Evaluation of Energy Performance of The Most Prevalent Housing Archetypes in Jordan

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Keywords: Energy Performance, Housing archetypes, Stock modelling.

Abstract

The residential sector is responsible for the consumption of 46% of the building's total primary energy consumption in Jordan. Despite the Jordanian government's commitment to significantly reduce national emissions by 2050, building Operational Carbon (OC) has been under-researched in the Jordanian context. This study aims to present the development of an archetypes-based housing stock model. The model is then used to evaluate the impact of a series of suggested refurbishment scenarios, to reduce the stock's operational carbon impact.

First, the most prevalent dwellings are identified and categorized into 'archetypes' based on the analysis of a housing survey database on Jordanian dwellings. Subsequently, the performance of these archetypes is evaluated in terms of OC. Finally, the improvement scenarios are investigated, and their impact on OC is evaluated.

Keywords: Operational carbon, Housing archetypes, Stock modelling, Refurbishment.

Abbreviations and acronyms

OC	Operational Carbon	HRM	House Rural Mountains
AUM	Apartment Urban Mountains	DOS	Department of Statistics
HUM	House Urban Mountains	JGBC	Jordan Green Building Council

1. Introduction

One-third of greenhouse gas emissions and 40% of the world's energy usage are attributed to buildings. Energy is one of the most important security issues facing Jordan since it depends extensively on imports [1]. Due to this, Jordan is one of the countries to be highly affected by climate change impacts.

Operational Carbon (OC) is the carbon that is emitted during a building's operation; by using lighting, small power, heating, cooling and other infrastructure [2]. Estimates of stock-level energy and environmental performance are carried through 'top-down' and 'bottom-up' approaches [4]. The energy consumption of a group of buildings is commonly assessed at the sectoral level without considering variations among individual buildings or end-uses in top-down models, which treat a group of buildings as a single energy unit. Bottom-up modeling strategies, in contrast, concentrate in specific structures and end-uses [5].

Since the bottom-up models operate at a disaggregated level, comprehensive empirical databases are required to support the description of each component [6]. Due to the increasing number of ageing structures and the quick pace of technological development, building refurbishment is emerging as a key economic driver in the construction industry [7]. Building refurbishment is an endeavour that crosses several technical disciplines and faces challenges in incorporating renewable energy in a built environment [8]. Energy consumption in dwellings is estimated using building physics, empirical data from housing surveys and other datasets, as well as assumptions about buildings' operation [5]. It is suggested that in residential buildings, retrofitting wall and roof insulation offers the most prospects for energy savings [9] [10] [11] [12].

In order to select the optimum technical solutions for the envelope and/or energy systems, different studies have used optimization methods for economic and/or environmental factors [13] [14].

This paper seeks to explore the impact of a series of refurbishment measures on the Operational Carbon performance of the Jordanian housing stock. The study first identifies an archetypes-based housing stock model in Jordan based on the available housing databases. It then presents the energy performance of the most prevalent archytypes as well as formulating and eploring the impact of a series of improvement scenarios, to reduce operational carbon emissions with different strategies at scale.

2. Methodology

This paper demonstrates the generation of a Jordanian housing stock model based on archetypes. The generated models are then used to analyse the OC and to evaluate the effects of several scenarios for the Jordanian housing stock improvement in order to reduce the operational carbon footprint.
Below are the procedures developed to identify the archetypes that are assessed in terms of OC to determine improvement opportunities.

2.1 Defining archetypes-based housing stock model

The classification used to identify archetypes, as shown in figure 1, is based on the typology, urban/rural distribution and age band based on the analysis of a housing survey database of Jordanian dwellings issued by the Department of Statistics (DOS) [15]. The dwellings are classified into three main typologies that represent Jordanian housing stock; Traditional house, Apartment and Villa. Classification of Jordan's cities according to climate zones is one of the criterias used to identify the archetypes, as seen in the flowchart below. Amman, Zarqa'a, Irbid, Balqa'a, Madaba, Ajloun, Jerash, and Karak are all represented by the mountainous region, whilst the Badia region includes Aqaba, Ma'an and Mafraq cities. A segment of the East African Rift System, the Jordan Valley follows the north-south course of the Jordan River from the Sea of Galilee to the Dead Sea. The majority of buildings used there is a commercial units (hotels). Within each climate region and typology, the buildings are divided into age groups according to when they were built: before 1950, between 1950 and 1970, between 1980 and 1990, and after 2000.

