Green Energy and Technology

Michael Gbolagade Oladokun
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Simulation-Based Analysis of Energy and Carbon Emissions in the Housing Sector

A System Dynamics Approach

Springer

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Preface

The effects of climate change as a result of the rising profile of carbon emissions globally have forced the governments of many nations to collaborate their efforts in order to counteract the damage caused by greenhouse gas emissions. This has resulted in agreements by participating governments to reduce the effects of climate change, the latest of which was the declaration of the 2015 United Nations Climate Change Conference in Paris. As such, governments of nations who are signatories to the accord have initiated schemes targeting the reduction of carbon emissions in all spheres of their economies, including the housing sector. Hence, this book describes the development of a system dynamics-based model that can capture the future trajectories of housing energy and carbon emissions.

This research book views energy and carbon emissions in the housing sector as a complex sociotechnical problem involving the analysis of intrinsic interrelationships among the dwellings, occupants, and environment. Using the UK housing sector as illustration, the book demonstrates how the system dynamics simulation can be used as a learning laboratory regarding the future trends in housing energy and carbon emissions over time, especially until 2050. One of the unique features of the approach used in the book is that it adopts the pragmatist research strategy. This strategy involves the collection of both qualitative and quantitative data to develop the model, which is not well pronounced in traditional building physics and regression-based forecasting. Consequently, the book will improve construction researchers' understanding regarding the complexity involved in housing energy and carbon emissions from the systems thinking perspective, thereby extending the frontier of the knowledge base in system dynamics to energy issues in housing. Additionally, using a nondeterministic systems approach, the book generates further insights for the readers on future profiles of housing energy and carbon emissions.

The book will be of interest to researchers in the fields of architectural engineering, housing studies, and climate change, among others. This research book will also be of interest to industry practitioners and policy makers in housing energy. The authors affirm that the texts utilised in this book reflect original ideas and, where necessary, sources that were of benefit to the book were appropriately cited and referenced.

Johannesburg, South Africa

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Prof. Clinton Ohis Aigbavboa is an Associate Professor in the Department of Construction Management and Quantity Surveying, University of Johannesburg, South Africa. Before entering academia, he was involved as quantity surveyor on several infrastructural projects, both in Nigeria and South Africa. He completed his Ph.D in Engineering Management and has published several research papers in the area of housing, construction and engineering management, and research methodology for construction students. His research interest is situated in the fields of sustainable human development, with the focus on: sustainable housing regeneration (urban renewal and binformal housing), Life Cycle Assessment in the Construction Industry, remanufacturing, leadership in low-income housing, Biomimicry, post-occupancy evaluation and green job creation. He has extensive knowledge in practice, research, training and teaching. He is currently the Vice Dean: Postgraduate Studies, Research and Innovation in the Faculty of Engineering and the Built Environment and the Head: Sustainable Human Settlement and Construction Research Centre, University of Johannesburg, South Africa. He is also an author of two research books that were published with Springer Nature and CRC Press. He is currently the editor of the Journal of Construction Project Management and Innovation (accredited by the DoHET) and has received national and international recognition in his field of research. The South Africa National Research Foundation rates him as a Young researcher with the potential of establishing himself within a five-year period.

Acronyms and Abbreviations

ABM	Agent-based modelling
ANT	Actor–network theory
BBN	Bayesian belief network
BRE	Building Research Establishment
BREDEM	Building Research Establishment's Domestic Energy Model
BREHOMES	Building Research Establishment's Housing Model for Energy Studies
BSRIA	Building Services Research Information Association
CDEM	Community Domestic Energy Model
CHM	Cambridge Housing Model
CLD	Causal loop diagram
CM	Configuration modelling
CREEM	Canadian Residential Energy End-use Model
DDM	Domestic Dwelling Model
DECarb	Domestic Energy and Carbon Model
DECC	Department of Energy and Climate Change
FL	Fuzzy logic
HECCE	Household energy consumption and carbon emissions
IEA	International Energy Agency
MA	Morphological analysis
ONS	Office for National Statistics
SAP	Standard Assessment Procedure
SD	System dynamics
SFD	Stock and flow diagram
SNA	Social network analysis
STS	Sociotechnical systems

TPB	Theory of planned behaviour
UKDCM	UK Domestic Carbon Model
UNDESA	United Nations Department of Economic and Social Affairs
UNFCCC	United Nations Framework Convention on Climate Change

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Chapter 1
General Introduction

