Advances in Sustainability Science and Technology

Robert J. Howlett
John R. Littlewood
Lakhmi C. Jain *Editors*

Emerging Research in Sustainable Energy and Buildings for a Low-Carbon Future

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Preface

There is a great awareness of the urgent need to eliminate carbon emissions and improve the operational energy efficiency of the built environment in order to reduce the harmful effects on the ecosystem of human economic development and mitigate climate change reality. This has led to a huge growth in research around the science and technology of sustainable and resilient development.

The series *Advances in Sustainability Science and Technology* (*ASST*) was created by Springer Nature and KES International to respond to the need for a publication channel for the latest high-quality research on a broad range of sustainability topics.

Emerging Research in Sustainable Energy and Buildings for a Low-Carbon Future is the first volume published in the ASST series. It contains an introduction and 20 studies of recent research in the area of sustainable and resilient buildings, built environment infrastructure and renewable energy.

The book is directed to engineers, scientists, researchers, practitioners, academics and all those who are interested in developing and using sustainability science and technology for the betterment of our planet and humankind.

Thanks are due to the authors and reviewers for their expertise and time. The assistance provided by Springer during the development phase of this book is gratefully acknowledged.

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Dr. John R. Littlewood graduated in Building Surveying, holds a Ph.D. in Building Performance Assessment, and is a Chartered Building Engineer. He is Head of the Sustainable and Resilient Built Environment group in Cardiff School of Art & Design at Cardiff Metropolitan University (UK). He coordinates three Professional Doctorates in Art & Design, Engineering and Sustainable Built Environment, plus contributing to teaching in Architectural Design & Technology. John's research is industry focused, identifying and improving fire and thermal performance in existing and new dwellings, using innovative materials and construction and also improving occupant quality of life and thermal comfort. He has authored and co-authored 150 peer-reviewed publications and was also Co-editor for the 'Smart Energy Control Systems for Sustainable Buildings' book published in June 2017.

Dr. Lakhmi C. Jain Ph.D., M.E., B.E. (Hons), Fellow (Engineers Australia), is with the University of Technology Sydney, Australia, and Liverpool Hope University, UK. Professor Jain founded the KES International for providing a professional community the opportunities for publications, knowledge exchange, cooperation and teaming. Involving around 5,000 researchers drawn from universities and companies worldwide, KES facilitates international cooperation and generates synergy in teaching and research. KES regularly provides networking opportunities for professional community through one of the largest conferences of its kind in the area of KES.

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Chapter 1
An Introduction to Emerging Research in Sustainable Energy and Buildings for a Low-Carbon Future

Robert J. Howlett, John R. Littlewood, and Lakhmi C. Jain

This book contains an introduction and 20 chapters, each describing a recent research investigation in the area of sustainable and resilient buildings, built environment infrastructure and renewable energy. Contributions are from many different countries of the world and on a range of topics, representing a sample of research within the 'sustainable energy and buildings' field.

Part 1: The first part of the book looks at the sustainable design of buildings.

Chapter 2, 'Designing Active Buildings', discusses the evolution and validation of a design guide for Active Buildings. This was developed to aid in building design to enable the Active Building concept to be adopted by the construction industry, contributing to reducing the energy consumption of buildings and aligning with the UK Government's industrial strategy to at least halve the operational energy consumption of all new buildings by 2030.

Chapter 3, 'Sustainable Housing Solutions', describes design based on experience gathered over more than 20 years in social housing construction in Argentina for vulnerable families. The design principles incorporate the axioms of sustainability in its three dimensions: economic, social and environmental. The design premise

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is based on reducing the energy demands of the housing, considering bioclimatic conditions appropriate to the location and incorporating the active participation of the families from the very beginning.

Part 2: The next four chapters describe issues relating to the renovation, restoration and reconstruction of existing buildings or in one case a railway wagon.

Chapter 4, 'Future Energy-Related House Renovations in Sweden: One-Stop-Shop as a Shortcut to the Decision-Making Journey', discusses the attitudes of owners of detached houses in Sweden towards future renovations and considers their opinions of a one-stop-shop to provide deep renovation services, based on an online survey.

