterion method was used to capture the greatest proportion of the variety of Jordanian healthcare facility building stock. Additionally, the selection criteria were established based on the recommendations of Focus Group and the literature review, which resulted in three filter stages:

- Stage One: Analysis of the climatic regions where healthcare centers are distributed,
- Stage Two: Analysis of the architectural prototypes of the healthcare centers, and
- Stage Three: Analysis of the life cycle span for the healthcare centers.

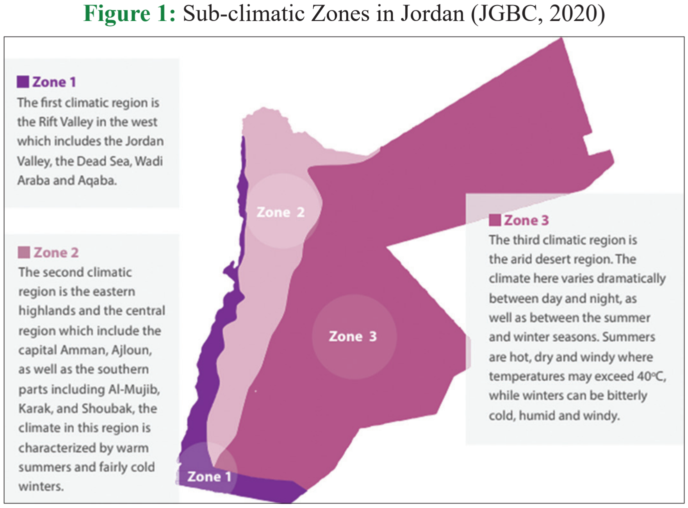
To obtain the highest concentration within the climatic zones of Jordan (Figure 1), the first stage investigated the distribution of healthcare facilities based on archival data from the MOH and the Ministry of Public Work and Housing (MPWH). The results indicate that 10% of the healthcare facilities are distributed in Zone

1, 78% in Zone 2, and 12% in Zone 3. Zone 2, which has warm summers and relatively cold winters, was used as the representative study region. In the same vein, Amman is a representative city because it is the capital of Jordan and contains the highest density of healthcare centers of any city in the country. Additionally, the MOH adopts three main public architectural prototypes: L shapes, E shapes, and T shapes (MOH, 2020). In this study, the L shape was the most utilized model, followed by the E shape and the T shape at 61%, 20 %, and 19 %, respectively. These centers are divided into three major categories: the first category with 20 years life span, the second with 35 years life span, and the third 40 years lifespan (MOH, 2020). Stage three revealed that 65% of all healthcare centers were 15 years old and still have a 35-years life cycle. Based on this analysis, two representative healthcare facilities were proposed, one representing healthcare facility buildings with external walls of natural stones and the other with external walls of concrete block.

4.2. Selection of Envelope Energy Efficiency Retrofit Measures

In this study, single and combined envelope energy efficiency measures were proposed and applied to the IES-VE modeled building to upgrade the thermal performance of the selected buildings. These measures, based on the recommendations of the focus group of architects and other building retrofit specialists, three main stages are involved: Stage One: Availability in the local markets, Stage two: Familiarity with the application from local contractors, and Stage three: Adherence to Jordan's Energy Efficiency Building Code (JEEBC). Applying these criteria to the solutions proposed by previous studies, sixteen energy efficiency measures were presented as the most common ones with the lowest prices in Jordan (Table 1). After retrofitting both centers, the researchers used IES-VE to obtain thermal conductivity (U-value) values for the envelope elements. Next, the measures initial costs (ICs) and configuration were obtained from focus groups involving retrofit specialties with good knowledge of local market's retrofit options. The embodied CO2 emission ratios from producing materials were obtained from previous literature (Aditya et al., 2017; Amirkhani et al., 2019; Asif et al., 2017; Kunič, 2017; Sabnis et al., 2015; Weir and Muneer, 1998).

Figure 1: Sub-climatic Zones in Jordan (JGBC, 2020)



4.3. Creating Energy Retrofit Scenarios

A 2*3 factorial design was structured to create retrofit scenarios, intersecting the two base cases with the proposed energy efficiency measures classified into three envelope retrofit levels (wall, roof, and window systems). Table 2 clarifies the retrofit scenarios creation matrix concept, resulting in six scenarios.

4.4. Assessment of Energy-saving, Life-cycle Economic, and Environmental Impacts of Energy Retrofitting Measures

This study's research methodology was a mixed method design (MMD), which included quantitative and qualitative methodologies. The underlying idea behind this technique was to achieve the study's principal goal of comparing the strengths and limitations of each approach to those of the others. Figure 2 shows the four stages of the developed methodology.

4.4.1. Data collection and base cases development

Data obtained on Jordanian healthcare buildings were used to develop two base case models for two healthcare centers. These data were collected from archives, self-reported filed data, and structured focused groups. Healthcare centers provided quick access to medical care and offered vaccination, maternity care,

Figure 2: Multi-stage criteria workflow of assessing energy-saving, life-cycle economic, and environmental impacts of energy retrofitting measures and a holistic retrofit strategy

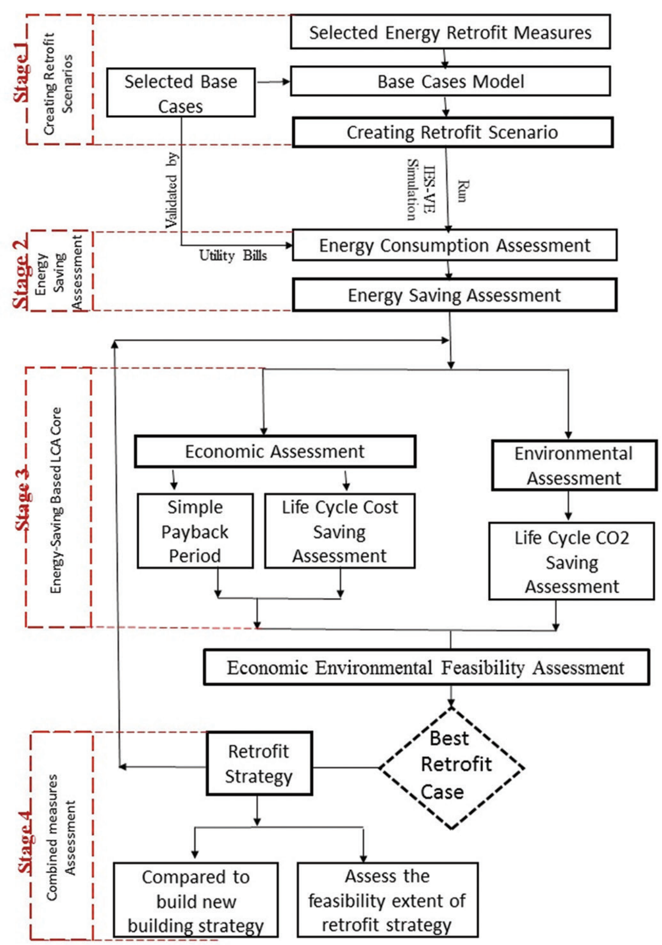


Table 1: Envelope energy efficiency measures configurations, U-value, initial cost, and embodied CO_2 emissions from material production

