Topic: Building Physics, Building Envelope and Materials, Low/Zero Carbon Emission Buildings and Communities

Identifying the Pathways Toward Zero Operational and Embodied Carbon Emissions for the Housing Stock in Jordan

Reham Alasmar*, Yair Schwartz, and Esfandiar Burman

IEDE Institute for Environmental Design and Engineering, UCL, London, United Kingdom

*Corresponding email: reham.alasmar.20@ucl.ac.uk

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

SUMMARY

Residential buildings in Jordan make up 72% of the total share of buildings. However, it is not yet a common practice to investigate Operational Carbon (OC) and Embodied Carbon (EC) of buildings following a holistic approach. This study aims to investigate the intricate relation between OC and EC to assess the feasibility of achieving zero carbon performance in dwellings in Jordan. First, the most common archetypes of residential buildings are identified. Next, thermal simulation is used to evaluate how these archetype dwellings might perform in terms of carbon emissions based on existing material and building services used in the construction supply chains. Finally, pathway scenarios to improve carbon footprint is investigated to find the optimum solutions in the 2000s apartments archetype in the future climate. The results show that implementing three levels of carbon emissions reduction measures can save up to 64% of annual OC and around 30% of EC.

INTRODUCTION

Global carbon emissions have increased by around 60% between 1990 and 2017 [1]. The construction sector is responsible for one-third of global carbon emissions and global resource consumption, 40% of the world's energy consumption and 40% of global waste [2]. A strong emphasis on improving the whole life carbon (WLC) of buildings should become mainstream to face these challenges and to meet long term carbon emissions targets. The Royal Institution of Charted Surveyors (RICS) has indicated that sizeable carbon emissions arising from the built environment are attributable not only to the use or operational emissions but also to their construction indirect embodied emissions [3]. OC is the CO2e emissions generated from the burning of fossil fuels used to heat, cool and power the building space during its service life [4], while EC emissions are incurred in material extraction and processing, component fabrication and construction of the building, although it may be extended to include the end-of-life carbon emissions [5].

Jordan has been facing substantial challenges including protecting its energy supply. Jordan imports more than 95% of its energy needs, mainly natural gas and oil, from neighbouring countries. Natural gas accounts for 88% of the total electricity generated in the country [7]. There is a gradual increase in electricity consumption in Jordan, and ascending levels of carbon emissions as well [8]. There are currently no mandatory requirements in terms of CO2 emissions for buildings in Jordan [9]. The last few decades in Jordan have seen a massive increase in energy consumption in the building sector Housing makes up to 72% of the total share of buildings in Jordan, and is considered to be a sector in growth: The number of housing units in Jordan increased from around 1.2 to 2,4 million between 2004 and 2015 [10]. This paper seeks to identify the main drivers for life cycle carbon emissions in residential buildings in Jordan. It also presents a suggested framework to reduce emissions with different interventions and in different building typologies.

METHODS

The framework aims to develop a pathway toward zero OC and EC emissions for residential buildings in Jordan. Below are the steps developed to identify the archetypes that are evaluated in terms of OC and EC to determine improvement scenarios.

1. Identifying the Most Common Archetypes of Residential Buildings

The most common archetypes are defined by the combination of building thermal properties, available statistical data (e.g., Jordan green building council survey and Housing census) and assumptions about building operation. Figure 1 depicts the distribution of the characteristics of dwellings in Jordan (Age band, Envelope materials, Number of floors, etc.). This helped identifying building archetypes by their characteristics.

As follows in figure 1, the buildings are categorized as apartments that were built in the 2000s (Archetype 1), 1980s apartments (Archetype 2) and traditional houses (Archetype 3) based on the percentage classification of the housing census in Jordan. The data required for modelling is illustrated with defined references in table 1.

2. Evaluation of Operational and Embodied carbon emissions

Dynamic simulation using DesignBuilder is used to determine the annual operational emissions for the three archetypes defined above. The simulation output is presented in figure 2For 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. The Jordan green building council (JGBC) developed an energy use benchmark for residential apartments in Amman by conducting an energy consumption survey. The average results of the survey were used to derive an Energy Use Intensity (EUI), which represents an energy benchmark for a typical residential apartment [10].

A preliminary estimate of embodied carbon is calculated by DesignBuilder using the Bath ICE (Inventory of Carbon and Energy) database for calculating embodied carbon emissions. As shown in Figs. 3 and 4, the embodied carbon of the archetype 1 dwelling is estimated for building materials of walls, roofs, floors and other components of a building.