1.1 Background and Significance

Governments at different levels globally are urgently seeking solutions to the problems emanating from energy consumption and carbon emissions in all spheres of the economy. This is because of the challenge of climate change and other related effects as a result of carbon emissions. For example, the evidence from the United Nations Department of Economic and Social Affairs [36] suggests that the climate change effects due to carbon emission could cause an increase in global temperature of up to 6 °C. This would invariably result in extreme weather conditions. Consequently, different initiatives and schemes of government have targeted a number of policies aimed at reducing energy and carbon emission, and the housing sector of the economy is no exception. In the UK (UK), based on the evidence from the Office for National Statistics (ONS) [28], energy consumption in buildings alone was about 42.3% of which the domestic sector accounted for around 27.5% of the total UK's energy consumption in the year 2008. Correspondingly, housing carbon emissions stand at about 26% of the total UK carbon emissions [24]. It is against this background that the housing sector of the economy has been chosen as a focal point for mitigation and adaptation agendas. As such, the UK Government, for example, has initiated a number of strategies aimed at reducing housing energy and carbon emissions (HECE). This is mainly due to the importance accorded this sector of the economy in realising a target of 80% reduction by 2050 based on the 1990 level as enshrined in the Climate Change Act of 2008.

From the foregoing, the menace posed by carbon emissions and other climate change-related effects has made it extremely difficult to accurately predict the energy and carbon emissions performance of dwellings once occupied [2, 34]. Way and Bordass [37] posit that dwellings are not only becoming more complex, but tighter energy and other environmental regulations are also increasing pressure regarding their greater predictability. Further, the outcomes of several studies have

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indicated that design predictions are not just the same as the operational outcomes of dwellings once occupied. One of the reasons advanced by the Building Services Research Information Association (BSRIA) [7] is because of the complex technology currently in use in order to allow dwellings to reach their targets of energy and carbon emissions reductions. Mahdavi and Pröglhöf [21] submitted that '…*the presence and actions of dwellings occupants have a significant impact on the energy and carbon emission performance of dwellings*'. Additionally, a number of researchers now attach much importance to occupants[1] and their behaviour in and around dwellings and advocate their inclusion while evaluating the energy and carbon emissions performance of dwellings [8, 12, 16, 26, 29, 34, 35, 38].

Therefore, it has been established that there is still much to do regarding housing energy when it comes to dwellings-occupants-environment interactions. Stevenson and Rijal [34] argue that one of the areas of uncertainty with which researchers are still struggling is in finding the means to establish a concrete methodology that links the technical aspect of dwellings' energy consumption with that of dwellings' occupants. This is with the view to capturing the effects of occupants on household energy consumption. Previous studies in this area of dwellings-occupants-environment interactions mainly focused on occupants' interactions with the control systems and devices put in place in dwellings [3–5, 10, 14, 15, 17–20, 22, 23, 25, 30, 32, 34]. The main thrust of the majority of these studies is on occupants' behaviour towards the control of windows for thermal comfort as well as lighting and shades for proper illumination in dwellings. Various models were recommended for use to predict these actions of occupants based on quantitative data collected and analysed. Generally, dwellings need to be acknowledged as being dynamic, and interactions of operators, occupants, and designers all influence the way they perform in terms of energy consumption and carbon emissions.

It is noteworthy that dwellings as a system on their own are engineered using tested components and generally reliable systems, whereas the occupants' aspect thereof can be unreliable, variable, and perhaps even behave irrationally. Borgeson and Brager [3] claim that owing to complexity in terms of energy consumption and carbon emissions, dwellings are now behaving in a nonlinear and irrational way that calls for an approach that is able to cope with this kind of complexity. Hitchcock [16] and Borgeson and Brager [3] argue that researchers are finding it difficult to predict the occupants' behavioural aspect of energy consumption in dwellings. This is mainly because the fundamental approach on which energy consumption models are based is quite different from that of the occupants' aspect. While energy models that try to capture the behaviour of occupants towards the opening of windows [3], for example, make use of a linear relationship of temperature difference, the actual actions consequently performed by the occupants follow a nonlinear and unpredictable way, which makes modelling this difficult.

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[1]Occupant(s) and householder(s) are interchangeably used throughout this book to have the same meaning.

One of the breakthroughs proposed by Borgeson and Brager [3] is to model occupants' behaviour using stochastic algorithms and map this with the climate data. These models are deficient in the sense that they still face the challenge of integrating the occupants' behavioural aspect with energy models. Furthermore, the UK Government's Standard Assessment Procedure (SAP) for the energy rating of dwellings [6] that tries to assign energy rating to dwellings incorporates a number of variables into their calculations. Unfortunately, the SAP fails to capture the variables related to the individual characteristics of the household occupying the dwelling, for example, household size and occupants' behaviour, amongst others [6]. This then shows that the calculation may be deficient because of the lack of inclusion of these occupant-related variables. It is therefore necessary to explore ways of significantly improving predictability of dwellings' energy consumption and carbon emissions by demonstrating a novel approach that takes into consideration the challenge of the occupants' aspect of energy consumption in dwellings.