Table 1 displays the proposed metrics for determining the archetypes within each typology after employing the classification approach. The number of buildings (M1), the number of units (M2), and the area of units (M3) are the parameters used to determine the most prevalent archetypes from the entire housing stock of each typology.

Based on a preliminary analysis of the available databases, the stock can be disaggregated into several archetypes that are characterized by age, number of floors, unit floor area and others. The different archetypes are classified into twenty-one variants. The most prevalent dwellings, based on the three metrics (M1, M2 and M3), are identified in table 1; Apartment-Urban-Mountain (AUM), House-Urban-Mountain (HUM) and House-Rural-Mountain (HRM). These archetypes are estimated to make up around 88% of the stock's total number of residential units and 84% of its overall number of buildings and respective areas. The percentages of buildings, units and area illustrated in table 1 correspond to the proportion from the entire housing stock.

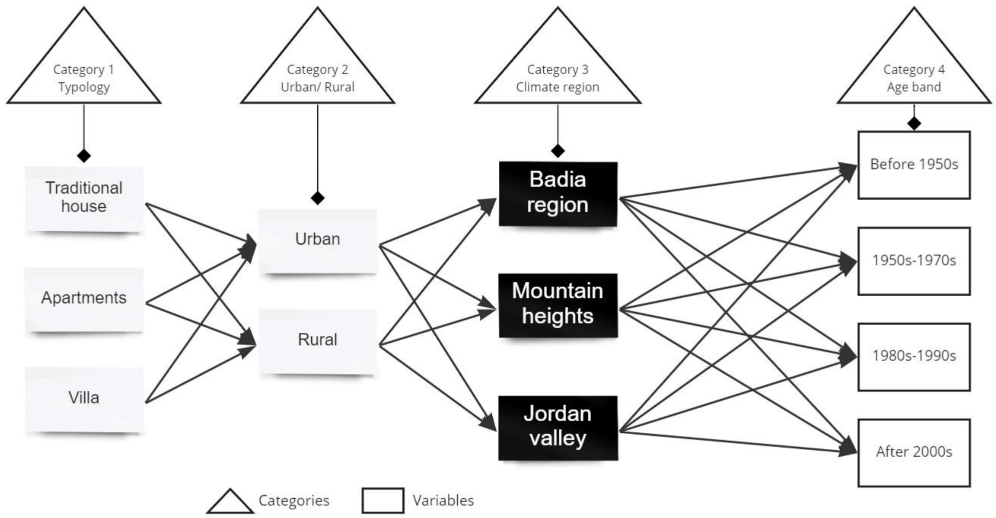


Figure 1, Flow-chart of the investigation of the current Jordanian housing stock

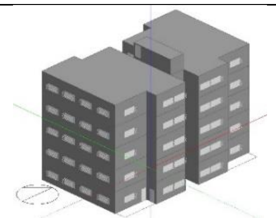
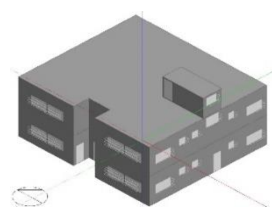
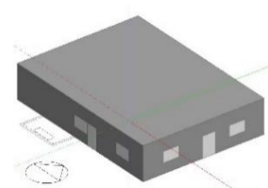
Table 1, Evaluated metrics for the Jordanian housing stock

Typologies	Urban/ Rural	Climate region	Buildings	% Buildings	Units	% Units	Area - Units	% Area
Apartment	Urban	Mountains	253,350	36.0%	1,167,481	57.9%	178,381,175	68.9%
		Desert	13,340	1.9%	62,713	3.1%	10,121,600	3.9%
		Jordan valley	5,479	0.8%	6,384	0.3%	2,859,125	1.1%
	Rural	Mountains	9,913	1.4%	31,807	1.6%	11,047,300	4.3%
		Desert	4,616	0.7%	5,285	0.3%	3,007,825	1.2%
		Jordan Valley	1,446	0.2%	2,332	0.1%	986,847	0.4%
House	Urban	Mountains	263,209	37.4%	481,230	23.9%	26,570,353	10.3%
		Desert	33,389	4.7%	77,986	3.9%	5,484,000	2.1%
		Jordan Valley	1,070	0.2%	1,234	0.1%	485,703	0.2%
	Rural	Mountains	71,965	10.2%	115,962	5.8%	10,827,625	4.2%
		Desert	28,140	4.0%	54,652	2.7%	6,489,350	2.5%
		Jordan Valley	1,030	0.1%	930	0.0%	291,501	0.1%
Villa	Urban	Mountains	15,045	2.1%	4,945	0.2%	2,045,800	0.8%
		Desert	404	0.1%	394	0.0%	63,350	0.0%
		Jordan Valley	0	0.0%	0	0.0%		0.0%
	Rural	Mountains	1,581	0.2%	1,571	0.1%	142,800	0.1%
		Desert	193	0.0%	183	0.0%	34,400	0.0%
		Jordan Valley	0	0.0%	0	0.0%	0	0.0%
Total			704,170		2,015,089		258,838,754	
Total percentage of the most 3 prevalent archetypes from the entire stock				83.6%		87.6%		83.4%
Total percentage of the most 5 prevalent archetypes from the entire stock				86.9%		92.3%		91.5%
Total percentage of the most 7 prevalent archetypes from the entire stock				95.6%		98.8%		96.2%

