International Journal of Sustainable Built Environment (2016) 5, 526–548

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International Journal of Sustainable Built Environment

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Review Article

State-of-the-art review revealing a roadmap for public building water and energy efficiency retrofit projects

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Received 24 June 2016; accepted 19 September 2016

Abstract

Governments occupy a significant proportion of building stock and their associated annual water and energy costs can be substantive. Research has shown that significant reductions in energy and water consumption as well as carbon emissions can be achieved through retrofitting public buildings. However, in most countries the current retrofitting rate is very low due to a number of barriers, including a lack of supportive legislation, regulations, guidelines, industry capacity and financial mechanisms. This paper provides a comprehensive review of the barriers as well as the best international practices covering numerous aspects of public building retrofits. Among others, the most important barriers identified were a lack of consideration of the water-energy nexus, and the limited availability of effective financing mechanisms. With a particular focus on the Australian context, a strategic roadmap, as well as a number of recommendations, such as the use of revolving loan fund financing and energy performance procurement, have been developed that aim to foster a greater rate of implementation of energy and water retrofit projects for public buildings. Achievement of such an aim will not only reduce ongoing operational costs of public buildings, but also lower their environmental impact and generate new employment opportunities.

Keywords: Water efficiency retrofitting; Energy efficiency retrofitting; Water and energy retrofit projects; Financial modelling for retrofit projects

Contents

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Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2016.09.004
2212-6090/

1. Introduction

The built environment accounts for half of the total energy consumption and greenhouse gases emissions in the developed countries, and a fifth of the world's total energy consumption (IEA, 2011). As inefficient energy and water equipment largely contributes to achieving these high levels, buildings represent the most effective target for energy and water conservation (Power and Zulauf, 2011); in fact, it was estimated that 41% of the possible global energy savings potential by 2035 is related to the building sector (IEA, 2012). It has been demonstrated how energy/water savings can be achieved by retrofitting buildings since three decades ago (Goldman et al., 1988), and more recently it was demonstrated how reductions of 30–40% in energy and water consumption are often achievable in buildings (e.g. Willis et al., 2011).

A specific building sector where considerable energy and water savings could be achieved is the public building sector (Ardente et al., 2011; Chidiac et al., 2011; Mahlia et al., 2011; Ascione et al., 2015; Xu et al., 2015). For instance, in Australia, governments occupy over 25% of the commercial building stock. The majority of public buildings (e.g., offices, schools, libraries, and hospitals, as well as galleries and museums) are existing stock that were designed and constructed often with insufficient consideration for energy and water efficiency, and the associated life cycle costs. As a consequence, it was estimated that for the State of New South Wales in Australia, up to AUD$99 million in total economic activity could be realised by 2020 with the building energy efficiency market (Ernst and Young, 2010). Retrofit projects could reduce the spending of Australian Governments in water and energy use associated with their building stock, which has been estimated to be over $1 billion per year (ANAO, 2009). Driving an efficiency agenda is particularly important, when also considering that it has been estimated that energy consumption in Australia could increase by up to 5% due to the effects of climate change (Guan, 2012).

A study by the US Department of Energy estimated that the local economic activity generated from energy efficiency investments is more than twice the value of the initial investment (NREL, 1995). There is also a growing interest towards energy efficiency of particular building areas such as data centres, as their energy demand per square metre is 100 times higher than for office accommodation areas (Oró et al., 2015). However, existing buildings continue to be retrofitted at a very low rate of about 3% per year in both the EU and US (Zhivov, 2013a). One of the negative consequences of delaying the refurbishment of water/energy-inefficient public buildings is also the loss of productivity due to a poorer indoor environment, which in the US was estimated to cost as much as US$22.8 billion per year (Milton et al., 2000). Despite some progress, many governments are failing to meet their targets, due to a number of reasons such as unsuitable contracting models and low priority given to this issue (Ryan and Murray-Leach, 2011).

A water/energy retrofit project consists of a large number of activities beyond the implementation itself. Prior to implementation, the building's water/energy consumption must be estimated in order to assess the current efficiency and predict possible savings. This can be achieved through monitoring and auditing activities (e.g. Willis et al., 2013). During this process, a certification rating label can be released, depending on government policies. The next step would be to predict the likely water/energy consumption for a number of retrofit alternatives using several different modelling tools. After these estimates have been completed, the results of the energy/water consumption model should be integrated with other environmental and financial assessment criteria, and a risk/sensitivity assessment conducted, in order to rank the different retrofit alternatives. Finally, the necessary funding for the retrofit project must be secured through available financial mechanisms and an appropriate procurement method chosen. The available financial support mechanisms and the regulatory context, will serve to enable or impede retrofit projects to proceed. Moreover, predicted savings must be verified using appropriate monitoring and verification activities that occur during and on completion of the retrofit project. This brief discussion highlights how governments play a significant role in establishing a financial and regulatory environment to support the retrofitting of their public buildings.

This paper describes the aforementioned main activities involved in a water/energy retrofit project in the context of public buildings, and for each step it provides a discussion of current issues, best practices, and impediments. Specifically, Section 2 will focus on monitoring and verification both before and after the retrofitting activity; Section 3 on auditing and certification in relation to water and energy consumption; Section 4 discusses existing water/energy modelling techniques, while Section 5 explains how their outputs must be incorporated with other project considerations in order to rank different retrofitting options; Section 6 identifies procurement issues; and Section 7 discusses financial mechanisms and regulatory frameworks to facilitate retrofit projects implementation. The goal of this review study, which is presented in Section 8, is to identify best international practices as well as current gaps limiting a more widespread diffusion of water and energy retrofitting of public buildings, with a focus on the Australian public building context. These are summarised in Section 8. Finally, Section 9 presents a number of strategic recommendations, a path model and a roadmap for accelerating the current rate of public building retrofit projects in Australia.

2. Retrofit project monitoring and verification

Monitoring and Verification (M&V) mainly refers to the activities post-retrofitting aimed at determining the actual energy/water savings reached with the retrofitting project and to compare them with the predicted savings. However, monitoring is also a critical pre-retrofitting activity to quantify the current energy and water efficiency of the building and thus assessing the best retrofitting strategy. Ma et al. (2012) provided a list of previous studies where the importance of M&V is highlighted. Typically, in terms of methodology M&V represents up to 10% of the project constructions costs (AEPCA, 2000, 2004; OEHNSW, 2012) and it is a critical step of any retrofit project (PNNL and PECI, 2011).

2.1. Pre-retrofit activities

The main activities involved in pre-retrofit monitoring are: data collection and analysis, and rating of the system (both asset and operational) (Hong et al., 2015). Monitoring of energy and water consumption can be performed by analysing metered data (e.g. Willis et al., 2010). Metered data can also be used for operational ratings when an audit is performed in order to release an energy/water certification; this rating has been preferred by many countries to asset rating for existing complex large buildings (IEA, 2010). In cases where no reliable metered data are available, utility bill analysis, normalised for weather patterns and other factors, helps identify the performance of each building, pre- and post-retrofit installation (USDE, 2012b). It is stated though that water bills or data with frequencies higher than 5 minutes are inappropriate for end-use analysis and leak detection (Quinn, 2006).

However, most of the energy savings reported in the literature are based on numerical simulations and no comparison with real measured data is available (Ma et al., 2012). Hence, data collection is crucial as it can help create large databases to be also used for other purposes. An example is provided by Hoos et al. (2016) who quantified and categorised the energy use of the public building stock in Luxembourg, which can help building managers to calculate the costs of potential retrofits. Existing building data can be also used as input for energy assessment and thus reduce the cost of energy certificates (Poel, 2007). Real-time data on a building's dynamic energy performance and the surrounding environment should be also collected to obtain reliable energy simulation models (Berman et al., 2012; Hong et al., 2015). Industrial associations and federations could help with data collection and communication for policy development, effectively acting as intermediaries between government and building owners (Tanaka, 2011).