Undoubtedly, the integration of the dwellings' occupants' aspect with that of the dwellings' characteristics/parameters regarding energy consumption in buildings sits squarely within the sociotechnical systems (STS) approach of the systems-based methodology of scientific inquiry. As pointed out earlier, dwellings as a system are seen to comprise two subsystems: a physical subsystem that relates to the dwellings' characteristics/parameters (technical system) and a human subsystem regarding the occupants' actions within the dwelling (social system). Dwellings as a system are affected should there be any change to either the technical or social systems. Invariably, any change to the technical system will have effects on the physical subsystem; likewise, any change in the social system will have corresponding effects on the human subsystem (Fig. 1.1). On one hand, some changes to the technical system may have an indirect influence on the human subsystem, while on the other hand, some changes to the social system may have an indirect influence on the physical subsystem as well (Fig. 1.1).

It should not be forgotten that the dwellings as a system relate with the outer environment, which has both a direct and indirect influence on the technical and social systems alike. Any change in the outer environment elements will definitely influence the behaviour of these technical and social systems. This will consequently have effects on household energy consumption and associated carbon emissions. This then presents a complex kind of system that calls for an approach that is able to cope with this type of situation. However, it necessary to note that engineering models can only deal with the changes to the technical system and social models can only cope with the changes to the social system. For example, within the energy sector, modelling energy consumption and carbon emissions has been purely based on an econometric [9], statistical [11], or building physics [33] method. One of the main thrusts of this research book is to present an approach that links this phenomenon, aids in its understanding, and offers ways of testing different strategies for reducing energy consumption and carbon emissions in the housing sector. This is in order to contribute to the carbon emissions' reduction target of the UK Government. Notably, there are a number of variables at play here. These variables are interrelated and depend on one another. Among them are the variables

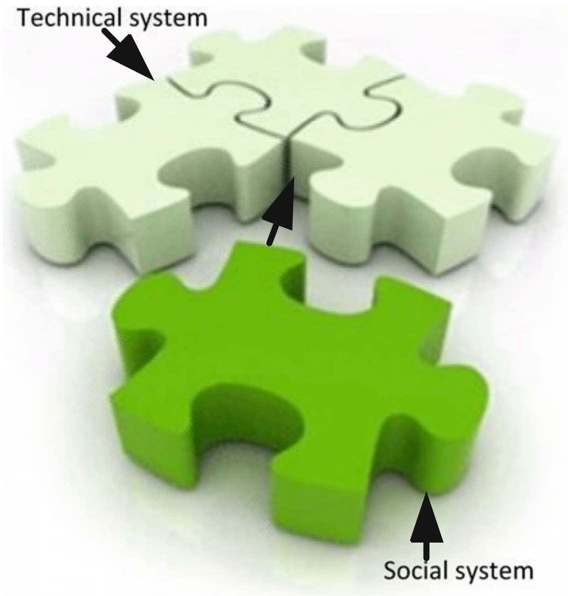

Fig. 1.1 Interactions between the social and technical systems

that are related to the interaction of dwellings themselves with the outer environment as well as the interaction of occupants with the systems put in place to operate dwellings in a sustainable way. All these present a complex system.

Climatic variables (outer environment element), for example, are unpredictable as any change in these (e.g. in terms of external temperature, rainfall) may haveeffects on heating, and ventilation, amongst others. They are then likely to trigger a response from the occupants to react appropriately to this situation in terms of heating and the use of hot water, for example. The reactions from occupants too still largely depend on a number of determinants (e.g. demographic, cultural, and economic variables, and behaviour). An analysis of this scenario presents a complex system that has multiple interdependencies with multi-causal relationships. The variables at play here are both 'soft' and 'hard', and their behaviour changes in a nonlinear way over time with multiple feedback loops. However, these variables are difficult to predict and keep under control. The situation described above illustrates an example of the STS problem of household energy consumption and carbon emissions. This research book then delves into the issue of STS of housing energy and carbon emissions with a view to adding to the understanding of the complex nature of energy issues of the housing sector. This is based on a novel approach proposed to policy makers that is capable of testing different strategies and interventions regarding the future profiles of energy and carbon emissions of the housing sector.

This research book then seeks to find answers to the following questions:

1. What are the social and technical variables influencing household energy consumption and carbon emissions?