3. Investigating improvement scenarios to reduce emissions:

Table 2 outlines three levels of the proposed intervention measures; level 1 suggests improvements for envelope components, level 2 improves the system used for heating and cooling and the third one is focused on generating energy onsite. To meet the best practice case in Jordan for improving the efficiency of building envelopes, the values recommended by local codes and Jordan green building council (JGBC) for building components such as external walls, roof, and glazing U-values were used [10]. In this paper, the intervention measures were only applied to Archetype 1 dwelling.

RESULTS

Fig.2 identifies space heating as the largest primary energy end-use (around 50 kWh/m² in Archetype 1). As shown in Fig.5 the reduction of the operational carbon emissions after improvements is 64%. The heating technology improvement (using electricity fuel through the heat pump system instead of LPG) and energy generation through the photovoltaic system are the most important contributors to the reduction of operational CO_2 emissions.

A 35% reduction in embodied carbon is attained through reducing the percentage of reinforcement from 2% to 1% (minimum requirement) in the roofs and floors, and eliminating the steel from reinforced concrete columns to achieve an 18.5% reduction. Furthermore, using PVC for window frames instead of aluminium reduces the carbon emitted from window frames by around 30%.

The improvement of the envelope to reduce the energy use of the archetype building 1 causes a slight increase in embodied carbon by adding insulation materials and shading elements.

Tables and illustrations

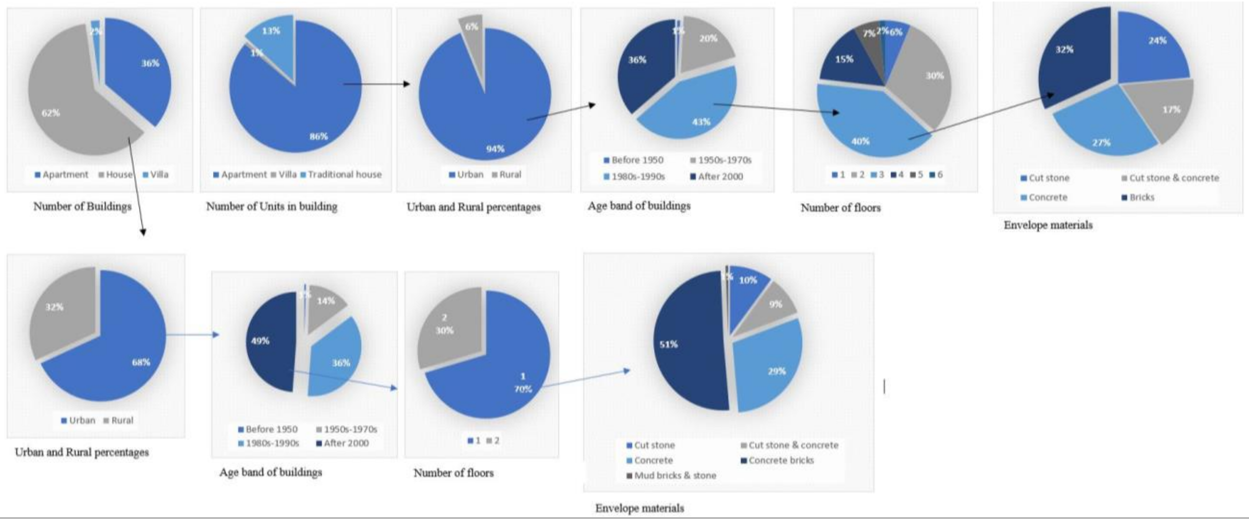

Figure 1, The distribution of Jordan residential building characteristics identified in the Jordan housing census 2015.