Chapter 5, 'Crisis of Institutional Change: Improving Restoration and Reconstruction Methods for Estate Cultural Heritage', presents the problem of institutional changes in Russian Urban planning. The chapter discusses institutional problems in the sphere of cultural heritage. The necessity for the research is justified, and methods and tools for evaluation of the effectiveness of the institutional are suggested. A programme of urban development is proposed, and tested methods for estate objects of cultural heritage protection, which are to be implemented further in Russia considering climatic, seismic and ecological peculiarities of the regions, are suggested.

Chapter 6, 'Greening Existing Garment Buildings: A Case of Sri Lanka', considers green retrofitting as a solution for contemporary issues such as global warming, resource depletion and greenhouse gas emissions which have arisen due to the conventionally built environment. Building owners may be unwilling to invest in green retrofits due to their perceptions of the first cost and payback period implications of the green retrofit. Therefore, the chapter assesses the first costs and life cycle saving implications of fourteen energy and water-efficient retrofits incorporated into four garment buildings in Sri Lanka to find the retrofit options which are financially sound.

Chapter 7, 'Sustainable Cultural Wagon', describes the conversion of a redundant railway wagon into a cultural and creative space for community use, responding to a local need in an area of Argentina. The cultural wagon was equipped with a range of features, including ramps for easy access, thermal-acoustic insulation, a photovoltaic panel system, indoor LED lighting, cross ventilation and a community accessible hot-water pump station powered by solar panels. This resulted in a public project that was sustainable, encouraging energy production through renewable sources, contributing to the reduction of energy consumption and the generation of clean energy with significant economic and environmental benefits.

Part 3: This section contains two chapters that consider barriers or impediments to low- or zero-carbon buildings.

Chapter 8, 'Unearthing the Factors Impeding Sustainable Construction in Developing Countries—A PLS-SEM (Partial Least Square Structural Equation Modelling) Approach', presents the result of a case study of the factors impeding the sustainability of construction projects in developing countries using Nigeria as an example. The study sought responses from construction managers, project managers and quantity surveyors from the six different regions of the country. Data gathered was analysed using factor analysis and structural equation modelling. The findings revealed that issues surrounding regulation and policy, information and management, sustainability knowledge and the availability of sustainable materials and technology are significant reasons for the poor record of sustainability in the country's construction industry.

Chapter 9, 'Barriers to the Adoption of Zero Carbon Emissions in Buildings: The South African Narrative', continues this theme with a study that evaluated the barriers to the adoption of zero carbon emissions in occupied buildings with a view to proffering ways to mitigate such practices. A comprehensive review of relevant literature was done which aided the identification of the barriers. Data for the study was elicited through questionnaire surveys from built environment professionals. Methods of data analysis used were percentage, mean item score and principal component analysis while Cronbach's alpha was used in testing the reliability of the questionnaire. Findings from the study revealed several factors hampering the adoption of zero carbon emissions in buildings. Recommendations were made to encourage the adoption of zero carbon emission processes in building operations and activities by its occupants.

Part 4: The next two chapters are on policy and certification.

Chapter 10, 'System Dynamics Analysis of Energy Policies on Buildings Performance', describes an investigation which aimed to develop a dynamic model to analyse the impact of energy policies on buildings performance in the UK. The principle of socio-technical systems was adopted as an approach to the modelling. A system dynamics model was developed to simulate the intrinsic interrelationship between the dwellings, occupants and environment systems. This chapter considered the impact of various policy scenarios on energy consumption in building towards achieving the UK national targets, namely improvements in the uptake of dwelling insulation measures, occupants' behavioural changes and policy change on energy prices. An integrated scenario was also assumed to combine the effect of the first three ones. The main findings indicate that it is unlikely for any one scenario alone to meet the required binding reductions unless an integrated solution is adopted. The developed model considers various qualitative conditions which are not usually simulated using the traditional regression-based forecasting of energy use in buildings. The developed model can be used to test various policies in other than UK context considering various datasets of the model variables.