2.2 Developing the AUM, HUM and HRM housing models

With regard to the annual growth rates of housing stock in Jordan, the study focuses on the most prevalent archetypes (AUM, HUM and HRM) after the 2000s in terms of age-band. The identification of data sources that can be utilised to fill any model's underlying databases is integral to the model development process. The required data sources for generating the models of the three archetypes are defined based on the available academic literature in the field, as well as readily accessible governmental databases and census data, e.g., Jordan Green Building Council (JGBC) survey and housing census issued by the Department of Statistics (DOS) [15] [16]. The models can be defined based on the prevalence of the primary parameters that define the envelope characteristics and building physics, (Table 2).

Table 2, The characteristics of the most prevalent residential buildings in Jordan.

		AUM (Apartment-Urban-Mountain)	**HUM** (House-Urban-Mountain)	**HRM** (House-Rural-Mountain)	**Source**
General	Number of floors	5	2	1	[15]
	Units/floor	2	1	1	[15]
	Area/ Unit	175 m²	250 m²	175 m²	[15]
	Plan				*Assumption*
	3D mode				*Assumption*
Fabric	External wall U-Value	1.99 w/m²K	1.99 W/m²k	2.55 W/m²k	[17] , [15]
	Slab between floors U-Value	1.7 W/m²k	1.7 W/m²k	1.7 W/m²k	[17]
	Internal partition U-Value	2.41 W/m²k	2.41 W/m²k	2.41 W/m²k	[17]
	Infiltration	0.6 ach	0.6 ach	0.85 ach	[18]
	Door U-value	2.85 W/m²k	2.85 W/m²k	2.85 W/m²k	[19]
Activity	Operation schedule	Weekday Hours / Factor 5:00am – 7:00 am / 0.75 7:00am - 2:00 pm / 0.25 2:00pm - 5:00 am / 1 Weekend Hours / Factor 11:00am – 1:00 pm / 0.50 1:00pm - 11:00 pm / 1	Weekday Hours / Factor 5:00am – 7:00 am / 0.75 7:00am - 2:00 pm / 0.25 2:00pm - 5:00 am / 1 Weekend Hours / Factor 11:00am – 1:00 pm / 0.50 1:00pm - 11:00 pm / 1	Weekday Hours / Factor 5:00am – 7:00 am / 0.75 7:00am - 2:00 pm / 0.25 2:00pm - 5:00 am / 1 Weekend Hours / Factor 11:00am – 1:00 pm / 0.50 1:00pm - 11:00 pm / 1	[17]
	Occupancy (m²/person/unit)	35	40	35	[18]
	Catering	LPG -190 Kg/Y – 15 Cylinder/Year	LPG -225 Kg/Y – 18 Cylinder/Year	LPG -190 Kg/Y – 15 Cylinder/Year	*Assumption*, [16]
Openings	Glazing type	Double clear glass - 6mm 13 mm Air	Double clear glass - 6mm 13 mm Air	Single clear glass 6mm	[18], [16]
	Dimensions	Width 2.00 Height 1.00	Width 2.00 Height 1.00	Width 1.50 Height 1.00	[16]
	Frame	Aluminum 0.04	Aluminum 0.04	Aluminum 0.04	[16]
	Solar transmission SHGC	0.53	0.53	0.71	[16]
	WWR (Window-wall ratio)	35%	40%	30%	[16]
	Glazing U-Value W/m². k	2.65	2.65	5.20	[16]
	Reveal (m)	0.2	0.2	0.2	[16]
Lig htin	Lighting intensity level Lux	Bedrooms, Stairs 100 Living room, Bathroom 150 Kitchen 225	Bedrooms, Stairs 100 Living room, Bathroom 150 Kitchen 225	Bedrooms, Stairs 100 Living room, Bathroom 150 Kitchen 225	Assumption, [20]
HVAC	Ventilation (ach)	Summer: 0.6 ach Winter: 0.6 ach	Summer: 0.6 ach Winter: 0.6 ach	Summer: 5 ach Wintetr: 0.85 ach	Assumption, [21]
	Heating	Electric heater (1)	Boiler/ Diesel (0.75)	Gas heater LPG (0.70)	[18], [15]
	Cooling	Air conditioner (AC Split unit CoP 2.4)	Air conditioner (AC Split unit CoP 2.4)	Electric fans	[22]
	Fan power density w/m²	-	-	2.3 (100 W- 4 box fans)	Typical product
	DHW source/CoP	Electricity - 0.9	Electricity – 0.9	Electricity – 0.9	Assumption [23]
	Daily DHW demand (l/P)	50	50	50	DB default data