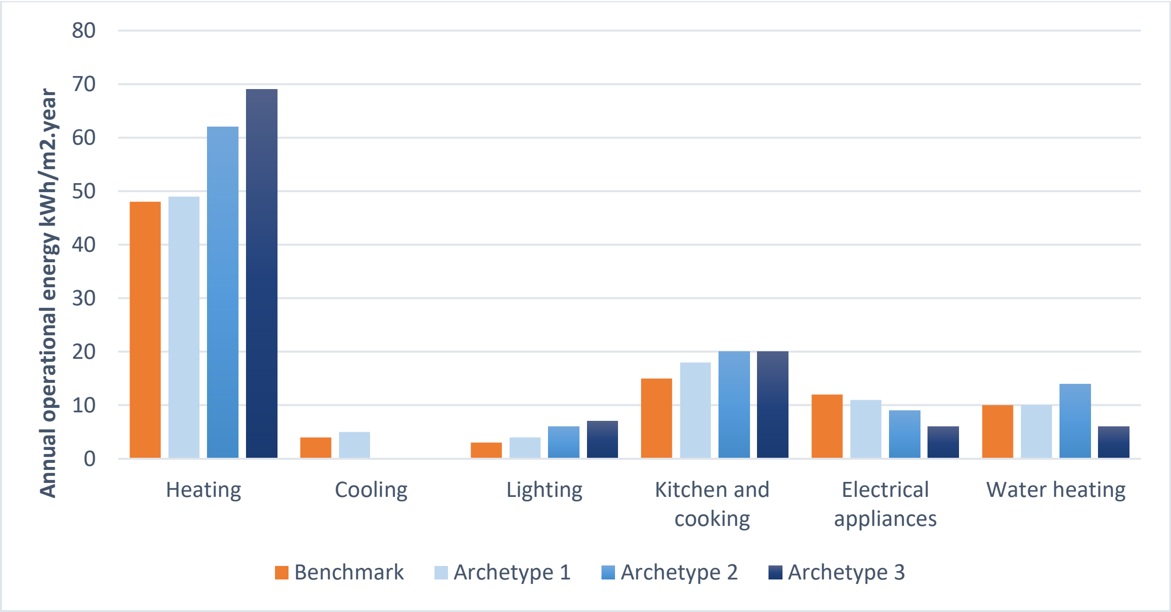

Figure 2, The analysis of annual energy use of the residential archetypes in comparison to a local benchmark derived for Archetype 1.

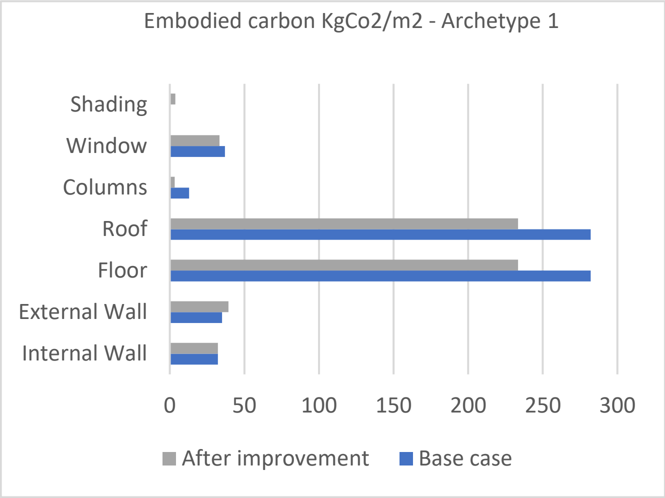

Figure 3, The embodied carbon of building components of Archetype 1 (Base case and after improvement)

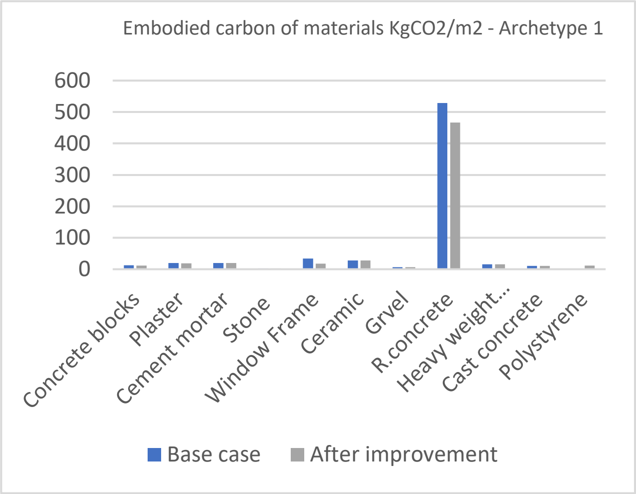

Figure 4, The embodied carbon of materials used in Archetype 1 (Base case and after improvement)