Data collection has become a priority in the US for over 25 years (Hirst, 1991). This is crucial for both modelling (i.e., seek the reasons behind any discrepancies, reduce uncertainty) and financial aspects. Denmark proved to be pioneering in this aspect as all the results of their mandatory certification scheme are stored and used to assess saving potentials and develop policy actions (IEA, 2010). The Australian Government is working on collating existing data from different institutions and industries to create and maintain a large energy use database (DIS, 2015). In China, monitoring has been given a lot of importance as part of the 'Eleventh Five-Year Plan' (2006–10), when a nationwide system to monitor energy performance of large-scale existing public and government buildings was initiated (Zhao et al., 2009), while for residential buildings in northern areas of China, heating metering was required (Shilei et al., 2009), and installation grants provided (Kong et al., 2012; Xiao et al., 2014). Also, under the subsequent Twelfth Five-Year Plan (Xiao et al., 2014), investigation and data collection for each building to be retrofitted became the regular first crucial step of the project (Kong et al., 2012). The three main activities undertaken were: (1) basic information census for large-scale public buildings; (2) design and installation of sub-metering systems of electricity consumption in energy intensive buildings, followed by energy auditing; and (3) provision of real-time statistics and establishment of a consumption monitoring platform in all cities (Kong et al., 2012). It is expected that the Thirteenth Five-Year Plan will keep supporting these kinds of initiatives, as it seems to show interest on improving the 'ecological environment' and help co-financing green development (Brødsgaard, 2016).

Recently, a number of more technologically advanced, high resolution 'smart' metres have been introduced and they provide higher-frequency data which can be very useful for water and energy consumption analysis (Nguyen et al., 2013, 2014, 2015) and for identification of potential water/energy conservation measures (Willis et al., 2010) For instance, Beal et al. (2012) provided a comprehensive analysis of potential water and energy savings for a number of households in South-East Queensland connected to smart water metres. Smart metre data, as well as other survey data, allowed for a detailed analysis and prediction of energy and water consumption of each end-use (e.g., shower, clothes washer) under different scenarios (e.g., B. A.U., new water heater, and new shower head). Electricity smart metres, although not mandatory, are recommended by the Australian Government (DIS, 2015), in order to enable an electricity pricing scheme where the price depends on the cost of supplying energy, which fluctuates during the day. Despite not directly related to retrofit options, such metres can lead to behavioural changes of the tenants and help reduce peak demand issues, as well as providing a large amount of detailed data which can be used for research and policy-making (Stewart et al., 2010). Additionally, in Queensland, Australia, the mandatory building code imposes, among others, appropriate electricity sub-metering for certain building categories and energy-efficient air conditioners (GMQ, 2011). Sub-metering implies that each tenant pays for his own energy consumption and thus can stimulate a reduction of the energy use (GMQ, 2011).

On the other hand, water metering is quite limited in Australia, with no mandatory metering and often no metering at all (Quinn, 2006). This is concerning considering that water issues can be potentially worse than with energy, with leakage losses of 10/30% quite common (Quinn, 2006; Britton et al., 2013).

Pre-paid metering, which has been recently used in countries such as the United Kingdom (Leiva et al., 2016) and New Zealand (O'Sullivan et al., 2015), are also considered a way to raise awareness and to better control the electricity usage and eventually reduce its consumption (Coutard and Guy, 2007; Faruqui et al., 2010); however, it is also argued that low-income households (who are the typical consumers of pre-paid metered electricity) have few opportunities to actually reduce their consumption, thus this scheme eventually leads to a higher risk of 'self-dis connecting' (e.g., running out of credit), resulting in no electricity and subsequent potential serious health implications (O'Sullivan et al., 2015).

2.2. Post-retrofit activities

M&V of the predicted savings is essential to justify the investment, either for the owner for directly funded projects, or for third-party contractors in more complex financing schemes such as energy performance contracting (EPC) (AEPCA, 2004). M&V can be also used to monitor parameters such as temperature, humidity, and other indicators of indoor environment quality (SBE, 2012) and thus of extra costs/benefits of the intervention. The link between these parameters, and data from surveys, health costs and absenteeism (SBE, 2012) can be derived to estimate the further environmental and social costs/benefits. M&V is also used for increasing the energy/water savings by proactively adjusting facility operations and maintenance based on the monitored parameters (EPEC, 2012).

It is important, and difficult, to distinguish changes in energy and water efficiency achieved through retrofitting from those affected by other factors. In fact, there is always a difference between predicted and measured savings (Hong et al., 2015), with energy/water intensities estimated with theoretical studies often lower than those based on empirical evidence (Vieira et al., 2014). However, standardised M&V procedures to normalise metre data exist (USDE, 2012a). A number of uncertainties, described later in this paper, also play a big role in creating discrepancies between predicted and monitored data.

This emphasises the importance of M&V policies promoting a cyclic feedback system that links the predicted and monitored improvements in energy and water performance (Hong et al., 2015). A good example is given by the US Energy Independence and Security Act of 2007 (USDE, 2012a) where a four-year cycle for a project plan, implementation and verification was proposed and great importance was assigned to M&V activities, both pre and post implementation. Another example is given by China's Eleventh five-year plan, whose goal, among others, was to increase monitoring and supervision of energy consumption (Kong et al., 2012). A number of incentives were provided for those projects including post-retrofit M&V; for instance, local retrofit projects could get a 50% fiscal interest discount on loans, while for central government projects undertaken through an energy management contract (EMC) that monitors the actual energy savings, the discount can go up to 100%. A number of special funds, that also incentivise an appropriate post-intervention monitoring, was put in place and while part of the funded budget is provided at the start of the project (i.e. 50–60%), the remaining funding was allocated after monitoring verifies that the predicted savings have been achieved (Kong et al., 2012; He et al., 2015).

In conclusion, M&V is essential for the implementation of successful retrofitting projects; however, there is a need for precise M&V standards to follow. The standards specified in the International Performance M&V Protocol (EVO, 2007) could set the foundations for each national government to create their own standards and regulation. Of particular note is that more emphasis should be given to water monitoring, as presently the focus is on energy M&V.

3. Retrofit project audits and certification schemes

3.1. Audits

An energy or water audit is a detailed report on the energy/water features of a building, resulting from inspections and data collection, and offering recommendations for improving its efficiency (Popescu et al., 2012). It forces the owners to become aware of problems whose existence was unknown (POWER, 2010). Since a landlord might not be familiar with the technical jargon typically used in these reports, it is important to consider the audit as an educational tool, where the benefits of a water and energy-saving project can be easily understood, thus increasing the interest towards retrofits (USDE, 2012b).

There is a need for national agreements and mandates on the level and type of audit required; standard audit packages should be created (USDE, 2012b) in order to provide consistency in determining water and energy consumption and savings opportunities, as previous studies have found that audit results can be highly variable, even across similar buildings (USDE, 2012b). In Australia and New Zealand, energy audits are already classified into three different levels of complexity (SA and SNZ, 2000); however, there are no existing regulations suggesting which level is required based on the project and building characteristics, and thus such level is chosen according to the project goals and budget available (Ma et al., 2012). A standardised approach is offered by ASHRAE (Alajmi, 2012); for common retrofit measures, a Level II is typically sufficient (PNNL and PECI, 2011). On the other hand, there are no standard water audits in Australia (Quinn, 2006).

In the US, as part of local energy efficiency policies, a number of cities (e.g., New York, Seattle, Philadelphia and San Francisco) have enforced energy auditing for certain categories of buildings. Importantly, due to various domestic and international statistical needs, many governments have introduced energy savings potential-oriented statistical surveys, introducing energy auditing and monitoring in addition to data collection (Tanaka, 2011). However, often the collected data are stored by different institutions and organisations (DIS, 2015), resulting in fragmented data with limited cost benefits.

In Sydney, the Smart Green Apartments Programme, launched in 2011, provided free water and energy auditing for several selected residential buildings in order to raise awareness and help owners to reach water and energy savings. The main problem resulted to be the lack of an appropriate benchmarking rating system, and thus the inability to actually score the calculated building energy/water consumption.

In conclusion, better regulatory frameworks and guidelines are needed for a more widespread implementation of energy, and especially water, audits. These can lead to a better quantification of energy and water savings resulting from the implementation of a retrofitting project, besides creating employment opportunities for a number of specialised, highly-trained professionals.

3.2. Certification schemes

Water and energy certificates are a means of quantifying and benchmarking the water/energy efficiency of a building; they provide a rating, compared to overall standards, based on data collected from metres, bills and audits.