Chapter 11, 'Investigating the Application of LEED and BREEAM Certification Schemes for Buildings in Kazakhstan', describes a study that looks at the application of rating and certification schemes on Kazakhstan and investigates some of the first pioneering buildings that have undergone certification process in that country. The construction industry in Kazakhstan has started adopting widely recognised environmental assessment certification schemes such as the Leadership in Energy and Environmental Design (LEED) and the Building Research Establishment Environmental Assessment Method (BREEAM). Up to the present time, more than 50 buildings, especially from rapidly expanding cities such as Nur-Sultan and Almaty, have obtained LEED and BREEAM certificates and have been recognised as green buildings. This study investigates the adoption of these methods in the context of Kazakhstan with the aim of understanding the driving factors of such application, characteristics of the certified buildings and potentials of promoting the certification schemes at a wider scale.

Part 5: There then follow four chapters on various topics related to sustainable buildings.

Chapter 12, 'Examining Undergraduate Courses Relevant to the Built Environment in the 4IR Era: a Delphi Study Approach', discusses a research project carried out in South Africa looking at undergraduate courses that will be relevant to the built environment in the imminent future. A qualitative Delphi approach was adopted to validate these courses as institutions of higher learning prepare students for this latest wave of innovation. Fourteen experts completed a two-stage iterative Delphi study process and reached consensus on all 29 courses identified. This study found that courses such as data analytics, artificial intelligence, computer programming, computer coding and data mining should be integrated into the curricula of universities to ease the transition of students from the lecture room to the world of work.

Chapter 13, 'An Appraisal of the Level of Awareness and Adoption of Insurance Policies on Sustainable Construction', describes a study, the purpose of which is to appraise the level of awareness and adoption of insurance policies on the sustainability of construction projects in Nigeria. The study involved a questionnaire survey method that was self-administered to a range of professionals in the construction industry. The data collected was analysed using Statistical Package for Social Sciences (SPSS). The findings of the study indicate the types of insurance policies available to the construction industry and concluded that insurance policies have positive impacts highly beneficial to the performance of construction projects.

Chapter 14, 'To What Extent is Biophilia Implemented in the Built Environment to Improve Health and Well-being?—State-of-the-Arts Review and a Holistic Biophilic Design Framework', is on an investigation of the application of biophilia in building design practices for improved health and well-being. Biophilic theoretical frameworks developed by leading biophilic experts were examined and compared to health and wellness performance certifications such as WELL Building and Living Building Challenge (LBC) standards. Then, a holistic biophilic framework inspired by Kellert and Calabrese was elaborated to assess the biophilic features in the built environment. Multiple case studies were studied during the project. The findings revealed that the biophilic applications linked to direct experiences of nature were implemented inefficiently and lacked a holistic approach to improve health and well-being. The authors argue that biophilia needs to be included holistically to maximise the benefits of nature's experiences.

Chapter 15, 'Thermal Conductivity Characterisation of Industrial Small-Sized Building Materials: Experimental and Simulation Study', describes a new experimental procedure for determining the thermal conductivity of small-sized building materials using the boxes method and an approach that does not require additional sensors. The measurement is based on the permutation of sensors and then the interpretation of the steady-state heat balance of samples. Local earthen blocks from eastern Morocco were developed. The measured thermal conductivity values were compared with those obtained by an accurate transient hot disc method. The comparison shows a good agreement and verifies the performance of the permutation approach. The chapter goes on to describe an evaluation of the thermal performance of the developed building materials and the results obtained. The building performance analysis clearly proved that earth walls can play a great role in mitigating the cooling demand and improving the thermal comfort of buildings in summer.

Part 6: This section contains three chapters relating to renewable energy.

Chapter 16, ‘Coordinated Control Strategy to Improve Performance of Permanent Magnet Synchronous Generator Wind Power Systems’, is intended to aid the reader in their understanding of the principles of control for wind energy conversion systems based on the permanent magnet synchronous generator. Modelling of the conversion system is described, including models of the wind turbine, the permanent magnet generator and the power converters. Then, the controls of the machine side converters and grid side converter are introduced. The proposed control methods were used to maximise the generated power from wind turbine generators, to keep a constant DC bus voltage for the grid side converter and to control the power fed to the grid.

