A Review of the Methodology Developed to Investigate CO_2 Emissions of 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 stock.

Summary:

The dwellings make up 72% of buildings and consume around 40% of the primary energy in Jordan. Consequently, reducing carbon emissions from existing residential buildings is crucial. However, there are no mandatory and explicit terms in the building codes concerning carbon emissions. This paper aims to present a methodology suggesting refurbishment strategies to assess the feasibility of achieving Net-Zero carbon performance in the Jordanian housing stock. It can constitute a theoretical framework to identify intervention measures.

Introduction

The carbon is emitted throughout the lifespan of buildings. Embodied Carbon (EC) is the sum of CO_2 emissions due to the extraction of resources, transportation to and from factories, manufacture, and building construction (Schwartz, Raslan, & Mumovic, 2018). Embodied Carbon Databases use generic embodied carbon figures for a range of materials. The Inventory of Carbon and Energy (ICE database) is one of the most used carbon databases that contains data for over 200 materials, broken down into over 30 main material categories. It was introduced by Dr Craig Jones – a researcher at the University of Bath – in 2005 and has been updated at periodic intervals ever since. The Operational Carbon (OC) impact of buildings is associated with the energy consumed during the use phase of a building; such as lighting, power, heating, cooling and other infrastructure.

The world's carbon emissions have increased by around 60% in the last three decades. In 2018, Jordan imported 92% of its primary energy needs, at a cost accounting for about 10% of its Gross Domestic Product (GDP) (IRENA, 2021). Fig. 1 shows the average population production of embodied CO2 emissions (CO2e/Capita) in Jordan for the last 30 years from fuel combustion only. The CO2 emissions in Jordan by sector over the period 1990-2016 is also presented below (Nazer, 2019).

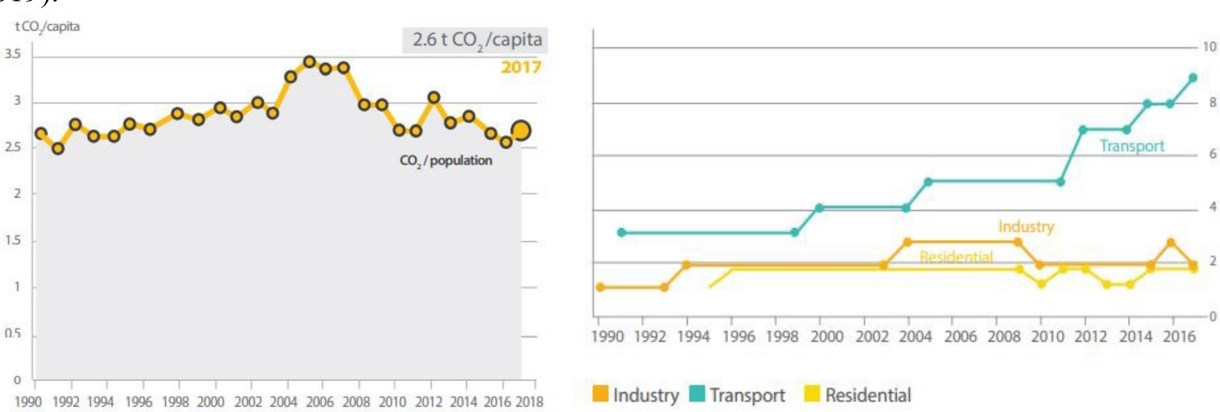

Figure 1 *EC* emissions production per capita and the emissions distribution by sector.

Despite this, no guidance is yet available on a suggested framework to reduce emissions in residential buildings in Jordan. In this context-specific background, the Jordanian residential sector, climate and data required to generate and analyze its housing stock model are presented.
In terms of climate, there are three major climatic zones in Jordan; the Jordan valley, Mountain Heights Plateau, and the Desert or Badia region, which constitute 75% of the total land area of Jordan. Each requires different design strategies. It is noteworthy that the mountain height zone constitutes around 75% of Jordan's inhabitants.

Fig. 2 shows the ratio of residential buildings and their consumption to other buildings in Jordan (Nazer, 2019). Given the high ratio of residential buildings, reducing their energy and electricity consumption can be a significant contributor to reducing the overall greenhouse gas emissions.