Additionally, a certification can help identifying interventions to improve the water and energy performance (Arkensteijn and van Dijk, 2010); as an example, the Danish labelling schemes provides advice on improvements (IEA, 2010). According to Ryan and Murray-Leach (2011), it is essential to place mandates on energy and water savings goals, as agencies generally focus on those performance measures against which they are rated. Alternatively, voluntary certifications can also be put in place, as it has occurred in Singapore, the United States and Australia (IEA, 2010); in these cases though owners of poorly performing buildings will rarely undertake the certification and subsequently display a negative label which could affect the rental value (IEA, 2010).

A number of other energy performance certificates schemes exist (Pérez-Lombard et al., 2009; Arcipowska et al., 2014;), such as ENERGY STAR in the US, and display energy certificates in the UK. In general, in the EU energy certificates for existing buildings are often required for the sale or lease of the building (IEA, 2010). In fact, the Energy Performance Building Directive (EPBD) forces buildings to provide an EPC at the time of sale or rental (Hong et al., 2015). In the US, a comparative labelling scheme has also been introduced, called RESNET, showing a comparison of the building's consumption with values of standard new/existing homes. Although voluntary, some states have made this labelling mandatory (IEA, 2010). However, once again, much of these efficiency efforts are focused on energy and overlook water issues.

Rating a building's efficiency based on energy consumption alone can be an incomplete assessment. In Singapore, the Building and Construction Authority (BCA) Green Mark labelling scheme also takes into account water use (IEA, 2010) and under the Second Green Building Master Plan, launched in 2012, minimum Green Mark Certified standards are required upon installation of a number of retrofit measures. There is also a voluntary global-scale scheme developed by the non-profit organisation, the International Initiative for a Sustainable Built Environment, called the Sustainable Building Tool, which rates the sustainable performance of buildings based on a wide range of factors. Other voluntary certification schemes, such as LEED in the US or BREEAM in the UK, also take into account other factors, such as materials and resources, pollution, health and ecology, beyond energy and water savings. It is indeed proven that benchmarking rating systems can be created based not only on quantitative indices (e.g., water/energy use per square metre), but also that qualitative factors (e.g., presence of energy manager, history of retrofit projects) can be integrated (PNNL and PECI, 2011). Despite being voluntary, they are seen as a valuable marketing tool (IEA, 2010), as they offer buildings a way to receive public recognition (PNNL and PECI, 2011).

Since 2008, the International Energy Agency (IEA) has recommended action on building certification schemes and policy packages to promote energy efficiency in buildings (Kolokotsa et al., 2009). In another report (IEA, 2010) it is also emphasised how energy performance certification is a key policy instrument and can help governments achieve energy efficiency targets.

A rating scheme to show the environmental performance of residential/commercial Australian buildings is the NABERS—i.e., the National Australian Built Environment Rating System (Hes, 2007). Software to complete the assessment was developed, and a similar tool, NABERS Office Water, released in 2006, rates the building in terms of water consumption on a scale from 1 to 5 stars (Hes, 2007). These rating tools take into account a number of adjustments based on climate and the nature of the building (Quinn, 2006), although water consumption was found not to correlate to a number of expectedly important factors (Quinn, 2006), and thus more work is needed to refine this tool. In terms of single appliances, in Australia there are energy performance and labelling standards in place under the Greenhouse and Energy Minimum Standards (GEMS) Act 2012 (DIS, 2015); also, the Water Efficiency Labelling and Standards (WELS) was introduced in 2006 and provides a mandatory 1 to 5 star rating to fixtures; at the time of its introduction it was predicted to lead to overall savings of $600 million by 2021 through reduced water and energy bills (Quinn, 2006).

In conclusion, worldwide examples of certification schemes exist and it seems that mandatory schemes offer a number of advantages compared to voluntary ones. Remarkably, these largely focus on energy, while water consumption rating schemes are a minority. It was also noted that not only it is important to include energy and water consumption, but also qualitative metrics should be integrated into these schemes.

4. Building retrofit project energy and water simulation tools

There are a number of whole building energy simulation packages, such as EnergyPlus (which includes optimisation tools such as BEopt driving its simulation engine), eQUEST, DOE-2, ESP-r, BLAST, HVAC- SIM+, TRNSYS, which can be used to simulate the thermodynamic characteristics and energy performance of different retrofit measures. It has become standard practice to use these building energy simulation packages to quantify and assess energy consumption and possible energy savings options (Rysanek and Choudhary, 2013). For instance, TRNSYS is a flexible software environment used for the simulation of transient systems (Poel, 2007; Li et al., 2009; POWER, 2010; Oró et al., 2015). Another example of energy simulation packages is EnergyPro (Berman et al., 2012). Alternatively, formulas such as heat transfer equations or steady state methods have been also used. Energy calculation methodologies/software often can be easily adapted to the local/national context (IEA, 2010), and thus also to different climate zones (e.g., PNNL and PECI, 2011).

Mathematical models have been developed to predict specific building water end-uses (Wong and Mui, 2007). A number of energy simulation models have been built with statistical or data-driven approaches, such as ANN (Wong et al., 2010; Murray et al., 2012). Unlike classical, forward models, data-driven (inverse) models require data from the system. Bayesian Networks have been also used to predict building energy use, based on historical data and experts' input (O'Neill and O'Neill, 2016). Statistical approaches have been also used to model both energy and water consumption (Suh et al., 2012; Kontokosta and Jain, 2015), although the integration of water consumption modelling is very rare. Combinations of engineering and statistical approaches have been also applied in this field (Xu et al., 2012). Guo et al. (1993) developed a software tool where data and knowledge are integrated and used to design lighting retrofit projects for commercial buildings. Further, (Howard et al., 2012) developed a model based on GIS and robust multiple linear regression to estimate the energy use intensity of buildings in New York City. A number of studies using GIS, LiDAR data or a combination of these to estimate energy consumption are presented in Hong et al. (2015). EnerGIS (Kim et al., 2012; Hong et al., 2015;) is another tool that, if enough appropriate data are collected, can estimate the energy consumption of a single building, as well as of the whole city, and can also provide colour-code comparisons between different building efficiencies. If validated, these approaches could be useful on a larger scale to estimate the energy efficiency of city districts, and to assess the potential of different large-scale retrofitting options. Nevertheless, for an accurate estimation at the building scale, detailed monitoring and auditing information must be collected and proper simulation tools accounting for energy changes, as well as other factors, should be implemented. Previous studies have mainly worked with monthly or yearly data, and although the goal may have been to establish a national energy policy and not a detailed strategy for single buildings, it has been argued that real-time data are necessary to also cope with climate change effects (Hong et al., 2015).

In conclusion, there are several options for modelling building energy consumption, but water consumption simulation models are far rarer. Given that, based on the concept of "water-energy nexus", water and energy consumption are strictly connected not only at a urban level (e.g. including drinking water production), but also correlated at a building level (see e.g. Kontokosta and Jain, 2015), it is important to integrate this aspect in a comprehensive modelling tool, which makes use of thorough and consistent input data from audits and other data collection activities.

5. Evaluating and ranking building retrofit options

More than 400 retrofitting options were already identified two decades ago (Wulfinghoff, 1999) and, nowadays, there exist thousands of the retrofitting options. Therefore, the availability and use of a ranking tool would enable the building managers/users to compare as many options as feasible and, consequently, increase the likelihood of identifying an optimal solution for larger savings. Notably, retrofit options can either lead to a reduced energy/water demand (e.g. taps aerators), or to an increased use of renewable energy which is cheaper and environmental-friendly (e.g. solar panels); often, it seems more cost-effective to use renewable energy sources instead of trying to reduce energy/water demand (Ferreira et al., 2016), although it is also possible to achieve demand reduction and, at the same time, increase renewable energy use. Nevertheless, different types of costs and benefits need to be considered for an accurate assessment and ranking.