2.3 Evaluation of operational carbon emissions

A dynamic simulation approach using DesingBuilder is adopted to evaluate the OC. The JGBC carried out an energy consumption survey to develop an energy use benchmark for residential apartments in Amman. The simulation result is presented in figure 2 for the annual energy use. Heating, cooling, lighting, domestic hot water (DHW), electrical appliances, and energy consumed for cooking and kitchen are considered. This follows the classification used for benchmarking new apartments in Amman.

Figure 3 illustrates the total annual energy consumption of the AUM, HUM and HRM archetypes (kWh/m² per annum). It presents the annual energy consumption for each of these three archetypes in GWh from the annual energy consumption of the entire housing stock. AUM consumes the highest amount of energy at around 8000 GWh/Y.

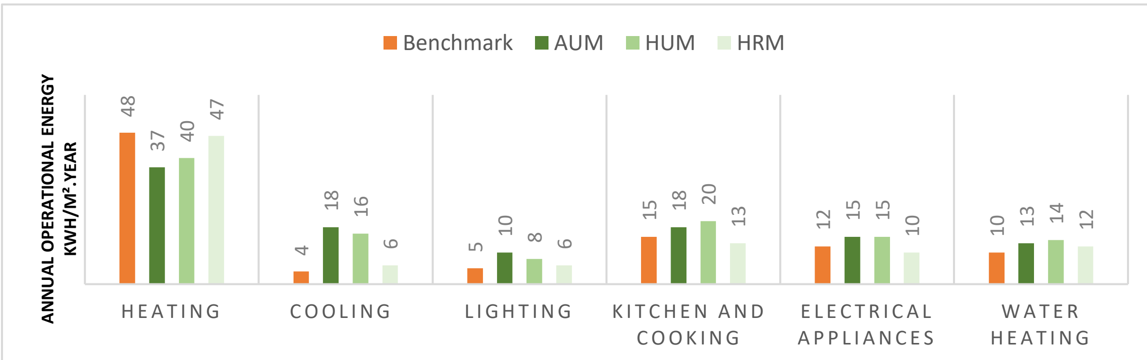
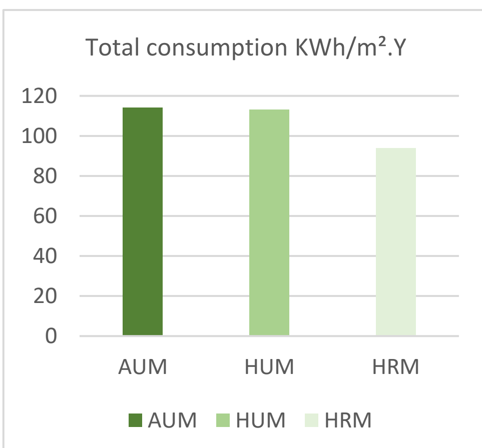


Figure 2, The analysis of annual energy use of the AUM, HUM, and HRM archetypes in comparison to a local benchmark derived for Apartments.



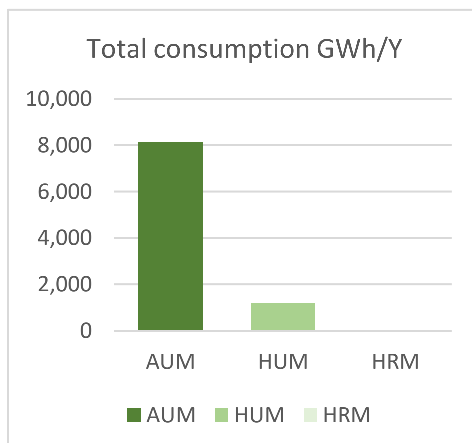


Figure 3, The total annual energy use of the AUM, HUM, and HRM archetypes in (kWh/m².Y) and the aggregated energy consumption (GWh/Y).