Envelope element	Measure code	Measure system configuration	U-Value (W/m²-K) Stone wall	U-Value (W/m²-K) Concrete block wall	IC (per unit)	Embodied Co_2 emissions form materials production (kg CO_2 per unit)
External walls (From inside)	M1	Existing wall+5 cm of Rock wool boards	0.45	0.56	14JD/m^2	4.3 kg CO_2/m^2
	M2	Existing wall+5 cm Extruded polystyrene XPS.	0.37	0.45	18 JD/m^2	33.6 kg CO_2/m^2
	M3	Existing wall+5 cm Expanded polystyrene EPS	0.39	0.47	16 JD/m^2	11.8 kg CO_2/m^2
	M4	Existing wall+5 cm Polyurethane boards	0.32	0.37	20 JD/m^2	22.9 kg CO_2/m^2
Concrete block only	M5	Existing wall+5 cm Polyurethane boards	-	0.37	20 JD/m^2	22.9 kg CO_2/m^2
Roof	M6	Existing roof+5 cm foam concrete.	0.46		21JD/m^2	24.4 kg CO_2/m^2
	M7	Existing roof+5 m Expanded polystyrene EPS	0.28		15JD/m^2	11.8 kg CO_2/m^2
	M8	Existing roof+50 mm Polyurethane PUR boards	0.24		20 JD/m^2	22.9 kg CO_2/m^2
	M9	Existing roof+5 cm Extruded polystyrene XPS	0.27		19 JD/m^2	33.6 kg CO_2/m^2
Window system	Window pane					
	M10	Dbl space Sel Clr 6 mm, 13-mm air gap.	2.8		100 JD/indow	14.28 kg CO_2/window
	M11	Dbl space Sel Clr 6mm, 13-mm argon gap.	2.1		120 JD/Window	14.29 kg CO_2/window
	Window frame					
	M12	Sgl LoE window CLR 6 mm			Window	1.2 6 kg CO_2/window
	M13	Metal with thermal break window frame	4.6		22 JD/Window	12.9 6 kg CO_2/window
	M14	UPVC window frame.	3.1		26.5 JD/Window	2.6 kg CO_2/window
	Shading					
	M15	Movable Shading device 58 cm for windows on south elevations.	-		60 JD/Window	6.5 kg CO_2/m^2
	Air sealing					
	M16	Change from 1 to 2 ac/h (Loose airtightness type) to 0.6–1.0 (Medium airtightness type)	-		5 JD/Window	2.7 kg CO_2/m^2

Table 2: Retrofit scenario creation matrix, two base cases (stone and concrete block), and three envelope retrofit levels

Scenario 1					Scenario 2				Scenario 3						
Stone external walls retrofit level					Roof retrofit level				Window system retrofit level						
M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16
B1M1	B1M2	B1M3	B1M4	B1M5	B1M6	B1M7	B1M8	B1M9	B1M10	B1M11	B1M12	B1M13	B1M14	B1M15	B1M16
Scenario 4					**Scenario 5**				**Scenario 6**						
Concrete block external walls retrofit level					**Roof retrofit level**				**Window system retrofit level**						
B2M1	B2M2	B2M3	B2M4	B2M5	B2M6	B2M7	B2M8	B2M9	B2M10	B2M11	B2M12	B2M13	B2M14	B2M15	B2M16

childcare, and chronic disease management services in urban and rural areas (Ministry of Environment MOE, 2017). The selected healthcare facility buildings are in Amman (35.88E, 31.96N), in which the average temperature ranges from 8.0°C in January to 25.3°C in July, with 1,471 heating degree days with a temperature limit of 18°C and 350 cooling degree days with a temperature limit of 24°C at an elevation of 779 m, dry bulb 37.50°C, wet bulb 19.94°C (Attia and Al-Khuraissat, 2016). Both facilities have the same total space, 1,557 m2, operational schedule, and clinic zones that are open 24 h a day, seven days a week. Following that, clinics were separated into operation profiles ranging from 8 a.m. to 8 a.m. and others with operation profiles ranging from 8 a.m. to 4 p.m. Other non-clinical areas were also scheduled to be open from 8 a.m. to 4 p.m. each weekday except Friday. For outpatient clinical spaces, occupancy density ranged from one to three people. For non-clinical spaces, occupancy density ranged from three to 10 people.

The envelope detail configurations are summarized in Table 3. Subsequently, the researchers set heating and cooling set-point temperatures based on ASHRAE 170-2011 (applications heating and cooling set-points). For outpatient clinical spaces, the heating point was set at 18°C, and the cooling point was 23°C, whereas for non-clinical spaces, the heating point was set at 21°C, and the cooling point was 24°C. Based on the poor thermal properties of the envelope and the old state of both centers envelopes, the infiltration rate was projected to be 2 AC/H (loose building type, as characterized in the literature) (Chadi et al., 2011). Based on a personal interview with specialists in medical appliances, clinics' internal heat gains were set as 80 W/person for occupants, 690 W/m3 for a small refrigerator, 310 W/m3 for a large refrigerator, 26 W for an incubator, and 40 W for miscellaneous elements. For outpatient clinical spaces, the occupancy density ranged from one to three people; for non-clinical spaces, this density ranged from three to ten people.

In healthcare facilities, cooling and thermal heating are required for the operation of basic services, including lighting, refrigeration, ventilation, communications, cooking, cleaning, laundry, and computer systems. Additionally, it is required to safely manage medical wastes and operate essential medical devices, such as emergency surgical, laboratory, and diagnostic equipment (World Health Organization, World Bank, 2014). In both cases, air conditioning (AC) operated by electricity was the only method used for cooling all central spaces. While investigating energy utilization, the specific nature of healthcare facilities in terms of limits on air recirculation to ensure indoor thermal comfort and air sterilization was considered. Beyond this, the 2019 IES-VE simulation software was used, employing ModelIT to create three-dimensional models of the analytically based selected RBs. Based on intensive interviews, questionnaires, and observations, several models were constructed and tested to match the real building using extensive interviews, questionnaires, and observations. Additionally, IES-VE was used to obtain the U-Value for envelope elements (external wall, roof, and windows) before and after modifications (Tables 3 and 4).

4.4.2. Validating the weather data file

The weather data file obtained for the IES-VE simulation program, involving outdoor temperature, wind speed, and direction, was validated by comparing the values obtained from the simulation program with the monthly mean dry bulb (DB) temperatures for the healthcare centers. Because of the variety of outside circumstances, there was strong agreement among the values, with a disagreement range of 2-6%, as illustrated in Table 5. Next, the weather data from the simulation program were employed in this investigation because the weather file acquired from the local station lacked certain crucial information, such as hourly wind speed, wind direction, and solar radiation. Jordan's Air Quality Index (AQI) is generally rated as good by the Jordan Ministry of Environment. This categorization is based on the AQI standards of the United States Environmental Protection Agency. Historical data for the research area revealed that particulate matter 10 m (PM10) values varied between 10 and 93 $\mu g/m^3$, nitrogen dioxide (NO2) 5-15 ppm, and carbon monoxide (CO) 11-33 ppm (Wood, 2006).