Chapter 17, ‘High-Temperature Heat Pumps for a Sustainable Industry’, discusses developments in heat pump technology applicable to the decarbonisation of industry. This chapter gives a comprehensive overview of the current status and future possibilities of high-temperature heat pump technology based on the working principles, working fluids, configurations, existing prototypes and the possibility of reversible operation. Many working fluids are available with low global warming potential, but none of them are perfect as they come with their own disadvantages. The selection must be based on many factors. As well as various working fluid options, there are several configurations. Working fluids and configurations are described and explained.

Chapter 18, ‘Replacing Fossil Fuels by On-Site Sources of Energy in a Residential Building in Chalus, Iran’, has as its aim the evaluation of the possibility of replacing fossil fuels by renewable sources of energy in a residential building in Chalus, an Iranian city with a high potential for using on-site sources of energy. This study first investigated the annual operating energy used by households in Chalus. To do this, the type of appliances and average time of their use, including heaters and air conditioning units, is extracted from official reports together with a local field study. The ability of renewable on-site sources of energy to supply this load was calculated by considering the specific characteristics of the region. The result shows these sources have the potential to provide approximately 98% of the annual energy the household consumes.

Part 7: This part of the book contains two chapters with a sustainable transport theme, one relating to electric vehicles and the other about a sustainable road infrastructure.

Chapter 19, ‘Simulation of an Adsorption Machine with Auxiliary Heater for CO_2-Neutral Air-Conditioning of Electric Utility Vehicles’, looks at air-conditioning for electric vehicles, which is important for driver comfort. In conventional battery-operated commercial vehicles, the energy required to operate the air conditioning system is used from the battery which can reduce the range of the vehicle by up to 30%. To reduce energy consumption due to air-conditioning, it is preferable to utilise a technology that is independent of the battery. There are a number of options for controlling the temperature of a moving vehicle, but only a limited number that is CO_2-neutral. This chapter focuses on adsorption chiller technology in combination with an auxiliary heater based on bioethanol. To understand the advantage of an adsorption machine, a simulation model can provide useful data on scaling and ease of use and thus be the basis for design and assembly of a prototype system. Therefore, a mathematical model of the adsorption technology is described which is combined with the known dimensional parameters of electric vehicles, and the results are presented in the form of a simulation model.

Chapter 20, 'Sustainable Road Infrastructure in Rural Areas in South Africa—A Preliminary Study', describes a study that assessed the possible measures for attaining sustainable road infrastructure within rural communities in Limpopo province, South Africa. The study sought answers from rural dwellers and construction workers within the study area through a questionnaire survey. Data gathered was analysed using percentage, mean item score, standard deviation and one-sample t-test. The reliability of the questionnaire was also tested using Cronbach's alpha which gave an alpha value of 0.948 which indicates the questionnaire used was reliable. Findings of the study revealed that the most significant measures for attaining more sustainable road constructions within the rural areas include the following: using quality materials that will last the expected lifespan of the road, having planned maintenance, proper investment on road projects and using contractors and skilled workers with the right experience in road construction. It is believed that the findings of this study will help increase the delivery of sustainable road projects within the rural areas in a bid to provide a better standard of living for rural dwellers.

Part 8: The final chapter is on the manufacture of sustainable building components for the UK housing sector.

Chapter 21, 'Optimising Offsite Manufacturing of Timber-Frame Roof Trusses for UK Housing', describes a study involving sustainable offsite manufacturing and modern methods of construction. This was undertaken in response to drivers from the Welsh Government to increase the number of houses, and their quality, to contribute to meeting Wales' low to zero carbon agenda, launched in March 2019. The chapter presents a case study undertaken in one of the largest manufacturers of timber-frame construction systems in Wales (one of the countries that make up the UK). The project involved time and motion and value stream mapping studies to evaluate optimisation opportunities in the offsite manufacture of roof components, such as trusses. The preliminary results are presented and highlight opportunities for quick win refinement to the company's operational processes with the aim of increasing production efficiency, reducing waste and closing the performance gap. By this means, increased quality and thermal performance of offsite manufactured timber-frame buildings were achieved, resulting in reduced operational energy usage and therefore minimising greenhouse gas emissions.

The chapters that make up this volume are from a range of diverse topics within the sustainable energy and buildings area. Hence, it is not claimed that they represent a comprehensive record of research in the field. However, this diversity does indicate the breadth of research that is being undertaken with the aim of reducing carbon emissions and achieving energy efficiency in sustainable building and renewable energy.