5.1. Economic considerations

A variety of analysis methods can be used to evaluate the economic viability of building retrofit measures. Certain indices, which can be used to assess the feasibility of retrofit measures, are:

- Net present value (NPV): it estimates the feasibility of a retrofit project by discounting future expected monetary savings for inflation; if, at the end of the retrofit life, NPV is positive, then it means that the project is viable. This index however does not allow for a fair comparison of different options, as larger projects might lead to higher NPV, but also much higher initial capital investments. Also, despite the benefits of referring to present values, the unconsidered uncertainty related to future water and energy prices could remarkably distort the results provided by NPV.
- Internal rate of return (IRR): it is calculated by setting the NPV to 0 and solving for the discount rate. Although very easily interpretable, it should be used in conjunction with other indexes to avoid misleading interpretations. For instance, a retrofit option with a short life cycle might have a high IRR and yield high returns for few years, however a retrofit option with a lower IRR but with a longer life cycle, might yield higher total investment return over the long term.
- Benefit-cost ratio (BCR): it is given by the ration between the discounted value of incremental benefits and the discounted value of incremental costs, with any project having $BCR > 1$ being viable. The main issues are: (1) a correct estimation of the discount rate, especially for long-term retrofit projects; and (2) the quantification of the non-monetary benefits.
- Simple payback period (SPP): it estimates the time required to regain, through water/energy savings, the capital invested in a retrofit project. The main limitations are: (1) it does not consider the time value of money; and (2) it tends to focus on the short term and not on the total life of the building. Thus, a valuable

project, having though a longer payback period, might be overlooked despite leading to larger returns over the long term. Thus, SPP must be used in conjunction with other indexes.
- Discounted payback period (DPP): it is a variation of the SPP which overcomes the first aforementioned limitation, by discounting future cash flow. However, issues can arise in determining the value of the discount rate.

Alternatively, the life cycle cost (LCC) analysis method can be used (Ardente et al., 2011): it is in fact important to use simulation tools to conduct a life cycle economic and environmental analysis (Hong et al., 2015). Examples are provided by Ma et al. (2012), in their review.

When assessing all the costs and benefits of a retrofit project, all the economic factors should be included, such as higher prices for buildings that have undergone energy/water efficiency upgrades (Popescu et al., 2012). Previous research studies proposed methods where a 'dynamic' payback period is calculated, based on the variable house transaction price, which typically results in much shorter payback periods (Entrop et al., 2010). In order to quantify the change in property value, different methods can be used; for instance, in some German cities, 'Ecological Rent Tables' are used to consider the building's thermal characteristics when determining the rent (Enseling and Hinz, 2006). Also, regression models can be developed to predict price variations based on a number of inputs; similarly, a comparison between the transaction prices of retrofitted versus non-retrofitted buildings can be performed. However, both require a large database to be collected (Popescu et al., 2012) and knowledge of other factors affecting the price (e.g., location); alternatively, a market coefficient can be calculated by using the scoring method (Popescu et al., 2012), which is highly customisable and can consider factors other than economic.

5.2. Co-benefit considerations

Conventional economic indices are not explicitly representative of a building's sustainability (Kolokotsa et al., 2009) and often there is a failure in identifying all the benefits of a project, with non-water/energy benefits potentially being dominant project drivers (PNNL and PECI, 2011), especially where energy and water costs are less important. For instance, improving the occupants' satisfaction and productivity leads to greater economic returns (SBE, 2012) where the building under consideration is a public office. Although it is typically difficult to give a monetary value to non-economic variables, this can be performed. For instance, McDuffie et al. (2015) monetised all the social and educational benefits of a storm water retrofit system installed in a US public school, demonstrating that the total social value exceeded the project cost; the approach used, which is quite common, is the "willingness to pay" method. Li et al. (2009) took into account the environmental benefits of certain retrofit options by considering (real or assumed) taxes on carbon and sulphur dioxide emissions, and calculated the savings in tax payments given by a reduction in their relative emissions. Moreover, they also calculated what values those taxes should have in order to make environmentally friendly energy retrofit options more cost-effective than traditional ones, and thus adoptable. Further, Kolokotsa et al. (2009) provide a list of economic and environmental costs quantified according to previous research.

A number of comprehensive performance indices have been created in order to concisely quantify the overall cost-benefit of different projects. For instance, the Marginal Abatement Cost (MAC) takes into account not only the project's economic costs, but also the carbon emissions reductions achieved, although hidden costs can be overlooked and predicted discount rates underestimated (Xiao et al., 2014); however, in their study, Xiao et al. (2014) proposed an improved approach where different scenarios were run to account for some of this uncertainty. Tuominen et al. (2015) proposed an assessment tool based on cost-effectiveness analysis (CEA): realising how indices such as the payback period have limitations (PNNL and PECI, 2011), they proposed CEA as an improvement to CBA. As for CBA, each outcome must have a monetary value, which is often difficult to estimate, and thus CEA is more suited for these kinds of situations and is also faster than CBA or MCA.

Interestingly, Roulet et al. (2002) developed ORME, i.e., a multi-criteria rating methodology, based on principal component analysis and ELECTRE algorithms, which takes into account not only energy use and costs, but also impacts on the external environment and indoor environmental quality for office buildings. Based on this approach, a similar decision support tool was built in another study (Flourentzu et al., 2002). Further, Rey (2004) used a multi-criteria approach, including environmental and socio-cultural aspects, to evaluate office building retrofitting options. More recently, Geng et al. (2015) used a fuzzy analytic hierarchy process to overcome the limitations of multi-criteria decision-making in dealing with uncertainty; however, social benefits were not considered.

5.3. Dealing with uncertainty

Uncertainties, such as climate change, services change, changes in human behaviour, changes in government policies and water/energy prices, represent one of the main challenges in developing a strong retrofitting policy (Ma et al., 2012).

The main risks and sources of uncertainty are listed below (Mills et al., 2006):

- Economic (energy and water prices, exchange rates, equipment costs)
- Contextual (facility data, weather and climate)
- Technological (equipment performance and lifetime)

- Operational (degradation, indoor environmental quality)
- M&V (data quality, modelling errors, metering precision)

Scientists and engineers typically avoid or devalue metrics showing evidence of uncertainty (Mills et al., 2006). The energy and water consumption of buildings can change over time due to different occupant's behaviours, ageing equipment or inadequate maintenance (EEWGSCCC, 2012), thus making the estimation and verification of energy and water savings even more challenging. As an evidence, previous studies have found that model predictions typically overestimate energy savings, and in general they are not consistent with the actual measured energy usage data (USDE, 2012b); this lack of accuracy in predictions poses a major limitation to any retrofit project, as there is insufficient credibility and trust in the estimated savings and thus a fear of monetary loss.

Specific difficulties in obtaining accurate estimates under deep uncertainty are, for instance, related to global warming and water/energy price volatility (Hong et al., 2015). Climate change is expected to affect energy/water demand and supply (Arent et al., 2014), and in turn the potential monetary savings from retrofitting activities (Daly et al., 2014). The energy price, on the other hand, should continuously increase due to the decrease in fossil fuel reserves (Hong et al., 2015), although a linear increase would be only a rough approximation at best, given that historical energy price data show strong fluctuations and even occasional reversals (Kumbaroğlu and Madlener, 2012). With traditional approaches, variations in price are often neglected (Xiao et al., 2014); instead, reference to energy agency predictions, such as the Annual Report from the US National Institute of Standards and Technology (Rushing et al., 2010), should be used (Popescu et al., 2012) or Monte Carlo simulations should be run to deal with this source of uncertainty (Kumbaroğlu and Madlener, 2012). It is important to quantify price uncertainty as it has been demonstrated that in the case of high price volatility, delaying the investment becomes a more profitable option (Kumbaroğlu and Madlener, 2012), although the building's performance will relentlessly decrease during its life cycle.

Therefore, it follows that risk assessment is essential to provide decision-makers with a sufficient level of confidence and thus reduce the uncertainty in investment in building retrofits (Ma et al., 2012). Additionally, a dynamic approach to represent and predict the aforementioned changes is necessary for a more robust assessment, which also reduces the potential risk in decision-making (Hong et al., 2015). A probabilistic view may reveal that, assuming certain conditions, the proposed investment is in fact not cost-effective at all (Mills et al., 2006). Probability-based methods are the most commonly used risk assessment approach and include expected value analysis, the mean-variance criterion and coefficient of variation, the risk-adjusted discount rate technique, the certainty equivalent technique, Monte Carlo simulations (Mills et al., 2006), decision analysis, real options and sensitivity analysis (Kreith and Goswami, 2011). Other non-probabilistic decision rules can be also used; an example is given by the Wald's criterion, the Hurwicz's criterion, or the Savage's regret criterion; the latter allows for an optimal solution to be sought by simultaneously minimising the risk (Rysanek and Choudhary, 2013).