2.4 Investigating refurbishment scenarios to reduce CO_2 emissions

The AUM archetype, which represents the Jordanian housing stock's largest energy consumer, as shown in fig.3, has the greatest potential to reduce the OC from the entire Jordanian housing stock. Table 3 outlines three strategies of refurbishment that were employed to enhance the energy efficiency of dwellings, using AUM model as a baseline. The strategies are divided into three categories: passive, active and renewable improvements. Strategy 1 (passive) suggests improvements for envelope components, strategy 2 (active) improves the system used for heating, cooling and lighting, and the third one is focused on generating energy onsite using PV system.

Table 3, Characteristics of adopted strategies used to improve energy performance of AUM archetype.

Parameters	AUM (Base case)	Strategy 1 (Passive)	Strategy 2 (Active)	Strategy 3 (Renewable)
Wall U-Value	1.99 W/m²K	0.54 W/m²K XPS Extruded polystyrene 5 cm (addition)	0.54 W/m²K XPS Extruded polystyrene 5 cm (addition)	0.54 W/m²K XPS Extruded polystyrene 5 cm (addition)
Internal wall U-value	2.41 W/m²K	2.00 W/m²K In-Out Plaster /Dense (addition)	2.00 W/m²K In-Out Plaster /Dense (addition)	2.00 W/m²K In-Out Plaster /Dense (addition)
Floor (Slabs) U-value	1.70 W/m²K	0.68 (W/m²K) 3 cm extruded polystyrene (addition)	0.68 (W/m²K) 3 cm extruded polystyrene (addition)	0.68 (W/m²K) 3 cm extruded polystyrene (addition)
Glazing type	Double clear glass - 6mm 13 mm Air (U value 2.65)	Double Clr glazing, LoE, Argon filled (U value: 1.49)	Double Clr glazing, LoE, Argon filled (U value: 1.49)	Double Clr glazing, LoE, Argon filled (U value: 1.49)
Cooling	Split unit, Energy Efficiency Ratio 2.4	Split unit, Energy Efficiency Ratio 2.4	Split unit – Energy Efficiency Ratio 3.5	Split unit – Energy Efficiency Ratio 3.5
Heating	Electric heater, COP 1	Electric heater, COP 1	Heat Pump- Electricity - CoP 4	Heat Pump- Electricity - CoP 4
Lighting control	None	None	Used (DB default)	Used (DB default)
Infiltration	0.60 ACH	0.60 ACH	0.35 ACH	0.35 ACH
PV	None	None	None	4 kW solar array 30˚ degree facing south Load centre: DC direct current with an inverter

The values recommended by local codes for building components including external walls, roofs, and glazing U-values were utilized to meet the best practice scenario in Jordan for enhancing the efficiency of building envelopes [16].

3. Results

Figure 2 identifies space heating as the largest primary energy end-use (around 37 kWh/m² per year in the AUM archetype as base case). As shown in figure 4 the reduction of the annual energy consumption after improvements is 14% in the passive strategy, and 41% in the active strategy. The annual energy is 70% less in strategy 3 of energy generation using the photovoltaic system.