4.4.3. Validating the IES-VE model

The simulation program was designed to run yearly energy, thermal, natural ventilation, and CO_2 simulations with two steps per hour for accurate results. During the given months, the simulation program generates an energy and comfort study for the building. On the other hand, running a continuous simulation in 30-min increments gives the suggested systems the time needed for optimal functioning. Furthermore, the program analyzes the loss of efficiency that occurs every night or the overheating that occurs on some days during the given months. Consequently, this

Table 3: Characteristics and envelope configuration of the representative healthcare facility

Envelope elements	Depiction	Configuration	U-Value (W/m2-K)
External Walls	Opaque walls part area: 434 m^2 Total thickness: 340 mm No thermal insulation	Stonewall Plaster (20 mm) Hollow block (200 mm) Cavity (50 m) Cement Base (20 mm) Stone (50 mm) concrete block wall Plaster (20 mm) Hollow block (200 mm) Plaster (20 mm)	1.1 2.7
Roof	Roof surface area: 779 m^2 Total thickness: 356 mm No thermal insulation	Water Membrane (4 mm) Screed (50 mm) Reinforced concrete slab (300 mm) Plaster (2 mm)	1.1
Window	Windows total area: 101.64 Single glazed window. WWR (South, 20%; West, 20%; North, 20%; and East, 20%). No shading, overhang, or louvers used	Clear single glazed (6 mm) Aluminum frame Light transmittance (0.71) Emissivity (0.83)	5.88
Floor	Ground floor area: 779 m^2 First-floor area: 779 m^2	Heavy Concrete slab (200 mm)	1.2

Table 4: System boundaries are defined as life cycle modules according to EN 15804+A2 [53]

Existing building before retrofit				
Possible boundary extension	Retrofit boundaries			Possible boundary extension
Substituted materials (end-of-life stage, C1-4)	New embodied materials (product stage, A1-5)	Operational use (use stage, B1-7)	New embodied materials (End-of-life stage, C1-4)	Remaining existing building materials (end-of-life stage, C1-4)

study structured to thoroughly demonstrate the effectiveness of the suggested systems during the cooling and heating seasons.

Additionally, the simulation results indicated the interior space's iT, VR, CO_2 concentration, and RH during the normal hours when the non-clinical spaces were filled (8:00 a.m. to 4:00 p.m.). The BC model's interior air temperatures were confirmed using site measurements to validate the simulation findings. During the occupancy period, the indoor air temperatures were measured for one average week during the summer season (August) and one typical week during the winter season (February). In the sample healthcare centers, one data logger was deployed. Next, the Extech SD800 datalogger was placed in the center spaces and used to measure the interior air temperature, relative humidity, and CO_2 concentration with accuracy readings of 0.8C, 4%, and 40 ppm, respectively. The datalogger was fixed 1.2 m above the floor in the center of the spaces, and measurements were taken at 15-min intervals when the spaces were 80% full. There was an agreement between the simulation program outputs and the measured data, with an average error of 2–3% throughout the week. Table 6 displays the acceptable iT's ranges for the selected months of February and August based on the adaptive model shown in Figure 3 and weather data from the case studies.

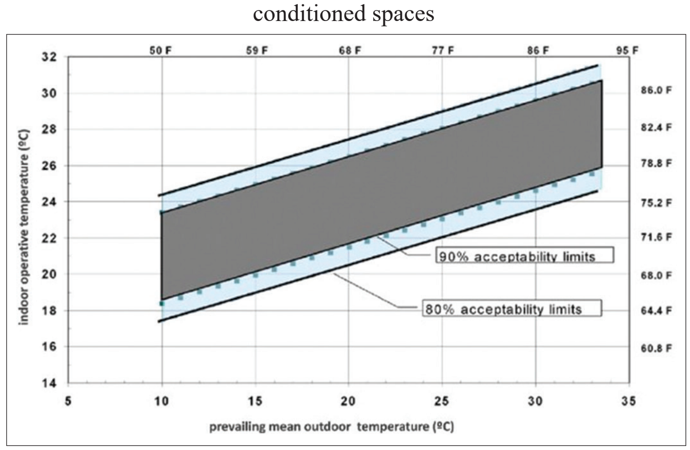
Table 5: Average monthly outside DB temperatures, Amman, Jordan

Date	Average Monthly Outside DB Temperatures		
	Simulation program dry bulb	Amman weather station	Discrepancies (%)
January 01, 2020	7.3	7.8	6
February 01, 2020	10.9	11.5	5
March 01, 2020	11.2	11.8	5
April 01, 2020	15.5	16.2	4
May 01, 2020	21	21.6	3
June 01, 2020	23.1	23.6	2
July 01, 2020	26	26.6	2
August 01, 2020	25.1	25.7	2
September 01, 2020	22.6	23	2
October 01, 2020	19.4	20.1	3
November 01, 2020	13.7	14.1	2
December 01, 2020	9.4	9.8	4

Table 6: Acceptable indoor air temperatures according to ASHARE adaptive model

Month	Mean monthly outdoor air temperature	Comfort range for indoor operative temperature
February	11.47°C	18.8–23.8°C
August	25.67°C	23.8–28°C

Figure 3: Comfort bandwidths of ASHRAE 55-2017 in naturally conditioned spaces



4.4.4. Energy-savings-based life cycle assessment

Energy saving is an advantage of increasing energy efficiency, as measured by the difference in energy consumption before and after retrofitting (Nicolae and George-Vlad, 2015). Energy savings are estimated by calculating the difference between the original base case (pre-retrofit energy consumption) and the base case's post-retrofit energy consumption after each retrofitting measure's implementation. This process is demonstrated here:

$$ES(X) = E_{Pre} - E_{Post} \tag{1}$$

Where Epre is the energy consumption derived from a pre-retrofit simulation of the building. On the other hand, Epost is the building energy consumption after implementing the retrofit actions, predicted by the simulation. These measurements reflect the total annual energy (kWh/year) used for heating and cooling requirements to provide flexible results.

In the IES-VE energy simulation program, ApacheSim was used to ascertain the thermal energy consumption based on a building performance simulation engine, measuring the reduction in heat transfer based on the fluctuation of the envelope material's thermal properties: thermal conductivity, specific heat capacity, and density. However, the annual heating and cooling energy consumption calculations for essential cases were validated using actual utility bills for healthcare centers. The electricity used in lighting and other appliances was outside the framework of the study.

4.4.5. Life cycle cost assessment

Next, the economic analysis calculated the initial investment cost for each retrofitting measure, the economic savings from saving energy, the net present value (NPV), and the simple payback period (SPP). Finally, the economic feasibility was evaluated. The entire initial investment cost (IC) of the retrofitting measures was determined by the area to be retrofitted:

$$IC(X) = mc(X) \times un(X) \tag{2}$$

Where mc(X) is the unit cost of the energy retrofitting measure X (JD/unit) and un(X) denotes the number of units of the energy retrofitting measure X (per m^2, m^3, and window). Energy savings (Eq. 1) are converted into economic savings depending on local energy source costs, which were limited to the electricity source in this study. The annual economic savings (EcS) provided by energy retrofitting measures were calculated using Eq. 3:

$$EcS(X) = ASE \times EC \tag{3}$$

EcS(X) represents the annual economic savings as the cost of total saved energy per year (JD/year), ASE represents the annual saved energy (MWh/year), and EC represents the electricity cost (JD/MWh). Calculating Net Present Value (NPV) impact is important because money has a time value, and cash flows that occur in separate periods must be discounted back to the base period before they can be compared [50]. Furthermore, the yearly money saved during the operating phase of retrofitted buildings happens throughout different times of a building's life cycle, therefore the life cycle economic evaluation must consider the time value of money. On the financial side, NPV is a fundamental technique for comparing money values across time (Spickova and Myskova, 2015). This figure indicates the difference between the present value savings (PVS) over a lifetime and the initial investment cost (IC; Eq. 2), as illustrated in Eq. 4:

$$NPV = PVS - IC \tag{4}$$

Based on the expected discount rate (d), PVS indicates the entire life-cycle dinar savings of the energy investment made in present-day money (JD). If appropriate, PVS can include annual operation and maintenance costs, following the equation below (Randolph and Masters, 2018):

$$PVS = (AES \times Pr - O\&M) \times UPV\ F \tag{5}$$

Where ASE represents annual saved energy (MWh/year), Pr represents the price of saved energy, O&M represents an annual operation and maintenance cost (JD/year), and UPVF represents the uniform present value factor. In this study, the uniform UPVF discounted future net annual savings in dinars that were assumed to be standardized each year to the present value by the UPVF, as indicated in Eq. 6:

$$UPV\ F = (1 - d)n - 1\ d(1 + d)n \tag{6}$$

where d represents market discount rate, and n represents building lifetime (years).