Part I

Chapter 2
Designing Active Buildings

Joanna Clarke

Abstract This paper discusses the development and validation of an Active Building Design Guide being developed to enable the design of Active Buildings. The definition of Active Buildings and the key principles to be considered when designing them are discussed and illustrated. The background to the research project is discussed, which includes addressing the UK Government's aim to at least halve the energy consumption of all new buildings by 2030, and how the author's experience in designing Active Buildings and developing a Design Guide to enable others to design Active Buildings could help achieve this aim. The author has identified a need for some design guidance to enable the Active Building concept to be adopted by the construction industry, contributing to reducing the energy consumption of buildings, aligning with the UK Government's Industrial Strategy. The paper presents progress on the Design Guide development, testing and refinement, including the considerations for ensuring it is a document that architectural designers of Active Buildings will genuinely find useful and will use to ensure reductions in energy use and associated carbon emissions through the design of such buildings.

Keywords Architecture · Buildings · Energy · Construction · Design · UK government's industrial strategy · Transforming construction · Low carbon · Net zero carbon

1 Introduction

An Active Building is one that *'supports the energy network by intelligently integrating renewable energy technologies for heat, power and transport'* [1]. The purpose of this paper is to discuss and illustrate the first Design Guide for Active Buildings, intended for use by Architects and others to aid the design of Active Buildings. This supports the role of the Active Building Centre (ABC), Swansea

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University, UK, in enabling the UK construction industry to meet the goal to halve the energy consumption of all new buildings by 2030 as set out in the UK Government's Industrial Strategy [2] and to reduce pressures on the wider UK energy networks that connect buildings. The energy networks in the UK were originally designed to supply power and heat to buildings in a distributed way from a centralised supply [3]. However, with the increase in renewable energy generation across the UK as reported since 2016 [4], the UK energy networks are now more dynamic, presenting both technical and commercial issues for the grid networks [3]. The UK electricity grid was not designed or installed to respond to dynamic electrical energy generation and supply, where at certain peak renewable energy generation across the UK, the grid has too much power and therefore must curtail the generation of renewable energy, and at times of peak demand, the grid struggles to supply the electricity demanded across the UK.

Active Buildings could offer a solution to the above peak electricity demand/supply of renewable energy generation. Using intelligent controls and energy storage, it is possible to manage import and export of energy from a building such that buildings could support the grid, rather than adding to its current constraints [1]. This concept is currently being tested on a building designed by the author whilst she was employed at SPECIFIC Innovation and Knowledge Centre (IKC) at Swansea University [5], prior to the establishment of the ABC, where she is currently employed as Head of Design. Known as the Active Office [6], this building acts as a demonstrator to trial different modes of interaction with the UK electricity grid, utilising a combination of renewable energy generation, energy storage, intelligent control strategies and smart electric vehicle charge points. Linking the Active Office's energy strategy to control algorithms that monitor the carbon intensity of the grid, the current energy tariffs, weather predictions and occupancy patterns, the building is capable of managing its import and export of energy, depending on different factors [7]. For example, the control system may choose to import energy when the carbon intensity of the grid is low, maximising the use of renewable energy generation, and to export energy when the carbon intensity is high, that is when the energy mix contains a high proportion of fossil fuel sources [8].

In September 2018, the ABC was established [9] to develop solutions to enable the UK construction industry to investigate how to adopt the Active Building concept, supporting the UK Government's ambition to Transform Construction, by at least halving the energy consumption of buildings by 2030 [2]. To date (2020), no specific guidance has been developed to aid those wishing to implement the Active Building concept. The Active Building Design Guide (ABDG) currently under development will be the first source of guidance produced to aid the design of Active Buildings and one of the first outputs from the ABC. Figure 1 illustrates the crucial role of the ABDG within the context of the ABC.

This paper sets the context to the development of the ABDG, describes the development to date (2019) and discusses the methods used to test the ABDG.