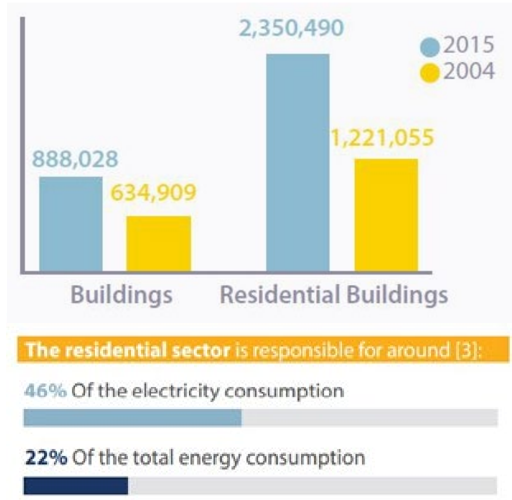

Figure 2, The distribution of Jordanian residential buildings and their energy consumption

As follows in table 1, the residential buildings are categorized as Apartments, Traditional houses, and villas from Department of Statistics (DOS) data. Further housing characteristics are used to define the stock.

Table 1 *Distribution of the archetypes of residential buildings in Jordan* (DOS, 2015)

	Apartments	**Traditional house**	**Villa**	**Total**
Number of units	1965512	299801	16970	2282283
Percentage	86%	13%	0.7%	100%

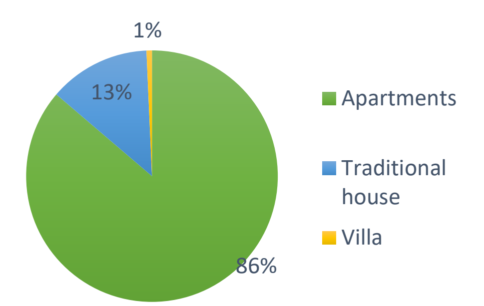

Figure 3 *Percentage of residential*

The Energy Efficient Building Code (EEBC) for Jordan was the first building-related sustainability code, which was developed to face the energy challenges Jordan has recently concurred (Awadallah, Adas, Obaidat, & Jarrar, 2009). Dependent on 92% of energy imports along with the regional instability and major supply disruptions, Jordan has faced an energy crisis in the past few years (MEMR, 2018). There are no obligatory terms in the building codes concerning building form, materials, site, orientation and many more. There are, however, obligatory requirements for building envelopes that were defined in the EEBC of Jordan after 2010 (EEBC, 2010). Subsequently, most existing residential buildings, built before 2010, do not comply with the baseline requirements of energy efficiency. The refurbishment of these dwellings becomes more challenging due to the legislative barriers.
Meanwhile, a strong emphasis on improving strategies to reduce the whole life carbon (WLC) of buildings should become mainstream to face these challenges and meet long-term carbon

emissions targets. As such, the use of the building stock under various scenarios of technology deployment has become an essential tool for the development of such strategies (J, et al., 2020).
While the research project aims to suggest a methodology to identify refurbishment strategies toward Net-Zero carbon performance in the housing stock in Jordan, this interim paper seeks to define the steps required to identify the archetypes that represent the entire stock and potential improvements to reduce their operational and embodied carbon emissions.

Methodology:

The research proposes Quantitative methods to address the research aim (energy modelling, analyzing and optimization). In response to the research aim of developing a holistic approach toward net-zero EC and OC, the method of generating Jordanian housing stock model is defined to implement the refurbishment scenarios. Fig. 4 summarizes the suggested approach to address the key aim of the study, which is divided into four stages (columns A-D). Table 2 presents the research stages, their activities involved, tools, and outcomes. The methods are classified in response to the defined suggested approach (A to D).

The combination of building physics and empirical data from housing surveys and other data sets about buildings operation from the ministry of planning, ministry of energy and built environment, and local building codes, give the means to generate Jordanian housing stock. The validation of data is carried out through semi-structured meetings with those who are familiar with the residential buildings in Jordan to carry out an in-depth contextual review and ensure the validity of the data required to generate a housing stock model.