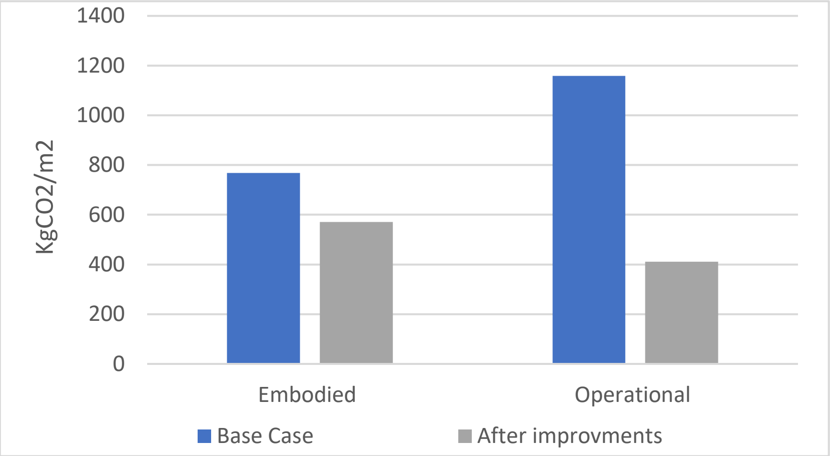

Figure 5 The reduction of operational and embodied CO2 emissions through 30 years of building operation to 2050s (a milestone considered for transition to Net-Zero) (Archetype 1).

Table 1, The characteristics of the most common archetypes of residential buildings in Jordan.

DesignBuilder		**Traditional house – Archetype 3**				**Apartments (1980s-1990s) – Archetype 2**				**Apartments 2000s – Archetype 1**				**Source**
Fabric	External wall	Name	Thickness (mm)	K-Value W/mk	R-Value M2K/w	Name	Thickness (mm)	K-Value W/mk	R-Value M2K/w	Name	Thickness (mm)	K-Value W/mk	R-Value M2K/w	[13] , [14]
		Hollow concrete block	100	1.00	0.1	Hollow concrete block	100	1.00	0.1	Stone	60	2.27	0.026	
		Air gap	50		0.11	Air gap	50		0.11	Cast in-site concrete	80	1.17	0.068	
		Hollow concrete block	100	1.0	0.1	Hollow concrete block	100	1.0	0.1	Air gap	50		0.11	
		Cement plastering	20	0.72	0.028	Cement plastering	20	0.72	0.028	Hollow concrete block	100	1	0.1	
										Cement plastering	20	0.72	0.028	
		U-Value	2.34 w/m2K			U-Value	2.34 w/m2k			U-Value	1.99 W/m2K			
	Floor	Name	Thickness (mm)	K-Value (W/mK)	R-Value (m2k/W)	Name	Thickness (mm)	K-Value (W/mK)	R-Value (m2k/W)	Name	Thickness (mm)	K-Value (W/mK)	R-Value (m2k/W)	[13]
		Ceramic tiling	8	1.05	0.0076	Ceramic tiling	8	1.05	0.0076	Ceramic tiling	8	1.05	0.0076	
		Concrete mortar	20	0.54	0.037	Concrete mortar	20	0.54	0.037	Concrete mortar	20	0.54	0.037	
	Roof	Gravel and Sand	70	0.30	0.233	Gravel and Sand	70	0.30	0.233	Gravel and Sand	70	0.30	0.233	
		Reinforced concrete	300	1.85	0.162	Reinforced concrete	300	1.85	0.162	Reinforced concrete	300	1.85	0.162	
		U-Value	1.7 W/m2k			U-Value	1.7 W/m2k			U-Value	1.7 W/m2k			
	Internal partition	Cement plastering	20	0.72	0.028	Cement plastering	20	0.72	0.028	Cement plastering	20	0.72	0.028	[13]
		Hollow concrete block	100	1.00	0.179	Hollow concrete block	100	1.00	0.179	Hollow concrete block	100	1.00	0.179	
		Cement plastering	20	0.72	0.028	Cement plastering	20	0.72	0.028	Cement plastering	20	0.72	0.028	
		U-Value	1.94 W/m2k			U-Value	1.94 W/m2k			U-Value	1.94 W/m2k			
	Infiltration	1.00 ach				0.6 ach				0.6 ach				[15]
Openings	Glazing type	Single clear 6 mm				Single clear 6 mm				Double clear glass 6mm 13mm Air				[10]
	Dimensions	Width	1.50			1.50				1.50				[10]
		Height	1.00			1.00				1.00				
	Frame	Aluminum 0.04				Aluminum 0.04				Aluminum 0.04				[10]
	Solar transmission SHGC	0.25				0.25				0.25				[10]
	WWR	30%				30%				30%				[10]
	Glazing U-Value W/m2. k	2.1				2.1				2.65				[10]
	Reveal (m)	0.2				0.2				0.2				[10]
Lighting	Power density W/m2.100lux	Compact Fluorescent lights CFL - Incandescent 2.6				Compact Fluorescent lights CFL - LED 1.85				Compact Fluorescent lights CFL - LED 1.50				[10]
	Lighting intensity level Lux	135 CFL: 2600 lm, 40W – Incandescent: 100W, 1600 lm				150 CFL: 2600 lm, 40W – LED: 10W				110 CFL: 2600 lm, LED: 10W				[10]
HVAC	Ventilation	6 ach				6 ach				6 ach				Assumption [16]
	Heating/ Cooling	LPG – Heating COP 1				LPG – Heating COP 0.8				LPG – Heating COP 0.8 AC Split units Cooling CoP 3.00				[15]
	Fan power density w/m2	1.6				40 W – 6 table/standing fans				100 W – 4 Box Fans				Assumption
	DHW CoP	0.9				0.9				0.9				Assumption