If a Monte Carlo approach is used, a large number of scenarios have to be run; if this approach is integrated in a complex building energy model (BEM), this is not recommended as the overall simulation becomes time-consuming and dependent on a large number of inputs that must be varied (Rysanek and Choudhary, 2013). Instead, simplified quasi-steady state BEMs, using linear energy balance models, may be used. These models are recommended as they are rapid and allow a large number of options to be considered (Rysanek and Choudhary, 2013); nevertheless, the large time-steps used (usually monthly) may represent a limitation in the accuracy of the assessment (Rysanek and Choudhary, 2013). The use of sequential models can be a way to reduce the computational demand of certain heavy simulation tools (Rysanek and Choudhary, 2013).

Other examples of including uncertainty are given by Menassa (2011), who presented a quantitative approach to determine the value of investing in sustainable building retrofits by taking into account different uncertainties associated with LCC and the perceived benefits of this investment. Moreover, Heo et al. (2012, 2013) presented a probabilistic method, based on Bayesian calibration of normative energy models, where the uncertainty of physical properties, investment costs and equipment performance are considered, although the SPP is used for evaluation, ignoring more detailed economic factors as well as other co-benefits. In Kumbaroğlu and Madlener (2012), a dynamic evaluation method, which also takes into account uncertainty related to future energy prices through Monte Carlo simulations, was developed. Dynamic BEMs have been developed where optimisation algorithms were integrated in the original model using a discrete sequential approach to reduce the computational time and non-probabilistic decision rules to handle uncertainty (Rysanek and Choudhary, 2013), although socio-environmental aspects were not included in the optimisation process. Daly et al. (2014) instead used EnergyPlus to estimate the effects of climate change on commercial buildings' energy consumption and thus the potential for retrofit projects; only a limited number of scenarios and uncertainties were considered, and in cases where the building is rented and the landlord does not profit directly from the energy savings but from a rent increase, the energy price uncertainty was not calculated. This is a limitation, as the savings for the tenants should be clearly estimated in order to justify and quantify the rent increase. Also, the NPV was used as an index and other co-benefits were not taken into account. In other models, different energy supply options were integrated in the economic analysis framework (Li et al., 2009) and the optimal choice for thermal efficiency requirements was identified, although renewable energies were totally neglected, as well as some other co-benefits or costs. Further, energy price increments were assumed deterministically instead of accounting for the high volatility and uncertainty of this factor.

We conclude that more research in risk assessment for water/energy retrofits is needed at this stage. For instance, more research into climate change and human factors and how these affect building energy and water use is necessary to reduce the uncertainty and obtain smaller discrepancies at the M&V stage (Ma et al., 2012). In terms of modelling, a consistent probabilistic approach should be identified and deployed, potentially integrated with deterministic energy and water calculators, in order to account for the large amount of uncertainty involved. More research dedicated to accounting for water-related uncertainties is also needed, as this is often not integrated with the energy considerations.

5.4. Financial modelling considerations

A financial tool should be developed (Kong et al., 2012) and integrated with the previously discussed models in order to rank alternatives based on certain policies being in place, as it has been demonstrated that the success of a retrofitting project relies in equal terms on the engineering performance estimation and on accurately depicting economic conditions (Rysanek and Choudhary, 2013). This has been already done with the development of the decision support tool 'EnERGo' (Zhivov, 2013a, b), which contains an energy calculation tool as well as a financial spreadsheet. This allows for the payback period and other economic indices to be estimated based on certain user-defined cost inputs, but it does not really allow for optimisation and ranking based on the financing options available. Also, water retrofits, and the water-energy nexus, are not considered. However, the development of optimal business models, possibly with combinations of public and private funding, such as energy savings performance contracting (ESPC) to reduce technical and financial risks, was one of the next tasks of the project (Zhivov and Lohse, 2014).

If enough data and knowledge of the location are available, it is important to incorporate the sale value information in the financial analysis, as it has been proven that the payback period considerably decreases when this monetary factor is taken into consideration (Entrop et al., 2010; Popescu et al., 2012); it might also be important to consider that certain countries may have regulations for rent control limiting rent increases due to major capital improvements (e.g., SFTU, 2016). All these considerations should be included in the financial module of the ranking tool.

Another factor that should be considered in the financial module in order to improve the optimisation and minimise the costs is the planned Operation and Maintenance (O&M) of the building. Implementing a comprehensive O&M programme is essential and can lead to large energy/water savings itself (Hall, 2011; PNNL and PECI, 2011), although with limited resources it is challenging (PNNL and PECI, 2011). A retrofit intervention would impact the O&M programme. Because retrofitting a building can be disruptive to the workplace, it is much easier to either undertake the work during weekends or when part of the building is vacant (Rhoads, 2010), possibly corresponding to other main planned building maintenance (Poel, 2007) and thus leading to shared implementation costs. This planning is called predictive maintenance (PNNL and PECI, 2011) and can help reducing costs. As delaying the implementation of a retrofit project could lead to either higher or lower costs (Tetreault and Regenthal, 2011; Kumbaroğlu and Madlener, 2012), it is important for a financial tool to explore scenarios in which the timing of the implementation is aligned with major O&M works thus potentially decreasing the project costs, especially for disruptive deep retrofit options.

5.5. Building retrofit option decision support tools

Eventually, decision support tools should be developed to identify critical goals and optimisation criteria, and then to weigh the different objectives, evaluate the overall performance and rank each option (Kong et al., 2012). In general, the selection of relevant criteria and weighting of each factor is essential in identifying the optimal retrofit option (Ma et al., 2012), and the development of a decision support tool in which the stakeholder can assign the weights to each factor on a case-by-case basis is advisable (Kolokotsa et al., 2009). Multi-criteria decision analysis (MCDA), or variations of this, is an approach that is quite popular in this field as it supports the inclusion of subjective aspects through the stakeholders' or decision-makers' preferences (Kolokotsa et al., 2009). Multi-objective optimisation has also often been applied in order to account for different multi-field factors, using a fitness function that is usually too complex for the user to understand (Hong et al., 2015). Interestingly, Shika et al. (2012) used a model, taking into account sustainability indices (i.e., economic, environmental, social) and associated risks. Their 'Sustainability Assessment Toolkit' also accounts for the M&V phase upon implementation.

6. Procurement of building retrofit projects

Traditional procurements methods, where a government agency seeks funding from central agencies to undertake retrofitting, demonstrated to be ineffective as often a project stalls when funding is sought; "integrated service models", where governments tender for a qualified service provider to design, install, optimise and manage the upgrade are instead seen as critical to facilitate the implementation of retrofitting projects (Ryan and Murray-Leach, 2011). ESPC is an option within the realm of integrated service models; it is a low-risk energy efficiency procurement model that can overcome issues such as an absence of public funding or limited knowledge of energy/water savings measures (EPEC, 2012). Energy conservation measures (ECM) implemented by an energy services company (ESCO) is an operating pattern where the total investment cost of a retrofit project are paid through energy savings. Specifically, the ESCO performs a comprehensive energy audit and develops a fixed price proposal for one, or a combination of, retrofitting measure(s); after construction, the ESCO monitors and verifies the performance of the ECM and it is paid by the building's owner through the energy savings that are generated (AEPCA, 2000; Tetreault and Regenthal, 2011). Typical contract terms are between four and 10 years (AEPCA, 2000). ESPC has proved to be very efficient because:

(1) It sets up a system where the building owner can avoid high upfront costs, if the contract is structured as an operating lease or if the ESCO provides direct financing (AEPCA, 2000);
(2) The building owner does not have to obtain in-depth knowledge of the different retrofitting options or make difficult decisions regarding the best one, as he or she will simply obtain a list of prices and predicted savings by the ESCO, which will carry the technical risk. If the savings are lower than estimated, the ESCO will be the damaged party, not the building owner. However, ESCOs typically do not take risks related to future energy prices (EPEC, 2012);
(3) It places strong emphasis on M&V activities; since with other financing systems the predicted savings are often lower than promised, with this system it is very important for the ESCO to be able to correctly estimate the energy savings and to monitor them in order to achieve positive returns (AEPCA, 2004);
(4) Considerable importance is also given to auditing activities, which therefore should be better regulated;
(5) Performance contracting is results-driven, thus ensuring the quality of the project.