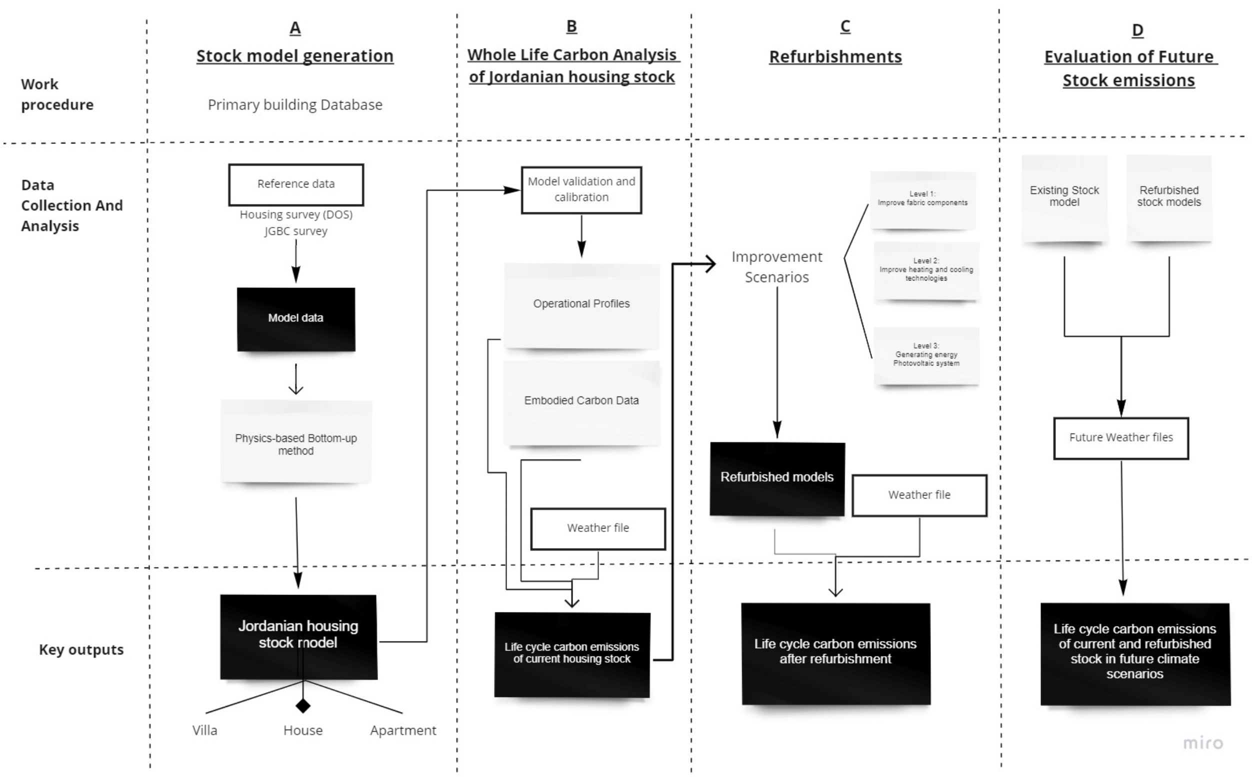

Figure 4 Flow-chart of the methods used to evaluate the pathways toward net-zero carbon Jordanian housing stock.

Table 2 Summary of the research methods

Research stage	Activities	Outcomes	Tools
Data processing	Data analysis	Generated Jordanian housing stock model	Bottom-up engineering approach
	Housing stock modelling and simulation	Energy models for housing stock to estimate the existing carbon emissions.	DesignBuilder - OC - EC/ Bath ICE
	Refurbished housing stock model simulation	Housing stock performance after implementing different levels of refurbishments.	
	Energy model optimization	Optimal refurbishment measures for the refurbishment packages.	DesignBuilder Python
	Existing and refurbished models in Future climate	Energy model performance in future climate scenarios	DesignBuilder Future weather files: 2030-2050-2080

* the activities are categorized in response to research stages in figure 4; A, B, C, and D.

A. **Stock model generation:** a physics-based bottom-up building stock analysis approach is applied. A database is developed of Energy Use Intensity (EUI) and associated building performance. The database is based on data collected under the Jordan Green Building Council (JGBC) survey and Department of Statistics (DOS) housing survey, supplemented with parameters on buildings characteristics. The key output of this phase is a stock model generated for Jordanian residential buildings.
Understanding existing dwellings stock is a prerequisite before evaluating the potential for energy efficiency improvements. The available data from national surveys is divided into categories; archetype, climate region and age band, which can be used to generate a Jordanian housing stock as shown in fig. 5.