Table 2, Proposed efficiency measures for residential apartment 2000s (Archetype1).

	Proposed Efficiency Measures	**Archetype 1**
Level 1: Improve fabric components	**Walls U-Value**	0.54 (W/m^2 °K) XPS Extruded polystyrene 5 cm (addition)
	Floor (Slabs) U value	0.68 (W/m^2 °K) 3 cm extruded polystyrene (addition)
	Shading	North and South: Horizontal louvres East and West: Vertical fin
	Window type	Casement window
	Lighting	Energy-saving LED light bulbs
	Glazing	Double glazing, LoE, Argon filled (U value: 1.8)
	Framing	UPVC
Level 2: Improve heating and cooling systems	**Heating CoP**	Heat Pump- Electricity - CoP 4
	Cooling CoP	AC split unit – Energy Efficiency Ratio 3.5
Level 3: Renewable system	**PV system**	30˚ degree facing south Load centre: DC direct current with an inverter

DISCUSSION

This investigation revealed the potential for reducing 64% and 30% of OC and EC emissions of an archetype post-2000s dwelling in Jordan respectively. This also points to the huge saving potential in older and less efficient dwellings in Jordan, Furthermore, a theoretical 're-generative capacity' is developed to show the extent of further improvements required to get to Net-Zero by 2050. These improvements may include further energy efficiency measures at the building level or at upstream to decarbonise the national electricity grid (with a current carbon intensity of circa 0.4 Kg CO2/m2/annum). To offset 570 kgCO2/m2 of the embodied carbon and annual operational emissions to get to net-zero for this archetype, the required regenerative capacity for 30 years (up to 2050s, a target assumed for transition to Net-Zero buildings in Jordan) is around 33 kgCO2/m2/annum throughout. The same concept could be applied to other archetypes in the future.

Other potential technologies can be considered to reduce operational carbon through the lifecycle of the building services; the use of energy-efficient appliances, solar water heating systems, and the use of electricity instead of LPG for cooking. On the other hand, as steel is the most contributor to embodied carbon and is used for slabs, a different slab structure could be developed for new buildings by eliminating or reducing the use of steel.

In this type of evaluation for 30 years, as we tried to decarbonize operational energy use as figure 5 suggests, the balance between OC and EC is shifting toward embodied carbon. This is an important implication for policymaking in Jordan. And this could be extended to future work in which we try to source more local emission factors associated with the supply chains in Jordan instead of estimating the EC using Bath ICE data.

CONCLUSIONS

This paper demonstrates a three-level approach to decarbonisation of the building stock in Jordan: the improvement of fabric components, the technology used for heating and cooling, and the use of renewable system, to reduce OC and EC of the identified dwelling archetypes (traditional house, 1980s apartments, and 2000s apartments). The proposed method of regenerative capacity to get to zero-emissions can be readily used by policy-makers to have a better understanding of the balance between operational and embodied carbon and also help them to plan for offsetting the remaining emissions and bridging the gap to net-zero. Future work will extend this theoretical framework to other intervention measures and other archetype dwellings in Jordan.

ACKNOWLEDGEMENT

The PhD project that led to this paper is funded by the Amman Arab University, Jordan.

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