One example of a successful ESCO-based retrofitting project is the Empire State Building (New York City), which was retrofitted with a number of integrated options that led to a 38% reduction in energy use, with a payback period of three years (Rhoads, 2010). In general, ESPC has been widely and effectively used by the US government and many other countries (Zhivov, 2013a), unlike traditional energy efficiency procurement models, which have had limited success globally (Ryan and Murray-Leach, 2011). Regardless, in some EU countries the number of ESPC-funded projects is not significant compared to the total budget for energy retrofits of public buildings, due to a number of barriers (Zhivov et al., 2015). The appropriateness of EPC through ESCO is related to building characteristics and potential savings; if there is low potential, other more traditional methods may be more appropriate; for instance, small projects (i.e. lower than $ 250,000) and remote locations can deter ESCOs (Ryan and Murray-Leach, 2011). Check-lists have been proposed (AEPCA, 2000) to help building owners assess if ESPC is suitable or not. A major limitation is that this procurement system applies specifically to energy-saving measures, while an equivalent water saving performance contracting system does not exist.

Due to the significant expenses associated with procuring the goods and services to deliver maintenance/improvement works in existing buildings, much attention has been drawn towards 'sustainable procurement', i.e., procuring goods and services in a way that minimises the economic cost, but also the environmental damage, while at the same time maximising the benefits to business, society and the economy (Smith and Owen, 2011). In this regard, 'green public procurement' is defined by the European Commission as a process by which public authorities procure goods, services and works with a reduced environmental impact. It is a voluntary instrument with a number of benefits, such as boosting innovation, environmental improvements and the development of new products, but it is facing implementation barriers due to the lack of a common legal framework in the EU, extra costs and the lack of a common monitoring methodology (Alejandre et al., 2012).

7. Supportive financial mechanisms and regulatory frameworks

7.1. Financing retrofit projects

The use of innovative financing methods (e.g., loans, rebates, grants, performance contracting) to cope with the high capital costs of energy efficiency systems has already been advocated by Hirst (1991) to change a trend in the system that favoured energy consumption rather than savings. Regardless of which retrofit package is most cost-effective, financing is a critical aspect that has to be politically safeguarded (Ferreira et al., 2016). A number of innovative finance methods are applicable to energy and water retrofit projects.

7.1.1. On-bill recovery

'On-bill recovery' is a financial tool where landlords can pay for the cost of energy and water use improvements in their utility bills (PNNL and PECI, 2011; USDE, 2012b). This not only avoids high upfront costs, but since these bills should be reduced due to the upgrades, the savings can compensate the extra costs. This is very important, as many owners are averse to apply for loans (USDE, 2012b) or take risks (AEPCA, 2000; Mills et al., 2006; Rhoads, 2010), and in this way it is possible to avoid extra costs related to loan interest. On-bill finance is typically suitable for relatively small (i.e. <$350,000) and targeted retrofit projects, and requires significant regulatory support, as well as acceptance by the mortgage industry (Rockfeller, 2012). The so-called 'Green Deal' in the UK is similar to this; many local city councils (such as Birmingham) have established energy savings programmes that take advantage of such proposals and other funding sources (Smith and Owen, 2011). Back in 2010, in the UK the cost of upgrading works was usually paid by the occupier; however, in case of high capital investment, options exist to transfer this expense to the owner and repay them over a predefined amount of time, which is usually no more than a year (Rhoads, 2010).

Similar to on-bill recovery, a utility energy service contract (UESC) is an agreement between a US government agency and an energy/water supplier that provides technical services and upfront payment of a retrofit project, which will be repaid by the agency through extra fees in the energy bills (USDE, 2012a).

Another method to avoid high upfront costs is provided by leasing equipment. This allows companies to manage energy and water efficiency projects within their operational budget.

7.1.2. Environmental upgrade finance

Another interesting system, which was set up, among others, for the Melbourne '1200 Buildings Programme' launched in 2010, consists of the so-called 'environmental upgrade finance'. Essentially, after facilitation by a government agency, the lender transfers the necessary funds to the building owner to finance the retrofit. Then, the loan is repaid through municipal taxes to the City of Melbourne, which then repays the lender. Environmental upgrade finance is now available in several other Australian cities (Sydney, Adelaide, Newcastle) due to a number of advantages, such as offering the potential for considering larger improvements due to more accessible finance, and also the chance of transferring the council levy to the tenants and thus removing the split incentive issue (Young, 2015). However, surveys after three years of implementation of the 1200 Buildings Programme showed contrasting results. The retrofitting rate was 5%, hence not high. The most common reason to retrofit appeared to be to replace a broken asset, instead of the minimisation of energy consumption. Further, more than a quarter of respondents stated that the split incentives issue and access to finance were still major barriers to retrofitting (MCC, 2013).

7.1.3. Revolving loan funds

A revolving loan fund is typically used in conjunction with ESPC. When approved, borrowers (such as an ESCO, selected through a competitive process) will repay the loan through the achieved cost savings and the money will be returned to the fund to make additional loans, thus making it an ongoing financial tool that continuously increases due to the interest paid (Booth et al., 2011; EPEC, 2012); these have typically lower interest rates and lower financial procurement costs than traditional financing, making them more competitive. The other advantage is a possible increase in the scope of the project, due to a shorter payback period, which can lead to increased savings (Booth et al., 2011). Likewise, these funds can provide financing to entities that would otherwise have difficulty in qualifying for credit (Booth et al., 2011). Revolving loan funds are typically set up for particular purposes (e.g., energy conservation, safe drinking water) with the goal of creating positive change within the community. By joint marketing with ESCOs, revolving loan funds can increase the interest in ESPC.

7.1.4. Climate bonds

Another option is climate bonds: being low risk and government-backed, they are traditionally attractive for institutional and retail investors (O'Connor and Chenoweth, 2010). An example is provided by the Property Assessed Clean Energy (PACE) Bonds issued by US municipalities to provide property owners with low-interest finance for long-term energy efficiency and renewable energy improvements. Essentially, the lender obtains the required fund and the security of a loan loss reserve from the Government, and hires contractors to undertake the upgrade. The investment is repaid through additions to property rates, which are lower than the energy savings created, thus mitigating the costs to households (O'Connor and Chenoweth, 2010). Both small and large retrofit projects can fit into this scheme; however, similarly to on-bill finance, a significant regulatory support is required (Rockfeller, 2012).

7.1.5. Grants

A different method to reduce the payback period of energy and water efficiency projects is offered by grants. Grants can help mitigate the financial risk associated with investing in innovative technologies. However, they intrinsically imply that only a certain number of winning applicants will be funded, and as they are not set up in a way to recycle their capital they are a one-off expenditure of public funds (O'Connor and Chenoweth, 2010).

7.1.6. Interest rate buy-downs

An interest rate buy-down is a financing technique where the borrower gains the benefit of a lower interest on a retrofit loan, thus considerably reducing the cost. The bank receives a payment(s) from a third-party organisation, which effectively covers the borrower's loan costs. With a funded loan, a borrower is more inclined to undertake necessary retrofit work on a home or building.

7.1.7. Loan loss reserve funds

A loan loss reserve fund is a pool of funds made available to a bank for the specific purpose of covering defaults on a particular class of loans. In this case, loan loss reserve funds insure a bank against defaults on its energy and water efficiency retrofit loans, a loan type that financial institutions tend to regard with suspicion and are less inclined to offer out of fear that a disproportionate number will default. The loan loss reserve fund acts as an internal insurance fund against potentially failed energy and water efficiency loans.

7.1.8. Insurance

Insurance products are also gaining ground as a financial means to manage risk. For instance, energy savings insurance guarantees that payments are made to the lender in the case that the expected energy savings are not reached. It can also result in lower financial costs (Mills et al., 2006). A potential market of $1 billion/year was identified (Mills, 2001). There has been increased interest from insurance regulators in the retrofitting market (Young et al., 2012), with many US states having, or considering, mandatory insurance credit schemes. Importantly, insurers also are major players in the real estate market, often as building owners (Mills, 2003). The major need to expand this market is to obtain robust M&V and quantification of uncertainties (Mills, 2003), as this would translate to lower premiums and financing costs; also, regulatory hurdles must be cleared (Mills, 2003).