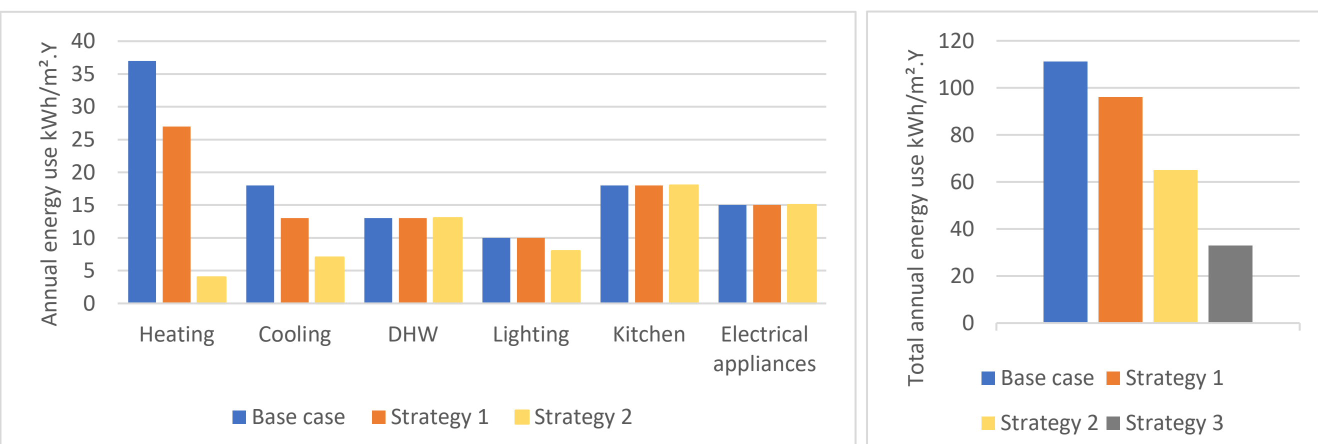


Figure 4, The analysis of annual energy use from fussil fuels and the national grid for the AUM archetype considering three scenarios of improvement strategies.

A 70% reduction in operational carbon after improvement, as shown in figure 5, is attained through the heating technology improvement (using electricity through the heat pump system), cooling system improvement (using DX air conditioning with a higher energy efficiency ratio) and onsite energy generation through PV systems are the most important contributors to the reduction of OC.

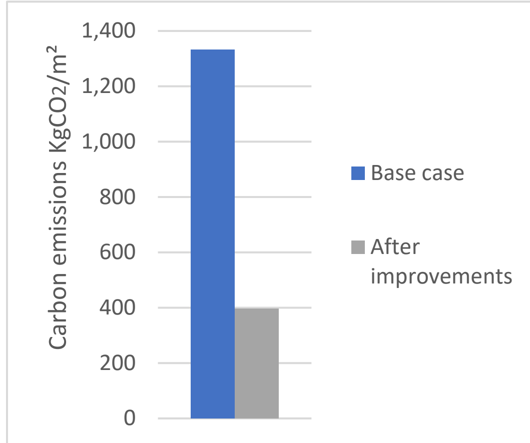


Figure 5, The reduction of OC through 30 years of building operation to 2050s (a milestone considered for transition to Net-Zero) (AUM).

4. Discussion

This investigation found that new dwellings and refurbishments in Jordan have the potential to emit 70% lower OC when compared to AUM archetype as a baseline.

A theoretical concept called 'renewable' is developed to provide additional improvements that include further energy efficiency measures at the building level or at upstream to decarbonize the national electricity grid (with a current carbon intensity of circa 0.4 Kg CO_2/m^2 per annum). This could be used to offset 396 $kgCO_2/m^2$ of the annual OC to get to net-zero dwellings. The same concept can be applied to the other archytypes in the stock model to identify improvement opportunities at scale and the renewable capacity required upstream at the national grid to facilitate the transition to net-zero carbon in building sector.. Other potential improvements at the building level include the utilization of energy-efficient appliances, solar water heating systems and the use of electricity instead of LPG for cooking.

Figure 5 shows the reduction of OC over 30 years , which is used to estimate the renewable capacity required at upstream to get to net-zero by 2050. Another crucial element to consider when conducting a life cycle analysis is the examination of embodied carbon. The improvement of the envelope to reduce the consumption of energy of the AUM archetype causes a slight change in embodied carbon by adding insulation materials.

5. Conclusion

This paper demonstrates a method of generating a housing stock model for Jordan by defining and categorizing the dwelling archetypes into variant models based on typologies, climate region, and urban/rural distribution. Three types of improvement strategies were considered following an environmental design hierarchy starting from passive measures: the improvement of the building envelope (passive strategy), the improvement of energy supply in the form of heating and cooling systems (active), and the use of onsite renewable technology. The proposed concept of regenerative capacity can be used by policy-makers to help them plan for offsetting the remaining emissions.

This study will be extended to embodied carbon in future to adopt a more holistic approach to the evaluation of carbon emissions of the building stock in Jordan.The generated housing stock model will feature prominently in the studies articulating life cycle assessments of Jordanian dwellings within different climate regions, facilitating the transition towards zero-carbon emissions buildings. Consequently, it can help identify the strategies for the refurbishments for each archetype in the current stock, and the improvements for the new-builds.

Other future research will define the characteristics of archetypes models that represent the entire housing stock in Jordan. This theoretical framework will be extended in future research to include further potential strategies and archetype Jordanian dwellings.

6. Acknowledgement

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