4.4.6. Measurement of the simple payback period (SPP)

Simple payback time (SPP) is used to assess the economic feasibility over time. The payback period is defined as the time it takes to repay a particular investment, calculated following the equation below (Randolph and Masters, 2018). The shorter the payback period of an investment project, the higher the probability of its adoption.

$$SPP = IC/ECS \tag{7}$$

where IC represents initial investment cost (JD), and ECS represents the annual economic cost saving representing the cash inflow through the year (JD/year).

4.4.7. Life cycle CO_2 assessment

In studies such as this one, LCA has been carried out following ISO 14040 (Heires, 2008) and the requirements of EN 15804+A2 (CEN, 2019) standards. This process comprises four stages: goal definition and scope, life-cycle inventory analysis, impact assessment, and results interpretation.

4.4.8. Goal definition and scope

This investigation aims to assess the environmental impact of the suggested energy retrofit measures while upgrading the representative healthcare facility buildings. The functional unit was determined based on the energy retrofitting measure (retrofit of 1 m^2 of the facade by adding external wall thermal insulation, retrofit 1 m2 of the roof by adding roof thermal insulation, and so forth). Table 4 represents the possible expansion in the life cycle phases boundary connected to the retrofit procedure, as indicated by EN 15804+A2 (CEN, 2019), and includes models A1-5, B1-7, and C1-4 (CEN, 2019; Vilches et al., 2017).

4.4.9. Life cycle inventory analysis

The life cycle inventory framework quantified and studied the operational energy usage and total embodied and operational CO_2 emissions during the building's life cycle phase. This procedure was carried out for each energy retrofitting measure at the relevant representative life cycle stage, with the required materials and energy consumption. The operational energy used in this study was calculated using IES-VE, and embodied carbon per unit values for the building components were extracted from the literature (Table 1). The primary energy conversion factors for the electricity consumed in Jordan are given in this paper as 0.581 kg CO2/KWh (Ministry of Environment MOE, 2017).

4.4.10. Impact assessment

Impact assessment of the proposed energy retrofit scenarios was quantified using the Life Cycle CO2 (LCCO2) emission.

4.4.11. Results interpretation

The results of the impact assessment were interpreted using the life cycle of CO_2 emissions. Additionally, LCCO2 is the most common approach for evaluating the environmental performance of a facility or product involving CO_2 emissions reduction measurements (Mangan and Oral, 2015). This study used (Eq. 8) based on the 41 Commission delegated regulation (EU.) No 244/2012.

$$LCCO2 = E_{annual} \times CF \times B(lifetime) - EMCO_2 \tag{8}$$

where E_{annual} represents annual energy savings (MWh/year), CF represents the conversion factor for electricity (kg CO_2/KWh), B(lifetime) represents a building's lifetime (years), and $EMCO_2$ represents the embodied CO_2 (kg CO_2 per unit) and the mean extra CO_2 emissions from materials and production.

4.5. Creating Integrated Economic-environmental Feasibility Criteria for Energy Retrofitting Measures

An integrated assessment criterion was used to assess the economic-environmental feasibility of the applied energy retrofit measures. In this way, two feasibility criteria were obtained in this study:

(a) General economic-environmental feasibility assessment criteria. Two economic–environmental feasibility criteria were adopted in this study. First, general economic–environmental feasibility criteria were created based on international feasibility methods, and recommendations which were collected through a focused group of retrofit specialists.

General economic–environmental feasibility assessment criteria are calculated as follows:

$$NPV > \text{and } SPP \leq 10 \text{ years and } LC\ CO_2 > 0 \quad (a)$$

(b) Best economic-environmental feasibility assessment criteria. These assessment criteria, which were applied to all economic–environmental feasible cases, are derived from general economic-environmental criteria. In general feasibility criteria, the best economic-environmental criteria were constructed based on matching Jordan government priorities (MOH) and international feasibility criteria. This procedure yielded the best-recommended selection criteria, as shown below:

If $SPP \leq 10$ years and $LC\ CO_2 > 0$, the higher the NPV the best (b)

4.6. Energy Saving Based Life Cycle Assessment of Combined Energy Retrofit Measures' Impact

Retrofit measures in wall, roof, and window system cases were evaluated in terms of economic-environmental feasibility criteria, and then the best criteria (b) were used to develop a retrofit strategy combining the best of these measures. A comparison of fixed retrofit strategy initial investment cost (IC) and embodied CO_2 emissions with the energy-saving cost for different healthcare facility life cycles was also undertaken to establish the economic-environmental feasibility of this method.

As displayed in Figure 2, another comparison was made with the retrofit strategy created (combining the best in Scenarios 1, 2, and 3) between three other energy-upgrading scenarios (Scenarios A, B, and C):

- Scenario A: energy retrofitting of the existing healthcare facility
- Scenario B: demolishing and rebuilding a new healthcare facility on the same site, and
- Scenario C: building a new healthcare center on new land.

The comparison, however, was done in terms of energy-saving costs vs. investment costs, as well as total energy saved CO_2 emissions reduction throughout the whole lifespan versus retrofit embodied CO_2. Total energy savings costs are calculated based on Eq. 9:

$$\text{Total energy saving} = SASC \times N \quad (9)$$

where SASA represents the retrofit strategy annual saved energy cost (JD), and N represents the representative healthcare facility's lifespan (years).

5. RESULTS AND ANALYSIS

The proposed energy retrofit measures are compared in Table 5. In this study, 32 envelope retrofit scenarios were assessed for economic and environmental feasibility using NPV, SPP, and $LCCO_2$. All the recommended measures were both economically and environmentally feasible. In BC1 cases, the best retrofitting scenarios were B1M4, B1M9, and B1M16. In BC2, however, the best retrofitting cases were B2M5, B2M9, and B2M16 (Table 7).

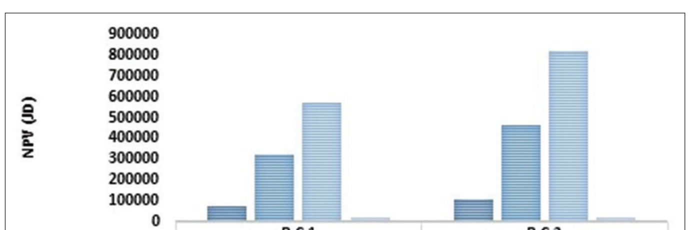
5.1. Energy Saving-LCA of Retrofit Strategy Impact

The holistic retrofit strategy reduced energy usage by 38% and 42%, respectively, in stone and concrete block centers. However, based on general criteria (g), the holistic retrofit strategy was economically and environmentally feasible. Thus, the application of this method resulted in a positive NPV for both stone and concrete block during the estimated life span (35 years). Furthermore, both centers' holistic strategy had a short SPP of <1 year, 0.9 for stone and 0.7 for concrete block. Based on LC Cost in Figure 4, the fixed initial cost of developing the holistic retrofit strategy 24645 JD was economically feasible, was covered by energy savings, and resulted in a positive NPV. For buildings erected in 1974 (3-year life cycle), 1984 (13-year life cycle), and 1994 (23-year life cycle), the NPV of the representative B.C1 was three, thirteen, and twenty-three times higher than the holistic strategy fixed initial cost. For the representative B.C2, however, the implementation of the holistic retrofit strategy resulted in a cost-profit four, 19, and 33 times higher than the holistic strategy's fixed initial cost of buildings built since 1974 (3-year life cycle), 1984 (13-year life cycle), and 1994 (23-year life cycle) respectively.