7.1.9. Energy services agreement

Under this finance mechanism, which partially overlaps with EPC idea, a lender assumes responsibility for undertaking the retrofit project, and paying the post-upgrade energy bills. The lender then charges the tenants/owner an agreed regular amount based on historical consumptions, which is supposed to be higher than newer energy bills due to the energy savings resulting from the upgrade. A continuous, remote energy consumption monitoring system is typically required. This financing structure is more appealing for large (i.e. > $250,000) retrofits, and has the advantage of not requiring particular regulation or subsidy (Rockfeller, 2012). However, given the limited benefits for owners and tenants due to the disruption costs, it seems that awareness-raising and landlords education about retrofit benefits is required, as well as placing retrofitting mandates, to accelerate the application of this finance system. Also, this could be extended to the water retrofit industry.

7.1.10. Green depreciation

Under this scheme, the government allows for accelerated depreciation of the value of green buildings and thus the deferment of tax by reducing the taxable income in early years in exchange for increased taxable income in future years. In this way, the lower financial pressure of the early years would provide an incentive to the owners to invest capital for greening the building. Higher taxes to be paid later on can be compensated with the energy/water savings achieved.

7.2. Essential elements of a building retrofit financial framework

In her work, Tanaka (2011) presented a list of features of a possible energy efficiency policy (prescriptive, economic and supportive) for the industry sector. These can also be applied to water efficiency policies. The main features a policy should have are: (1) the potential to reduce energy and water consumption and carbon emissions; (2) be easy to develop, implement and evaluate; (3) have a number of ancillary effects, such as job creation. A number of risks must be avoided, such as (Berman et al., 2012): programmatic risks, e.g., low uptake, unattractive business models, failure of contractors to respect the guidelines; or technical risks, e.g., low-quality installation, overestimation of predicted savings and post-installation technical problems.

An important consideration is also whether it is appropriate to mandate a policy. Although many previous studies have found that mandatory policies are more effective (He et al., 2015), it might be preferable to introduce incentives such as tax benefits, loan assistance or even honour awards if a project meets the required performance standards (He et al., 2015). A list of government mechanisms to leverage these investments is provided in O'Connor and Chenoweth (2010). In fact, in the absence of regulation, incentives programmes help to stimulate interest in the market (USDE, 2012b); financial incentives can help maximise the market and encourage building owners to undertake the water/energy retrofit recommended at the time of certification (IEA, 2010).

No single policy or measure fits all countries/situations within a country. There are a number of differences (geographic, demographic, programmatic) that affect the ability to compare different programmes and identify the most 'successful' ones (Gillich, 2013).

7.3. International practices

7.3.1. Europe

To overcome the fact that no single policy can be suitable for every retrofit project, in the UK the Green Investment Bank was created (O'Connor and Chenoweth, 2010). It is a government agency, seeded with public funds, with a number of financing mechanisms available. In order to accelerate investment in low carbon assets, it aims to leverage significant private capital with a mix of targeted direct and indirect financing mechanisms. Similarly, in London the RE:FIT programme aims to retrofit 40% of public buildings by 2025, with a combination of financing options such as bank loans and public funds and the work to be carried out by ESCOs (Tanaka, 2011). Other policies also exist in the UK, such as (Rhoads, 2010): (1) feed-in tariffs, where generated and exported renewable electricity is paid for; (2) a renewable heat incentive, which applies to the usable heat generated; and (3) the CRC 'cap and trade' energy efficiency scheme, where for organisations with large energy consumptions, a cap is placed on total allowances (priced at £ per t/CO_2) and a number of allowances must be purchased based on the emissions forecast. In this way, organisations are pushed to find ways to reduce their emissions and buy fewer allowances.

Germany is at the forefront in Europe, and world-wide, in terms of energy efficiency, with a plan for an accelerated transformation of the energy system that began in 2011, called ‘Energiewende’, which introduced major changes in energy policies (Schlomann and Eichhammer, 2012) and laid the foundations for the development of a new sector of the economy and for substantial energy use reductions. The three pillars on which the German programme is based are: (1) a clear legal framework and tight regulation at the federal level; (2) strong financial incentives through loans and subsidises though a public investment bank that offers special funds to promote energy efficiency projects; and (3) campaigns to raise awareness and change behaviours.

Expanding the ESCOs access to innovative project-based financing was part of the objectives of the European Commission’s ‘Energy Efficiency Plan 2011’ (EC, 2011). Within the same plan, public authorities were required to refurbish at least 3% of their building stock by floor area each year (EPEC, 2012).

7.3.2. United States

A number of revolving loan programmes for which EPSC qualify have been also rolled out in a number of US states, such as the Texas LoanSTAR scheme (Booth et al., 2011), initiated in 1988 and qualifying ESPCs since 2001; Alabama’s Local Government Energy Loan Program (LGELP), initiated in 1997 and opened up to ESPCs in 2009; the Green Bank of Kentucky, financing ESPCs from its inception in 2009; and the Alaska Revolving Loan Program (AEERLF), which began lending in September 2010. All of these proved to be successful in engaging borrowers, creating more work opportunities for ESCOs, reducing energy costs and environmental pollution. To date, more than 30 states have established loan programmes for energy efficiency and renewable energy improvements.

Also, the US Energy Independence and Security Act of 2007 proposed a comprehensive approach to deploy energy and water efficiency and conservation measures to address some of the current issues. It consists of a four-year cycle of activities, where much importance is given to M&V, both pre- (e.g., installing metres and collect data) and post-retrofit (USDE, 2012a). LCC analysis is the index/method used for the evaluation of different projects.

7.3.3. International agencies

The IEA has launched a set of annex projects to promote the energy efficiency of existing buildings, such as: *Annex 46*—a holistic assessment toolkit on energy-efficient retrofit measures for government buildings; *Annex 55*—the reliability of energy-efficient building retrofitting and *Annex 56*—energy and greenhouse gas optimised building renovation (Zhivov, 2013a).

7.3.4. China

In China, the GV50189-2005 regulation established minimum energy performance of public and commercial buildings, defining mandatory values not only for heating and cooling consumption, but also for lighting, ventilation and electric appliances (MOC and NAQSMIQ, 2005). Following the mandatory trend, the ‘Energy Conservation Ordinance on Civil Buildings’ was enforced, introducing regulations regarding the management and supervision of buildings’ energy performances (Kong et al., 2012).

It was found that provinces with mandatory policies performed better in the implementation phase (He et al., 2015). Moreover, in the international context, policies with an implicit threat of future taxes or regulations are typically the most successful. An example of a non-penalising measure is given by the Hainan Department of Housing and Urban-Rural Development, which in 2010 proposed a reward policy where the increased building area due to the inclusion of solar hot water systems can be excluded from the calculation of the total building’s floor area, leading to fiscal advantages for the owners (He et al., 2015); this policy is more attractive for residential buildings than public buildings, due to the lower floor area ratios (He et al., 2015).

7.3.5. Australia

In its 2009–2010 budget, the Queensland Government invested $8.0 million to progressively retrofit existing government buildings and increase their energy efficiency. However, Federal efficiency schemes exist only in three states: New South Wales, Victoria and South Australia. At the national level, the ‘Commercial Building Disclosure’ (CBD) programme, which came into effect on 1 November 2010, requires the owners of Australia’s large commercial office buildings to provide energy efficiency information to potential buyers or lessees (Young, 2015). The Australian Government also offers a Research and Development (R&D) tax incentive programme to encourage more Australian companies to engage in R&D. The tax offset is available for energy efficiency projects aiming to test or develop new technologies and generate new knowledge.

EPC has been applied in Victoria’s ‘Efficient Government Buildings’ programme, which since 2009 has invested $134 million in upgrades (including the 1200 Buildings Programme) to 389 government buildings, achieving cost savings of $335 million, resulting in a positive NPV of $107 million and the annual avoidance of 134,000 tonnes of greenhouse gas (GHG) emissions: a 5.1% saving on total government buildings’ emissions. Here, EPC aims to achieve a seven-year SPP for all projects. However, it is stated that EPC is suitable for large, complex buildings, but for departments with a level of energy consumption too low to attract interest for EPC (i.e., less than 1Gwh per year), other financial alternatives must be sought.

A number of financial grants scheme also exist, such as: (1) the Australian Renewable Energy Agency, which is an independent Commonwealth authority supporting innovation in renewable energy technologies; (2) the Emissions Reduction Fund, which provides incentives to businesses to reduce carbon emissions through energy-efficient technologies; and (3) the Energy Efficiency Information Grants programme, which in 2011 provided $40 million to help industry, local government and medium enterprises reduce their energy consumption and reach economic and environmental benefits. However, none of these schemes specifically target retrofit projects, and they focus on energy efficiency, overlooking water efficiency. Moreover, as discussed before, these grants are usually merit-based, competitive, one-off schemes, which do not allow all eligible stakeholders to win and benefit from such programmes, thus limiting the potential of widespread implementation of retrofitting projects.