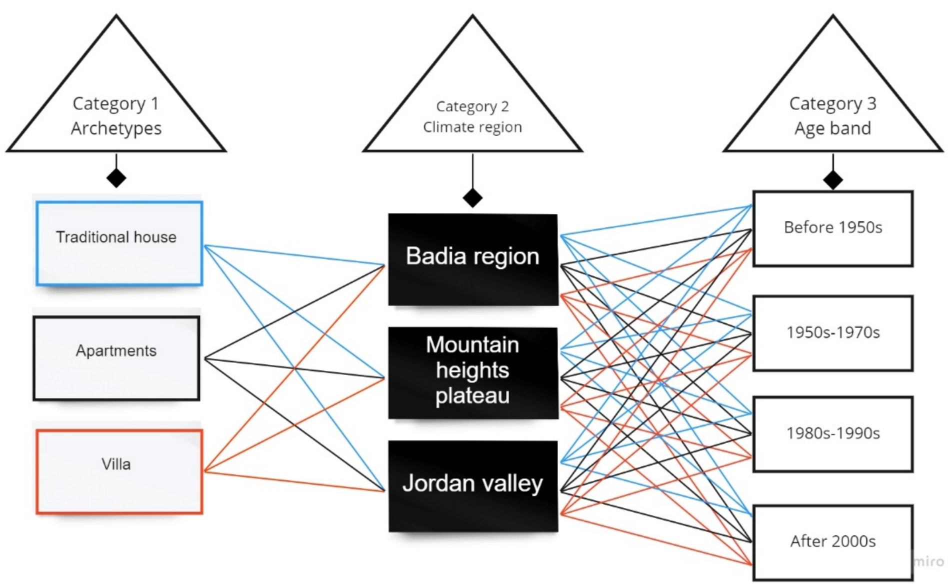

Figure 5 Flow-chart of the investigation of the current Jordanian housing stock.

B. **WLC Analysis of stock model:** The findings from A that formed the operational profiles and embodied carbon data of validated Jordanian housing model are used to estimate the life cycle carbon emissions of current housing stock. Energy, geometry, fabric, systems, and operational data were combined in operational and embodied carbon thermal simulation tools to calibrate the base model.

After developing an energy model of Jordanian housing stock, Design-Builder is used to model the geometry of the archetype buildings and analyze their performance in terms of embodied and operational carbon emissions. A preliminary estimate of EC is calculated by DesignBuilder using the Bath ICE (Inventory of Carbon and Energy) database for calculating embodied carbon emissions.

The local benchmarks are used to validate the models as it is deemed to be more accurate compared to the international benchmarks. The JGBC developed an energy use benchmark for residential apartments in Amman by conducting an energy consumption survey that was used to derive an Energy Use Intensity (EUI) for a typical residential apartment (Nazer, 2019).

C. **Refurbishment measures:** The generalized findings in accordance with stage B, and the improvement scenarios developed in this section proposed to be used to measure the impacts following hypothetical refurbishment scenarios and define the embodied and operational carbon emissions of refurbished stock model. Optimal refurbishment measures for the proposed scenarios are determined.

By developing different scenarios, the bottom-up models have the potential to be used to assess the impact of carbon emissions reduction measures on the overall energy demand. The proposed refurbishment packages as shown in table 3 are classified into three levels of intervention measures; the simple first level suggests improvements for envelope components, the medium one improves the system used for heating and cooling and the third level of refurbishment is focused on generating energy onsite.

The values recommended by local codes and Jordan green building council (JGBC) for building components such as external walls, roof, and glazing U-values are illustrated in table 4 (Nazer, 2019). This study utilizes the values from local codes as a mandatory requirement to meet the best practice case in Jordan for improving the efficiency of the building envelopes.

Table 3 Proposed efficiency measures for housing stock in Jordan

	Proposed Efficiency Measures
Level 1: Improve fabric components	**Walls U-Value**
	Floor (Slabs) U value
	Shading
	Window type
	Lighting
	Glazing
	Framing
Level 2: Improve technology used for heating and cooling	**Heating CoP**
	Cooling CoP
Level 3: Generating energy	**PV system**

Table 4 The maximum permissible level of thermal transmittance -U-value (W/m2K) according to the energy-efficient building codes and Jordan green building council.

Element	*Local Codes*	*JGBC*
External Wall	0.57	0.40
Internal partition	2.00	1.80
Floor	1.20	1.00
Roof	0.55	0.40
Envelope Glazing	N/A	Does not exceed 3.00

D. **Evaluation of future stock emissions:** In response to the findings from B and C, this stage includes the analysis of the existing Jordanian housing stock model and refurbished stock using a future climate file to assess the housing stock performance and the refurbishment scenarios toward net-zero future.