Furthermore, based on $LCCO_2$, the energy-saving emissions reduction covered the fixed embodied CO_2 emissions caused by the holistic retrofit strategy manufacturing in all scenarios. The findings were 6, 25, and 45 times more than the holistic-retrofit-strategy-embodied CO_2 emissions for buildings erected in 1974 (3-year life cycle), 1984 (13-year life cycle), and 1994 (23-year life cycle), as illustrated in Figure 5.

Consequently, the life cycle of a building is critical in determining the economic-environmental feasibility of a retrofit for that structure. Simultaneously, the designed holistic retrofit method has a very low initial cost and exceptionally low embodied CO_2 emissions, which are covered by an envelope retrofit associated with energy savings (appositive NPV obtained) and energy-saving emission reductions ($LCCO_2$). Other methods that have higher initial costs, embodied CO_2 emissions, or both may make retrofitting buildings built after 1974 impractical. As a result, when modernizing old structures, one must consider each building's lifetime.

Figure 4: Total energy savings for various expected lifespans versus fixed investment costs



	B.C 1	B.C 2
3 years life cycle	74650.5	106299.45
13 years life cycle	323485.5	460630.95
23 years life cycle	572320.5	814962.45
Fixed initial cost	24645	24645

Table 7: Retrofit scenarios, energy savings percentages of total used energy, NPV, SPPLCCO2, and economic-environmental feasibility

Base case	Analysis aspects		Before retrofit	Envelope retrofit levels																Retrofit strategy
				External wall retrofit level					Roof retrofit level				Window system retrofit level							Combined best economically–environmentally feasible measures
				Stone external walls									Windowpane		Window frame		Window shading	Window air sealing		
			B1M0	B1M1	B1M2	B1M3	B1M4	B1M5	B1M6	B1M7	B1M8	B1M9	B1M10	B1M11	B1M12	B1M13	B1M14	B1M15	B1M16	B1M4, B1M8, B1M16
Stone healthcare center	Energy	AEC (MWH)	378.0	358.8	356.5	357.1	354.9	_	365.9	360.5	359.2	360.2	370.4	364.1	369	373.8	367.4	332.6	261	284
		ES(%)	_	5.1	5.7	5.5	6.1	_	3.2	4.6	5.0	4.7	2.0	3.7	2.3	1.1	1.7	12	31	24.9
	Economic	NPV (JD)	_	95154	105608	103296	113220	_	47241	80535	83530	79009	32580	63900	195	19771	32939	239038	583675	473025
		SPP (Years)	_	1.20	1.38	1.26	1.42	_	5.14	2.53	3.14	3.16	3.82	2.53	0.81	1.58	1.17	0.07	0.01	0.99
	Environmental	LCCO2 (kg CO 2 eq./m^2)	_	382192	420587	417848	457766	_	225012	344637	362425	333755	153446	279523	180898	81363	134011	1227756	2377116	1880974
Economical–environmental feasibility				✓	✓	✓	*BEST*	_	✓	✓	*BEST*	✓	✓	✓	✓	✓	✓	✓	*BEST*	✓
				Concrete block external walls					Windowpane			Window frame			Window shading		Window air sealing			Combined Best Energy Saving Measures
			B2M0	B2M1	B2M2	B2M3	B2M4	B2M5	B2M6	B2M7	B2M8	B2M9	B2M10	B2M11	B2M12	B2M13	B2M14	B2M15	B2M16	B2M5, B2M9, B2M16
Concrete block healthcare center	Energy	AEC (MWH)	426.5	362.1	358.7	359.5	356.5	355.5	414.5	408.5	406.8	408.1	418.8	412.6	417.5	421.9	419.7	383.8	306.1	292.7
		ES (%)	_	15.1	15.9	15.7	16.4	16.6	2.8	4.2	4.6	4.3	1.8	3.3	2.0	1.0	1.6	10	28	31.4
	Economic	NPV (JD)	_	332594	348878	345506	359670	366560	47241	83715	88839	82719	33110	64430	45775	22686	33999	225470	637735	684018
		SPP (Year)	_	0.36	0.44	0.39	0.47	0.46	5.14	2.45	2.98	3.04	3.77	2.51	0.81	1.39	1.13	0.07	0.01	1.00
	Environmental	LCCO2 (kg CO 2 eq./m^2)	_	1293200	1353963	1347156	1403344	1429779	225012	356838	382760	347990	155480	281556	181915	92548	138078	93478	2448288	2691169
Economical–Environmental Feasibility				✓	✓	✓	✓	*BEST*	✓	✓	*BEST*	✓	✓	✓	✓	✓	✓	✓	*BEST*	✓

5.2. Energy-savings-based LCA of Retrofit Strategy Economic-environmental Feasibility Extent

This study compared the economic and environmental feasibility of three building energy upgrading scenarios, Scenarios A-C, for a 1557-m^2 healthcare building. To illustrate the economic feasibility, Figure 6 depicts the cost of energy savings against total investment across the estimated lifespans of the two base case buildings. Economic feasibility in terms of SPP is illustrated in Table 6, and the holistic retrofit strategy was economically feasible (SPP ≤10 years) with an SPP shorter than 1 year in the two base cases. In contrast, new construction in the new land strategy was economically infeasible (SPP <10 years) in the two base cases. Although the demolishing-and-rebuilding approach had an SPP of fewer than 10 years in B.C1, it was 26 times greater than the SPP of the retrofit method.

Furthermore, Table 8 compares energy-saving CO_2 emissions reduction versus holistic retrofit embodied CO_2 emissions during the estimated lifespans of the healthcare centers in Scenarios A and B based on LC CO_2. Scenario A embodied

Figure 5: Total energy saved cost for various expected lifespans versus Manufacturing embodied CO_2 Emission