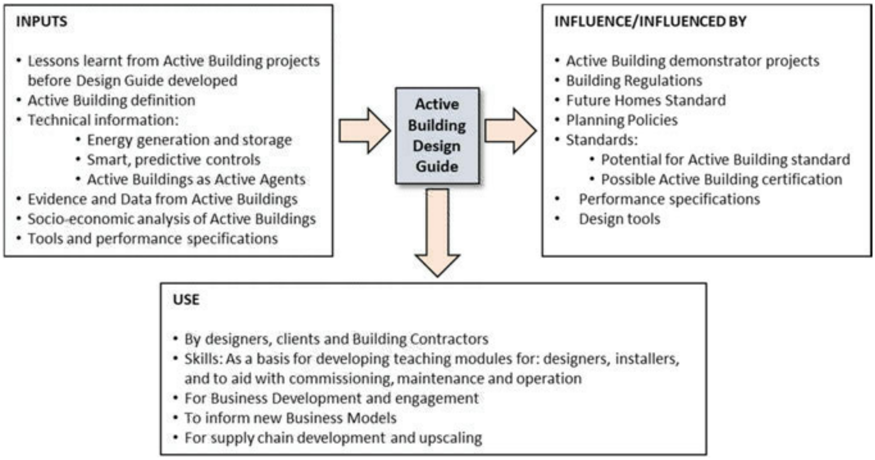

Fig. 1 Inputs, influencers and use of the active building design guide (ABDG)

2 Background and Related Work

Before the ABC was established in 2018, the author worked as the Building Integration Manager for SPECIFIC IKC [5], where her role was to encourage UK construction industry stakeholders to adopt the Active Building concept on building projects, utilising renewable energy technologies developed by SPECIFIC and their industry partners. The author's experience as an architect helped her to identify the best way to achieve this as being to develop demonstrator buildings to showcase the Active Building concept, which was at the time (2014) referred to as *'Buildings as Power Stations'*—buildings that generate, store and release their own energy. The first building designed by the author was a garden office building, known as the Pod [10], which demonstrated the *'Buildings as Power Stations'* concept on an off-grid and self-sustaining building (see Fig. 2). The aim of the Pod was not only to demonstrate the concept to the UK construction industry stakeholders and potential building

Construction
Structurally Insulated Panels (SIPs)
Innovative Technologies
Building Integrated Photovoltaic (BIPV) Roof
Glazed Solar Air Collector
Battery Storage
Novel Resistive Heating System
Bespoke Control System

Fig. 2 Pod [10]

Construction
Novel interlocking steel framed panels
Innovative Technologies
BIPV Roof
Transpired Solar Collector (TSC)
Air Source Heat Pump (ASHP)
Mechanical Ventilation and Heat Recovery System (MVHR)
Battery Storage
Novel Resistive Heating System
Bespoke Control System

Fig. 3 Active classroom [11]

owners and clients, but also to provide a building that the researchers at SPECIFIC could relate to as a home for the innovative technologies they were developing.

The Pod became the catalyst for a new opportunity for SPECIFIC (to focus on demonstrating generate, store and release technologies on buildings, rather than simply developing individual technology prototypes), and soon after, the author was asked to design a second building—the Active Classroom [11], shown in Fig. 3.

The name Active Classroom was chosen as it highlights that the building envelope is 'activated'. Rather than the facades and roof being 'passive' elements to simply provide shelter for the building occupants, the technologies embedded within the fabric generate heat and electricity, for use in the building. Hence, the term *'Active Buildings'* was created [11]. The Active Classroom has been successful in raising the profile of SPECIFIC within the Welsh and UK construction industries, winning several awards, including the prestigious 'Project of the Year' at the Royal Institute of Chartered Surveyors (RICS) Wales Awards in 2018 [12].

In designing and delivering the Active Classroom, the author worked with the technical team of scientists and engineers at SPECIFIC, who developed control systems to ensure the building operated effectively, and that data collected from a range of sensors within the building could be used to learn about what worked well and what did not work so well—lessons that could be used in the design of further Active Buildings. The Active Classroom demonstrated that it was possible for a building to produce more energy than it consumed over an annual period, described as being *'energy positive'* [11]. However, during the process of designing the next building—the Active Office [6], a two-storey office building (shown in Fig. 4)—it became clear that achieving *'energy positive'* is more challenging the more storeys a building incorporates. With experience, the SPECIFIC team also realised that the capability of a building to interact intelligently with the energy grid, controlling when power is imported to or exported from (made possible through the use of energy storage and smart controls), has the potential to truly transform both the energy and building sectors and is hence of more value than simply being energy positive over a year.