Future Plans/ Insights:

The result of implementing refurbishment packages as shown in table 4 might not meet the net-zero emissions target comprising both operational and embodied carbon. This may be addressed by suggesting an equivalent regenerative capacity required to achieve net-zero by further improvements on-site or decarbonization of the national grid upstream. Other options might utilize a JGBC target or further improvement in terms of U-values and glazing and other extensive improvements in fabric components in addition to other potential low or zero carbon technologies. The method of estimating EC could be extended to future work of sourcing the local values for embodied carbon factors associated with the supply chains in Jordan instead of Bath ICE data.

References

Akbarnezhad, A., & Xiao, a. J. (2017). Estimation and Minimization of Embodied Carbon of Buildings: A Review. *Buildings, 1: 5*.

Alrabai, L. I., Al-Ghandoor, A. M., Obaidat, M., & Zawaydah, S. (2017). Decomposition analysis of CO2 emissions of electricity generation in Jordan: Toward zero emissions. Jordan.

Awadallah, T., Adas, H., Obaidat, Y., & Jarrar, I. (2009). Energy Efficient building code for Jordan . Jerusalem.

Bataineh, K., & Alrabee, A. (2018). Improving the Energy Efficiency of the Residential. *Buildings*, 104.

Bataineh, K., & Dalalah, D. (2012). Optimal Configuration for Design of Stand-Alone PV System. *Smart grid and renewable energy*, 3. 139-147.

Cabeza, L. F., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renewable and Sustainable Energy Reviews, 29(C)*, 394-416.

DOS. (2015). *Department of Statistics*. Retrieved December 22, 2021, from http://dosweb.dos.gov.jo/censuses/population_housing/census2015/census2015_tables/

EEBC. (2010). *Energy Efficient building code* . Amman, Jordan .

Hawkins, G. (2011). *Rules of Thumb.* UK: BSRIA.

IRENA. (2021). *Renewables readiness assessment: The Hashemite Kingdom of Jordan* . Abu Dhabi: International Renewable Energy Agency,.

J, L., J, R., S, E., N, S., P, F., C, N., . . . C, C. (2020). Developing a common approach for classifying building stock energy models. *Renewable and Sustainable Energy Reviews*.

JMEMR, T. M. (2018). Annual Report., Jordan.

Mcauley, B., & Behan, A. (2019). Improving the Sustainability of the Built Environment by Training its Workforce in More Efficient and Greener Ways of Designing Constructing . (pp. 63-70). Dublin, Ireland: School of Multidisciplinary Technologies.

MEMR. (2017). *The Second National Energy Efficiency Action Plan (NEEAP) for the Hashemite Kingdom of Jordan.* Amman Jordan.: Ministry of Energy and Mineral Resources.

MEMR. (2018). *Annual Report* . Jordan : The Ministry of Energy and Mineral Resources .

Nazer, H. (2019). *Developing an energy benchmark for residential apartments in Amman.* Amman: Jordan Green Building Council.

Obaidat, M. (2010). *Jordan Green Building Guide JGBG.* Jordan, Amman: The Jordanian National Building Council .

RICS. (2017, November). Whole Life Cycle Assessment for the Built Environment. *RICS professional statement*, p. UK 1st edition.

Sabbah, E. (2020). *Net Zero Buildings in Jordan.* The Hashemite Kingdom of Jordan: Jordan Green Building Council.

SAP. (2012). *The Government's Standard Assessment Procedure for Energy Rating of Dwellings.* UK: BRE.

Schwartz, Y., Raslan, R., & Mumovic, D. (2018). The life cycle carbon footprint of refurbished and new buildings - A systematic review of case studies. *Renewable and sustainable enegy reviews* , 231-241.

Shamout, S. (2018). *Your Guide to building envelope retrofits for optimizing energy efficiency and thermal comfort.* Amman: JGBC, Jordan Green Building Council.

UNDP, M. o. (2014). *Jordan's Third National Communication on Climate Change.* Retrieved from Amman: Ministry of Environment (Jordan): http://www.jo.undp.org/content/dam/jordan/docs/Publications/Enviro/climate-changet from%20batir%2