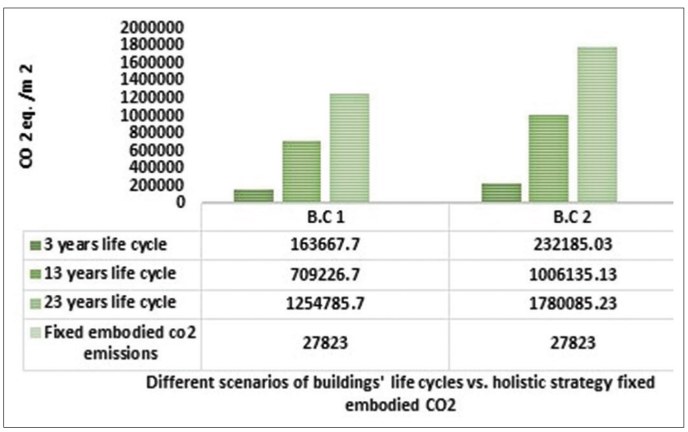
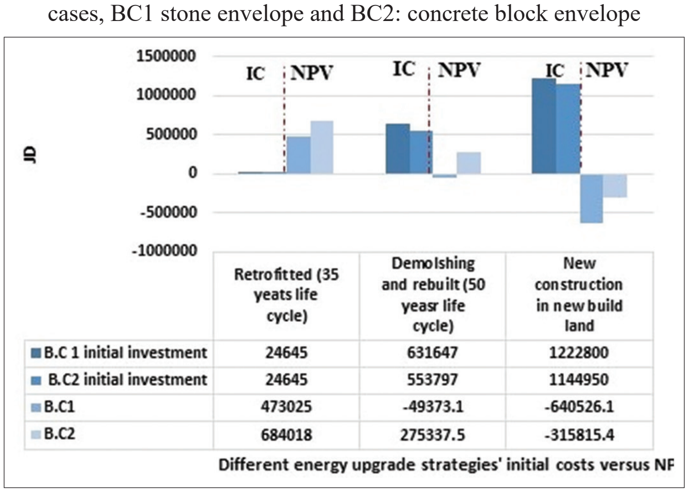


Figure 6: Energy-saving costs versus investment costs; (a) Retrofitting existing building. (b) Demolishing and rebuilding a building, (c) Construction of the new building on new build land for the two base cases, BC1 stone envelope and BC2: concrete block envelope



carbon is the total of (PUR and window air sealing embodied emissions, wall embodied emissions) (434 m²) 22.9 kg CO_2/m² PUR insulation, roof (779 m²), 22.9 kg CO_2/m² PUR insulation and window (1.2*1 m²) rubber air sealing 2.08 kg CO_2/m³). Additionally, Scenario B related embodied emissions involved building new healthcare facility-related CO_2 emissions, calculated by multiplying (building material emissions 731 kg CO_2 eq./m² + building structure emissions 227 kg CO_2 eq./m²) (SILVIA, 2018)* the new center area 1557 m². Based on Figure 7, CO_2 emissions reduction (LCCO_2) in Scenario A were approximately 25% and 50% higher than in Scenario B in BC1 (stone envelope center) and BC2 (concrete block envelope center), respectively, due to high embodied CO_2 emissions for new buildings.

6. DISCUSSION

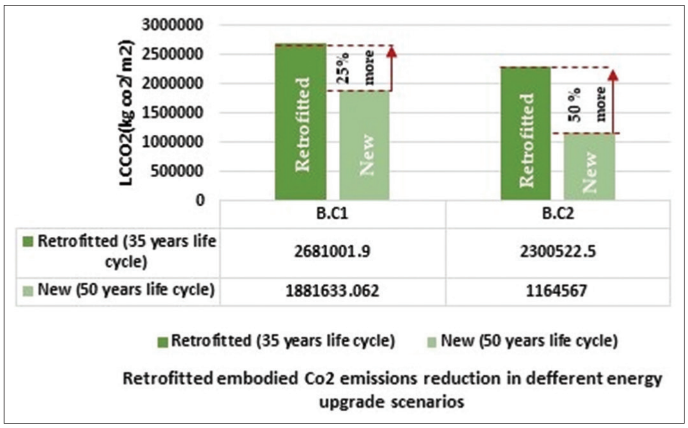
In this study, all energy retrofit measures for walls, roofs, and windows resulted in yearly energy reductions that were both economically and environmentally feasible. Cases B1M4 (6.1%) and B2M5 (16.6) in the wall retrofit strategy, Cases B1M8 (5%) and B2M8 (4.6%) in the roof retrofit strategy, and Cases B1M16 (31%) and B2M16 (28%) obtained the highest energy savings percentages. B2M4 is also depicted as inside concrete block insulating employing a PUR insulation system in the concrete block wall retrofit. However, employing this technique from the outside was more efficient than inside by 0.3% total energy savings. Thus, in 24-h health care facilities, utilizing an external isolation system is more efficient than using an internal one. These results were similar to those of Cheng et al. study (Cheng et al., 2017), which recommended using ETI in buildings occupied during the day instead of ITI.

Furthermore, although cases B1M1 and B2M1 had the lowest costs among wall retrofit cases, they were not the best to suggest in the developed retrofitting guideline. In contrast, cases B1M6 and B2M6 had the highest costs between roof retrofit cases and were less economically and environmentally feasible cases. These findings show that evaluating energy performance, initial cost, and embodied CO_2 as independent parameters to establish the viability of energy retrofit methods is unproductive since the data must be combined to provide the optimal solution. These results are similar to those found in Khoukhi's study (Khoukhi et al., 2020), where the wall and roof U-values were decreased because using different thermal insulation reduced energy consumption. However, these results differed from those in (Lucero-Álvarez et al., 2016)'s study, in which using thermal insulation for all envelope opaque parts increased energy consumption. This disparity stemmed from the studies being done in regions with relatively low heating and cooling requirements, such as Mexico City and Pachuca, where the optimum insulation choice for a building is to insulate only the roof. External insulation was three times more efficient on a concrete block wall than on a stone wall. Although there was no significant difference in savings percentages between the stone wall and roof retrofits (1.1%), there was a substantial difference in savings percentages between these parts in the concrete block center (up to 12%). Because of the differences in thermal

Table 8: Energy upgrade scenarios' economics assessment variables

Scenario Code	Annual energy saving cost		Initial investment cost (JD.)	SPP (years)		Lifespan (years)
	BC1 (stone)	BC2 (Concrete block)		BC1 (stone)	BC2 (Concrete block)	
Scenario A	1244175	35433	Retrofit strategy cost (24645 JD).	0.24	0.69	35
Scenario B	1244175	35433	Demolition cost (8847JD) in addition to constructed stone center cost (400JD/m²) and concrete block center cost (350 JD/m²).	6	15.6	50
Scenario C	1244175	35433	Constructed stone center cost (400 JD/m²) and concrete block center cost (350 JD/m²) in addition to new landfill cost (600000 JD).	12	32.3	50

Figure 7: Total energy saved from CO_2 emissions reduction over the entire lifespan versus retrofit embodied CO_2 of (a) Retrofitting existing center and (b) Construction of a new concrete block center for the two base cases, B.C1 stone envelope, and B.C2: concrete block envelope



characteristics between stone and concrete block walls, this finding was warranted.

B1M16 and B2M6 were the best options for window system scenarios, saving 31% and 28% of total energy consumption for stone and concrete block, respectively. These were likewise the cases with the greatest NPV. In contrast, (Emmerich et al., 2015) indicated that infiltration might either raise or decrease cooling loads depending on climate and other building variables. Aside from that, the window frame retrofit was the least efficient retrofit scenario because of the low energy efficiency, which is related to the window frame's small size, which accounts for 5% of the total area of the window system.

In this study, holistic retrofit strategies for stone and concrete block saved 24.9% and 31.4% of energy, respectively. Despite having a shorter life cycle time (35 years) than other building energy upgrade techniques, the holistic retrofit approach was more cost-effective and environmentally beneficial than the demolition and rebuilding methods. This study's findings are similar to those of Dong et al., Jagarajan et al., and Wastiels et al. (Dong et al., 2005; Jagarajan et al., 2017; Wastiels et al., 2016). In other cases, however, poor building condition can dramatically increase retrofitting costs, making new construction more enticing (Wilkinson Sara, 2009). Furthermore, a new construction option may be advantageous, particularly in an urban setting with space constraints (Wastiels et al., 2016).

