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Role of financial mechanisms for accelerating the rate of water and energy efficiency retrofits in Australian public buildings: Hybrid Bayesian Network and System Dynamics modelling approach

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HIGHLIGHTS

- Retrofitting rate of public buildings constrained by lack of financing schemes.
- We modelled potential retrofitting rate of Australian public buildings.
- We ran scenarios considering different financing and procurement methods.
- We coupled Bayesian Networks and System Dynamics modelling.
- A proper financing mechanism would remarkably boost the retrofitting sector.

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ABSTRACT

In Australia, the government spending on public buildings' energy and water consumption is considerable; however the building energy and water retrofit market potential has been diminished by a number of barriers, especially financial. In contrast, in other advanced economies there are several reported financing strategies that have been shown to accelerate retrofit projects implementation. In this study, a coupled Bayesian Network – System Dynamics model was developed with the core aim to assess the likely influence of those novel financing options and procurement procedures on public building retrofit outcomes scenarios in the Australian context. A particular case-study focusing on Australian public hospitals was showcased as an example in this paper. Stakeholder engagement was utilised to estimate likely preferences and to conceptualise causal relationships of model parameters. The scenario modelling showed that a revolving loan fund supporting an energy performance contracting procurement procedure was preferred. Subsequently, the specific features of this preferred framework were optimised to yield the greatest number of viable retrofit projects over the long term. The results indicated that such a financing scheme would lead to substantial abatement of energy and water consumption, as well as carbon emissions. The strategic scenario analysis approach developed herein provides evidence-based support to policy-makers advocating novel financing and procurement models for addressing a government's sustainability agenda in a financially responsible and net-positive manner.

1. Introduction

1.1. Contextual background

Government buildings are responsible for a large proportion of water and energy consumption; the potential savings which could be accrued through a widespread installation of water and energy efficient devices would be significant; however a number of implementation barriers, even more impeding than in the residential sector, currently hinder the establishment of a robust, effective retrofitting industry.

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Such barriers were previously identified [1,2], and include the lack of initial capital investment [3] that is essential to cover the retrofit projects' high upfront cost [4]. This underlines the importance of having financial and procurement mechanisms in place in order to facilitate access to the capital needed to fund the project. Successful examples showcased in the United States, United Kingdom and Germany make use of innovative approaches such as revolving loan funds (RLF) and energy service companies (ESCOs) to facilitate the procurement process, to name a few [1]. What is evident from the reported international case studies is that each country context is very different and it is important to be able to model and simulate the effects of such policies in a different place (country) based on local technological, climate, social, economic and political factors. Hence the purpose of this study was to simulate the costs and benefits of the introduction of a number of accessible financial mechanisms and procurement models for government building water and energy efficiency retrofit projects in Australia.

The forecasting model would have to go beyond simulating the payback period for energy and water saving alternatives for a certain building and portfolio of buildings since the aforementioned financial and procurement barriers often block the commencement of retrofit projects in the government sector. Therefore, the model must be able to integrate traditional technical and economic indicators with less tangible financial, political and procurement alternatives in order to fully understand the likely take-up of retrofit projects over time for various proposed strategies. Additionally, the forecasting model needs to simulate the best decision for each individual building, while concurrently optimising the best funding scheme at a national level considering the overall expected retrofitting uptake. Importantly, the modelling framework will have to holistically account for all the challenging aspects of the water-energy-climate nexus involved in such a system, so that all the costs and benefits are comprehensively quantified, since typically water efficiency and the water-energy nexus are overlooked in policy-making [1,5]. Fortunately, modelling techniques are available to handle complex scenario forecasting problems with uncertainty and time-based parameter interdependency, including general data-driven models, water/energy simulation models, Bayesian Networks, Agent-Based Models, System Dynamic models, or combinations of them.