Construction
Modular – 12 modules
Innovative Technologies
BIPV Roof
Battery Storage
Combines Solar Thermal and PV (PV-T) System
Thermal Store
Bespoke Control System

Fig. 4 Active office [6]

These Active Buildings are fully electric, operating without consuming gas for heating and hot water, aligning with the UK Government's target to decarbonise heat in buildings, as outlined in their Clean Growth Strategy [9].

2.1 Professional Doctorate—Sustainable Built Environment

The ABDG will form part of a Professional Doctorate in Sustainable Built Environment (D.SBE) [13] research project which the author commenced in April 2017, after completion of the Active Classroom [11], based on her work to date on designing Active Buildings [14]. The progress of the author's doctorate project has included taking a multi-methods approach after Creswell and Plano Clark [15] including a critical review of both academic and professional publications; engaging with UK construction industry stakeholders and architectural students (delivering workshops and Continuous Professional Development (CPD) seminars and hosting innovation visits to the Active Building demonstration projects); developing and testing a Design Guide for Active Buildings; presenting at various events; and contributing to articles in publications [16, 17, 18, 19, 14], Premier [20, 21].

In addition, performance data is being collected from demonstration buildings the author has either designed or influenced the design of. This data is analysed by the technical teams at SPECIFIC and the ABC and used to detect faults, optimise performance of building systems and develop predictive control strategies for Active Buildings. Data collection is essential to enable the ABC to build an evidence base that can be used to support the transformation of the UK construction industry to meet the goals set out in a report entitled *Construction 2025* [22] and the UK Government's Industrial Strategy [2]. Ambitious targets for the UK construction industry, including lowering carbon emissions from the built environment by 50% by 2025 [22], indicate the need for innovative solutions to reducing energy consumption and carbon emissions from buildings, which the Transforming Construction Challenge [23] and the Active Building approach [1] set out to deliver.

Before embarking on the development of the Active Building Design Guide (ABDG), the author undertook literature reviews on the current status of the UK construction industry and the UK Government's ambitions to reduce the energy consumption of buildings [2, 22]. The evaluation of these publications was discussed and presented in a paper at Eco-Architecture 2018: 7th International Conference on Harmonisation between Architecture and Nature [17].

The ABDG under development is an enabler to the adoption of the Active Building concept in the UK, setting out the six core principles and the process for meeting these, as summarised in Fig. 5. As Active Buildings are a relatively new concept in the UK and there is currently (2020) limited data available from Active Building projects, the principles are deliberately not too prescriptive which may otherwise reduce clients and developers' consideration for future projects. As data and evidence are collected from Active Building projects, the minimum performance specifications will be developed, which will prescribe target energy values to be achieved.

In developing the ABDG, the author has reviewed existing information available to Architects on these topics and referenced the most appropriate documents within the Design Guide, for example, environmental design [24] and building physics [25] to reduce the energy consumption of buildings, which relate to the first principle of an Active Building. The intention is that section one (energy reduction) will act as an

Fig. 5 Core principles of an active building [1]

aide-memoire to those reading and using the guide on fundamental passive design principles without repeating information described in detail in existing literature [26, 25, 24, 27].

To further support the development of the ABDG, existing guidance documents used by Architects in the UK will be reviewed, including the Approved Documents used to provide guidance on compliance with UK Building Regulations [27] and guidance documents produced by other bodies, such as Local Authorities (e.g. [28]).

Feedback from a pilot project undertaken as part of the author's D.SBE between February and June 2019 and documented in a paper entitled *'Active Buildings in Practice'* was presented at the 11th International Conference on Sustainability in Energy and Buildings [18]. This paper (ibid) and the feedback from the presentation are being used to refine the ABDG in development. In the pilot project, the author tested a first version of the ABDG with Architects in UK practice and feedback suggested that a mixture of small amounts of text, images, diagrams and tables is preferred to a document consisting of main text. The ABDG will be developed to align with existing design guidance used by UK-based Architects and feedback from participants of the pilot project.