7. CONCLUSION

This research created an analytical knowledge base to determine the economic-environmental feasibility of locally accessible energy retrofitting solutions for the entire stock of healthcare facility buildings by examining their energy, economic, and environmental implications. The research methodology was developed to be replicated in various geographical regions using representative healthcare buildings. First, this method identified the reference healthcare facilities, and then the entire healthcare facility stock was subjected to three selection criteria: climatic region, public architectural prototype, and life cycle span. For each representative healthcare facility, the energy-saving and economic–environmental feasibility of multi-stage criteria are assessed based on selected energy retrofitting measures. The latter process was conducted to select the best measures for upgrading each envelope element (the external wall, roof, and window system) and combine these elements to create a retrofit strategy.

All the proposed energy retrofitting measures were economically and environmentally feasible in the two base cases. A PUR insulation system for wall and roof and window air tightness was the best way to combine and create a holistic retrofit strategy, leading to lower energy consumption of stone and concrete block by 24.9% and 31.4%, respectively. This technique resulted in yearly profits of 473,025 JD and 684,018 JD, as well as reductions in CO_2 emissions of 1,880,974 (kg CO 2 eq./m^2) and 2,691,169 (kg CO 2 eq./m^2). where this emission decrease is owing to a drop in end-of-life energy (electricity) consumption, which is provided by fossil fuels (primary energy). In Jordan, fossil fuel is used to generate the electricity content of diesel and natural gas with 74.1 kg CO_2/GJ and 55.82 kg CO_2/GJ emissions factors, respectively. This, in turn, represents a significant reduction in CO_2 emissions.

In the two base cases, the holistic retrofit strategy developed in this study was more economically and environmentally feasible than demolishing and rebuilding or beginning new construction on new land. Providing effective and transparent guidance and recommendations to local clients with varied knowledge levels will improve their quality of life in an economical and environmentally friendly manner. Since they were developed in response to local circumstances and government policy, these proposals may be incorporated into codes and institutionalized. This method will also provide for more extensive and well-structured standards to guide existing building efficiency upgrades. These data might be utilized as the foundation for retrofit software in the future, providing decision-makers with a rapid overview of their future intentions. Another research might look at all present healthcare facility life spans because they play a significant role in retrofit feasibility and offer additional options for rebuilding and establishing new structures. Alternatively, a study might be conducted using social life cycle methodologies to analyze the surrounding environment as part of the building envelope and how the surrounding design can affect energy usage and social aspects.

REFERENCES

Aditya, L., Mahlia, T.M.I., Rismanchi, B., Ng, H.M., Hasan, M.H., Metselaar, H.S.C., Aditiya, H.B. (2017), A review on insulation materials for energy conservation in buildings. Renewable and Sustainable Energy Reviews, 73, 1352-1365.

Akadiri, P.O., Chinyio, E.A., Olomolaiye, P.O. (2012), Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector. Buildings, 2(2), 126-152.

Amirkhani, S., Bahadori-Jahromi, A., Mylona, A., Bohdanowicz, P., Cook, D. (2019), Impact of Low-E window films on energy consumption and CO_2 emissions of an Existing UK hotel building. Sustainability, 11, 11164265.

Anwer, G., Mohd Faizal Mohideen, B., Juntakan, T. (2020), Energy efficiency and thermal comfort in hospital buildings: A review. International Journal of Integrated Engineering, 12(3), 1-17.

Asdrubali, F., Grazieschi, G. (2020), Life cycle assessment of energy efficient buildings. Energy Reports, 6, 270-285.

Asif, M., Hamoud, A., Ashraf, F., Khan, H., Mobeen, M., Hassan, M. (2017), Life cycle assessment of a three-bedroom house in Saudi Arabia. Environments, 4, 52.

Attia, S., Al-Khuraissat, M. (2016), Life Cycle Costing for a Near Zero Energy Building in Jordan: Initial Study. The 5th Architectural Jordanian International Conference.

Başarır, B., Diri, B., Diri, C. (2012), Energy Efficient Retrofit Methods at the Building Envelopes of the School Buildings, PhD Thesis.

Bawaneh, K., Ghazi Nezami, F., Rasheduzzaman, M., Deken, B. (2019), Energy consumption analysis and characterization of healthcare facilities in the United States. Energies, 12(19), 3775.

Benzar, B.E., Park, M., Lee, H.S., Yoon, I., Cho, J. (2020), Determining retrofit technologies for building energy performance. Journal of Asian Architecture and Building Engineering, 19(4), 367-383.

Bullen, P. (2007), Adaptive reuse and sustainability of commercial buildings. Facilities, 25, 20-31.

CEN. (2019), European Committee for Standardization CEN. Brussels, Belgium: CEN.

Chadi, Y., Caesar, A.S., Girma, B. (2011), Air infiltration through building envelopes: A review. Journal of Building Physics, 35(3), 267-302.

Cheng, F., Zhang, X., Su, X. (2017), Comparative assessment of external and internal insulation for intermittent air-conditioned bedrooms in Shanghai. Procedia Engineering, 205, 50-55.

Dixit, M., Fernandez-Solis, J., Lavy, S., Culp, C. (2012), Need for an embodied energy measurement protocol for buildings: A review paper. Renewable and Sustainable Energy Reviews, 16, 3730-3743.

Dong, B., Kennedy, C., Pressnail, K. (2005), Comparing life cycle implications of building retrofit and replacement options. Canadian Journal of Civil Engineering - CAN J CIVIL ENG, 32, 1051-1063.

El-Darwish, I., Gomaa, M. (2017), Retrofitting strategy for building envelopes to achieve energy efficiency. Alexandria Engineering Journal, 56(4), 579-589.

Emmerich, S.J., Persily, A.K., McDowell, T.P. (2015), Impact of Infiltration on Heating and Cooling Loads in US Office Buildings. AIVC.

Ergin, A., Tekce, I. (2020a), Enhancing sustainability benefits through green retrofitting of healthcare buildings. IOP Conference Series: Materials Science and Engineering, 960, 032066.

Ergin, A., Tekce, I. (2020b), Enhancing Sustainability Benefits Through Green Retrofitting of Healthcare Buildings. Paper Presented at the IOP Conference Series: Materials Science and Engineering.

Fan, Y., Xia, X. (2015), A multi-objective optimization model for building envelope retrofit planning. Energy Procedia, 75, 1299-1304.

Fifield, L.J., Lomas, K.J., Giridharan, R., Allinson, D. (2018), Hospital wards and modular construction: Summertime overheating and energy efficiency. Building and Environment, 141, 28-44.

Franco, A., Shaker, M., Kalubi, D., Hostettler, S. (2017), A review of sustainable energy access and technologies for healthcare facilities in the Global South. Sustainable Energy Technologies and Assessments, 22, 92-105.

Gangolells, M., Casals, M., Ferré-Bigorra, J., Forcada, N., Macarulla, M., Gaspar, K., Tejedor, B. (2020), Office representatives for cost-optimal energy retrofitting analysis: A novel approach using cluster analysis of energy performance certificate databases. Energy and Buildings, 206, 109557.

Gangolells, M., Gaspar, K., Casals, M., Ferré-Bigorra, J., Forcada, N., Macarulla, M. (2020), Life-cycle environmental and cost-effective energy retrofitting solutions for office stock. Sustainable Cities and Society, 61, 102319.