1.2. Previous water and energy-efficiency models

Data-driven models have been extensively applied in the energy sector for a range of purposes including costs reduction and energy optimisation, provided that enough data is available. As an example, Rieger, Thummert [6], based on a comprehensive dataset including more than 200 German households, developed a data-driven model and ran several simulations in order to estimate the potential cost-savings of different demand-response strategies, concluding that a two-part tariff (i.e. with a consumption-based component) would lead to at least 5% cost saving and a 14% reduction in peak demand. Fang and Lahdelma [7] also combined two data-driven models (namely, multiple linear regression and SARIMA) to predict district heat demand based on both weather and social input factors, in order to optimise the operations planning of district heating systems. Also in this case, a large amount of historical data is required. Walter and Sohn [8] used a database containing data for energy use, building features and equipment for almost 900,000 US buildings, to develop a multivariate regression model able to estimate the likely energy savings due to a particular energy retrofit. Regression analysis was also used in Lam, Hui [9] to quantify the importance of a number of input parameters in affecting energy consumption in Hong Kong high-rise buildings, and such models could potentially be used to estimate the expected change in consumption based on a retrofit (i.e. variations in some of the input parameters' value); a survey of Hong Kong commercial buildings was the foundation to develop the model. A very similar approach was subsequently used to predict building energy use in different Chinese climate zones [10]. A difference of less than 10% was found between statistical and energy model prediction accuracy. A more complex model, based on genetic algorithms was developed by Siddharth, Ramakrishna [11]; this model was able to identify critical input factors for building energy consumption, and could estimate energy and monetary savings resulting from a number of energy conservation measures. Several different energy-efficient options can be also assessed for a specific building through multi-objective optimisation, such as in Diakaki, Grigoroudis [12]. Another example of regression modelling is given by Guerra Santin, Itard [13], who used data for 15,000 homes in the Netherlands to understand the importance of, in particular, occupants behaviour in affecting energy use for heating, concluding it does partially influence energy consumption. Although related to water heating too, this study was focused on energy consumption while water efficiency is not considered. As a matter of fact, one of the main current gaps in the retrofitting industry is the lack of awareness, and interest, in water retrofitting [1] and of the potential combined savings due to the nexus between water and energy. As a result, modelling of water-efficient technologies is not as common as for energy retrofits.

In the Australian context, Beal, Bertone [14] modelled the estimated water, and energy, savings of water-efficiency devices for residential households, such as tap aerators and efficient shower heads. Talebpour, Sahin [15] investigated the performance of residential rain water tanks with an empirical approach based on water, energy, socio-economic and stock inventory data for a number of houses in South-East Queensland. Kenway, Scheidegger [16] developed a static mathematical model to simulate household water use and analyse different scenarios incorporating technical and behavioural changes, with the scenarios combining both strategies predicting much larger water-related energy savings than technical improvements alone. Vieira, Humphrys [17] used the software EnergyPlus to understand and quantify the effects of site-specific features on the performance on domestic water heating systems. Gurung, Stewart [18] analysed and modelled a number of water savings technologies and quantified the mutual benefits for householders and water utilities.

More detailed, building-specific computer models typically would not allow for a large scale feasibility assessment of a retrofitting policy, however to overcome this it is possible to follow the methodology proposed by Dascalaki and Santamouris [19]. They ran an energy model on ten buildings only, however, since each of these was representative of a particular office building type, it can be assumed that the model would yield similar outputs for other buildings within the same category; thus the outcomes were extrapolated to estimate the energy saving potential of a number of retrofitting actions for the whole office stock. Another study focusing on a particular category of public buildings was undertaken in Beusker, Stoy [20], where data for over 100 schools and sport facilities in Germany were used as input for a regression model able to estimate energy consumption for heating. Similarly to Dascalaki and Santamouris [19], energy models were used in Saari, Kalamees [21] to estimate the financial viability of different options (e.g. solar collectors, heat pumps) for new detached houses in Finland, providing the payback period as output.

In terms of financial modelling, in their integrated retrofitting optimisation tool Rysanek and Choudhary [22] incorporated a cost and savings analysis using net present value, also accounting for the uncertainty associated with factors such as engineering performance and energy price. Interestingly, other studies found that the energy savings for solar retrofitting options are typically overestimated [23]. A similar approach, using NPV to find the optimal retrofitting option and accounting for uncertainty in energy price, was used in Kumbaroğlu and Madlener [24]. An "augmented" NPV method, using the capital asset pricing model, is instead proposed in Menassa [25], in order to allow the decision maker to assess and prioritise different retrofitting options over time.

Based on the available literature herein discussed, there are a number of gaps and limitations which need to be addressed. It can be