3 Methods to Test the Active Building Design Guide (ABDG)

Qualitative research methods are deployed in this D.SBE project in order to test, evaluate and refine the ABDG using semi-structured interviews and focus groups, following research methods described by Saunders et al. [29]. As mentioned above in Sect. 2.1, before commencing development of version two of the ABDG, the author undertook a pilot project, which took place in two stages:

Stage 1. Identified the main challenges facing UK construction industry stakeholders when introducing innovative technologies and practices into construction projects, between March and November 2018. The results from the analysis of this stage influenced the decision to develop an ABDG to address some of the challenges identified;

Stage 2. Development of a draft ABDG which was tested with UK-based Architects in professional practice between January and March 2018 and also with architectural students studying at one of the two Schools of Architecture in Wales during the same time period, January–March 2018. The analysis of the feedback led to version two of the ABDG.

Final testing and refinement of version two of the ABDG will be undertaken between January and June 2020. This final testing and evaluation will use *Action Research* [29], more specifically a *design-decision research* approach described by Groat and Wang [30], where the researcher is embedded in the research process. Figure 6 shows the strategy for developing and testing the different versions of the ABDG.

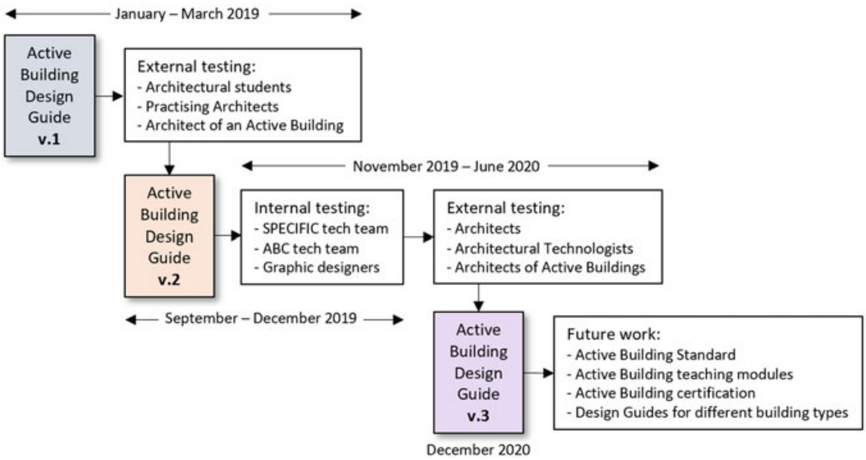

Fig. 6 ABDG development and testing

A *probabilistic* or *random* sampling strategy [30] was used in the pilot project, with the aim of achieving a sample representative of the larger population of Architects Participants included those who signed up to workshops, rather than selecting individual participants. As climate change and the need to reduce the energy consumption of buildings are high on the UK Government agenda and that of construction industry stakeholders, the author has been approached by Architects known to her and bodies, such as the Royal Society of Architects in Wales (RSAW) [31], requesting workshops on the design of Active Buildings. This suggests there is a desire within the UK construction industry to seek ways to reduce the energy consumption of buildings, potentially by incorporating the Active Building concept, and an appetite for some guidance on how to do this. Table 1 illustrates the proposed sampling plan for testing the ABDG in the final phase of the D.SBE project [18].

As illustrated in Table 1, before testing the ABDG externally to the ABC with UK construction industry stakeholders, the author will obtain validation from the internal teams at both the SPECIFIC [10] and the ABC [1]. After any refinement to version two of the ABDG from the internal testing, testing will take place with external stakeholders, primarily Architects in professional practice, and students of both architecture and architectural technology, who are the main target audience for the Design Guide. Feedback will be sought on aspects such as technical content accuracy; level of technical content provided; usability of the ABDG, including accessibility, intelligibility, visual appearance, structure and graphical representation; and use of Active Building case studies.

An *Active Building Overlay* to the RIBA Plan of Work [32] has also been developed to form part of the ABDG, as a way of ensuring Active Building elements are considered at every stage in the design and delivery of Active Building projects. Figure 7 illustrates how this will be presented within the ABDG.