González, A.G., Sanz-Calcedo, J., Salgado, D. (2017), A quantitative analysis of final energy consumption in hospitals in Spain. Sustainable Cities and Society, 36, 169-175.

Güçyeter, B., Günaydın, H.M. (2012), Optimization of an envelope retrofit strategy for an existing office building. Energy and Buildings, 55, 647-659.

Heires, M. (2008), The international organization for standardization (ISO). New Political Economy, 13(3), 357-367.

Hong, Y., Deng, W., Ezeh, C.I., Peng, Z. (2019), Attaining sustainability in built environment: Review of green retrofit measures for existing buildings. IOP Conference Series: Earth and Environmental Science, 227, 042051.

Husin, S., Zaki, N., Husain, M. (2019), Implementing sustainability in existing building through retrofitting measures. International Journal of Civil Engineering and Technology (IJCIET), 10(01), 1450-1471.

Ingrao, C., Messineo, A., Beltramo, R., Yigitcanlar, T., Ioppolo, G. (2018), How can life cycle thinking support sustainability of buildings? Investigating life cycle assessment applications for energy efficiency and environmental performance. Journal of Cleaner Production, 201, 556-569.

Jaber, J.O., Mohsen, M.S., Al-Sarkhi, A., Akash, B. (2003), Energy analysis of Jordan's commercial sector. Energy Policy, 31(9), 887-894.

Jafari, A., Valentin, V. (2017), An optimization framework for building energy retrofits decision-making. Building and Environment, 115, 118-129.

Jagarajan, R., Abdullah Mohd Asmoni, M.N., Mohammed, A.H., Jaafar, M.N., Lee Yim Mei, J., Baba, M. (2017), Green retrofitting-a review of current status, implementations and challenges. Renewable and Sustainable Energy Reviews, 67, 1360-1368.

JGBC. (2020), Net Zero Buildings in Jordan. Berlin, Germany: ResearchGate.

Karmany, H., El-Haggar, S., Tarabieh, K., Sewilam, H. (2016), American University in Cairo, Master's Thesis. AUC Knowledge Fountain. Available from: https://www.fount.aucegypt.edu/etds/386

Khoukhi, M., Darsaleh, A., Ali, S. (2020), Retrofitting an existing office building in the UAE towards achieving low-energy building. Sustainability, 12, 2573.

Kovacic, I., Reisinger, J., Honic, M. (2018), Life cycle assessment of embodied and operational energy for a passive housing block in Austria. Renewable and Sustainable Energy Reviews, 82, 1774-1786.

Kumar, G., Raheja, G. (2016), Design determinants of building envelope for sustainable built environment: A review. International Journal of Built Environment and Sustainability, 3, 127.

Kunič, R. (2017), Carbon footprint of thermal insulation materials in building envelopes. Energy Efficiency, 10(6), 1511-1528.

Lucero-Álvarez, J., Rodriguez-Muñoz, N., Martin-Dominguez, I. (2016), The effects of roof and wall insulation on the energy costs of low income housing in Mexico. Sustainability, 8, 590.

Mangan, S.D., Oral, G.K. (2015), A study on life cycle assessment of energy retrofit strategies for residential buildings in Turkey. Energy Procedia, 78, 842-847.

Ministry of Environment MOE. (2017). Jordan's First Biennial Update Report to the United Nations Framework Convention on Climate Change. New Delhi: Ministry of Environment MOE.

MOH. (2020), Healthcare Centers Archive Data. New Delhi: MOH.

Nicolae, B., George-Vlad, B. (2015), Life cycle analysis in refurbishment of the buildings as intervention practices in energy saving. Energy and Buildings, 86, 74-85.

Oregi, X., Hernandez, P., Gazulla, C., Isasa, M. (2015), Integrating simplified and full life cycle approaches in decision making for building energy refurbishment: Benefits and barriers. Buildings, 5, 354-380.

Ortiz, O., Castells, F., Sonnemann, G. (2009), Sustainability in the construction industry: A review of recent developments based on LCA. Construction and Building Materials, 23(1), 28-39.

Pistore, L., Pernigotto, G., Cappelletti, F., Gasparella, A., Romagnoni, P. (2019), A stepwise approach integrating feature selection, regression techniques and cluster analysis to identify primary retrofit interventions on large stocks of buildings. Sustainable Cities and Society, 47, 101438.

Pratt, D.M. (2006), Selecting Energy Efficient Building Envelope Retrofits to Existing Department of Defense Building Using Value Focused Thinking. 125, ADA446354.

Rabani, M., Madessa, H.B., Ljungström, M., Aamodt, L., Løvvold, S., Nord, N. (2021), Life cycle analysis of GHG emissions from the building retrofitting: The case of a Norwegian office building. Building and Environment, 204, 108159.

Randolph, J., Masters, G.M. (2018), Energy for Sustainability. 2nd ed. Australia: Island Press.

Ruparathna, R., Hewage, K., Sadiq, R. (2016), Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings. Renewable and Sustainable Energy Reviews, 53, 1032-1045.

Sabnis, A., Mysore, P., Anant, S. (2015), Construction Materials-Embodied Energy Footprint-Global Warming; Interaction. Singapore: Structural Engineers World Congress.

SILVIA. (2018), Environmental Benchmarks for Buildings. Luxembourg: Publications Office of the European Union.

Spickova, M., Myskova, R. (2015), Costs efficiency evaluation using life cycle costing as strategic method. Procedia Economics and Finance, 34, 337-343.

Thinate, N., Wongsapai, W., Damrongsak, D. (2017), Energy performance study in thailand hospital building. Energy Procedia, 141, 255-259.

Vilches, A., Garcia-Martinez, A., Sanchez-Montañes, B. (2017), Life cycle assessment (LCA) of building refurbishment: A literature review. Energy and Buildings, 135, 286-301.

Wastiels, L., Janssen, A., Decuypere, R., Vrijders, J. (2016), Demolition versus Deep Renovation of Residential Buildings: Case Study with Environmental and Financial Evaluation of Different Construction Scenarios. Zurich: SBE16 - Sustainable Built Environment Conference.

Weir, G., Muneer, T. (1998), Energy and environmental impact analysis of double-glazed windows. Energy Conversion and Management, 39(3), 243-256.

Wilkinson Sara, J. (2009), Using building adaptation to deliver sustainability in Australia. Structural Survey, 27(1), 46-61.

William, M., Elharidi, A., Hanafy, A., El-Sayed, A.H. (2019), Assessing the energy efficiency and environmental impact of an egyptian hospital building. IOP Conference Series Earth and Environmental Science, 397, 012006.

William, M.A., Elharidi, A.M., Hanafy, A.A., Attia, A., Elhelw, M. (2020), Energy-efficient retrofitting strategies for healthcare facilities in hot-humid climate: Parametric and economical analysis. Alexandria Engineering Journal, 59(6), 4549-4562.

Wood, B. (2006), The role of existing buildings in the sustainability agenda. Facilities, 24, 61-67.

World Health Organization, World Bank. (2014), Access to Modern Energy Services for Health Facilities in Resource-constrained Settings: A Review of Status, Significance, Challenges and Measurement (Reprinted in 2015 with Changes ed.). Geneva: World Health Organization.

Zuo, J., Zhao, Z.Y. (2014), Green building research-current status and future agenda: A review. Renewable and Sustainable Energy Reviews, 30, 271-281.