There are also a number of mandatory State schemes:

- The NSW Energy Savings Scheme (ESS) provides financial incentives to companies undertaking projects to reduce electricity consumption or improve energy efficiency. Electricity retailers and other liable parties must obtain and surrender energy savings certificates (calculated in tonnes of carbon dioxide equivalent) to meet their energy efficiency targets.
- The Victorian Energy Efficiency Target Scheme (VEET) has offered householders and businesses discounts and special offers on a range of prescribed energy efficiency products since 2009. These can then be converted to Victorian Energy Efficiency Certificates (VEEC). Each certificate represents a tonne of greenhouse gas abated, and energy retailers are required by law to release a certain number each year.
- The SA Residential Energy Efficiency Scheme (REES). Similarly to the VEET scheme, the REES requires energy providers to help households and businesses reduce their energy consumption; in this case, by offering energy audits and energy efficiency activities, such as installing energy-efficient light globes and standby power controllers. It commenced in 2015 and it will end in 2020.
- The ACT Energy Efficiency Improvement Scheme (EEIS) is also similar to those outlined above. It requires electricity retailers to achieve energy savings in households and small-to-medium enterprises, with 24 activities being eligible under the EEIS. These include upgrades to appliances and lighting, replacement of energy intensive water and space heaters, weather sealing, installation of thermally efficient windows and installation of standby power controllers.

Recently, the Australian Government has begun working on a new energy policy framework, trying to create a more business-friendly environment with lower regulations and taxes (DIS, 2015). In particular, the Energy Efficiency Council, the peak body for companies that provide energy efficiency services to business and governments, introduced three principal policies: (1) setting medium-term energy efficiency targets and energy demand cuts; (2) targeted investment in efficiency by electricity distributors; and (3) unification and expansion of Federal efficiency schemes into a National Efficiency Scheme, which will cut compliance costs for retailers and businesses.

8. Current challenges and recommended strategies for Australia

Based on the above discussion, a number of challenges must be addressed in the context of retrofitting public buildings (see Table 1).

8.1. Challenges and barriers

The main challenges and barriers are:

(1) Lack of knowledge (e.g., no reliable information on costs and benefits, shortage of technical skills, risk aversion);
(2) Modelling challenges (e.g., often unclear evidence of the cost-effectiveness of a retrofit project to support capital investment; failure to consider all the costs, benefits and uncertainties of a retrofit project, as well as the effects of bundled alternatives, and the water/energy nexus);
(3) Financing and market challenges (e.g., budget constraints, split incentives issues, no long-term financing at a moderate cost, unattractive financial returns); and
(4) Regulatory deficiencies (e.g., general lack of national commitment, lengthy internal procedures, lack of mandatory efficiency standards, multiple professions involved in the decision process, lack of clear identification of professional roles involved, lack of proper M&V).

8.1.1. Knowledge barriers

Consumers often find it difficult to obtain information on the relevant water and energy-efficient options they have, and even if this information is available, often it is too complicated to analyse (Hirst, 1991). In fact, building owners could become the essential promoters of energy/water efficiencies, but poor awareness and knowledge limit this (AEPCA, 2000; Darus and Hashim, 2012; EPEC, 2012; Kong et al., 2012; USDE, 2012b). Problems also arise due to the split incentive issue, where the owner pays for an upgrade, while the savings from this will benefit the tenants (Goldman et al., 1988). Because it is in the interest of the owner to minimise the capital cost of the building (with little regard for energy and water savings), while the tenants wish to maximise the water/energy efficiency to reduce their energy costs, improvements are often not made (IEA, 2010). As a consequence, in some countries, such as the UK, most retrofitting of commercial buildings has taken

Table 1
Barriers and coping strategies for retrofitting Australian public buildings.

Stage/component	Barriers/challenges	Potential coping strategy
M&V	• Lack of regulation • Lack of data (USDE, 2012b)	• Follow US Department of Energy example with 4-year cycle including M&V (USDE, 2012a) • Introduce regulation for nationwide system to monitor water and energy performance and provide incentives to install meters such as in China (Kong et al., 2012; Xiao et al., 2014)
Auditing	• Not mandatory • Not always standardised • Dependent on the available budget (Ma et al., 2012) • No standard water audits (Quinn, 2006)	• Follow US cities example enforcing auditing for certain buildings (Tanaka, 2011) • Standard audit packages to be created (USDE, 2012b)
Certification	• Lack of water/energy mandatory national certification scheme • Lack of retrofit professionals' certification	• Follow cost-neutral Irish example where qualified assessors release water/energy certification (IEA, 2010) • Enforce performance certificate at the time of sale/rent such as in Europe (Hong et al., 2015) • Provide suggestion on improvements together with the certificate such as in Denmark (IEA, 2010) • Mandatory accreditation for ESCO if EPC use (Ryan and Murray-Leach, 2011)
Modelling	• Water-energy nexus overlooked (GHD, 2006) • Non-economic benefits overlooked (Kolokotsa et al., 2009) • Uncertainties overlooked (Kong et al., 2012) • Finance options not considered at this step (Mills et al., 2006) • Confusion among stakeholders on the best retrofit option	• Use modelling approach accounting for co-benefits (Flourentzu et al., 2002; Li et al., 2009; Rey, 2004; Roulet et al., 2002) • Use modelling approach accounting for uncertainties (Menassa, 2011; Heo et al., 2012; Kumbaroğlu and Madlener, 2012; Heo et al., 2013; Xiao et al., 2014; Daly et al., 2014; Geng et al., 2015) • Use a comprehensive model including ranking and financial tool (Zhivov, 2009, 2013b)
Procurement	• Traditional methods are ineffective and often stall when seeking funding (Ryan and Murray-Leach, 2011)	• Use of integrated energy/water service models, such as EPC (Ryan and Murray-Leach, 2011)
Finance, regulation	• High upfront costs (Hirst, 1991; USDE, 2012b) • Long payback period (Rhoads, 2010; Kong et al., 2012) • Split incentives (Rhoads, 2010; Kong et al., 2012) • No interdepartmental cooperation (He et al., 2015) • Limited supervision of introduced regulation (Kong et al., 2012; He et al., 2015)	• Revolving loan funds (Booth et al., 2011; EPEC, 2012) coupled with ESPC (AEPCA, 2000; Tetreault and Regenthal, 2011) for both split incentive and high upfront costs issues • Use of a mix of different finance mechanisms for different payback periods and capital investments (Young, 2015); see UK example (O'Connor and Chenoweth, 2010) • Unified, clear regulation at a national level • Environmental Upgrade Finance for split incentive issue; on-bill financing for upfront costs (Young, 2015) • Discount on stamp duty to encourage retrofit before sale (Young, 2015)
General	• Lack of knowledge (AEPCA, 2000; Darus and Hashim, 2012; EPEC, 2012; Kong et al., 2012; USDE, 2012b) • Lack of motivation (MCC, 2013; Young, 2015) • Lack of government commitment (Young, 2015)	• Increased information dissemination and demonstration projects such as in China (Kong et al., 2012) • Increase education around financial analysis to highlight long-term savings against upfront cost (Young, 2015) • Commitment to strong and consistent policies (Young, 2015) • Implement a comprehensive, single protocol to improve energy/water efficiency (Ryan and Murray-Leach, 2011)

place in properties occupied by the owner (Rhoads, 2010). However, in a few areas of China, building owners and tenants have begun to share the cost of energy retrofits, following demonstration projects that proved the benefits of these interventions (Kong et al., 2012). Knowledge of energy and water savings should be popularised among consumers through public education (Kong et al., 2012), but so far, at least in China, there is a lack of mechanisms for the dissemination of such information (He et al., 2015).

Issues also arise due to the different social and institutional levels involved in water/energy retrofit policy-making: (1) the state level, which must require water and energy conservation, but also environmental protection through measures such as carbon emissions reduction; (2) the local level, which must comply with the water/energy efficiency tasks imposed by the state through the development of a market for them, thus promoting local economic development; and (3) the user level, which requires reduced water and energy costs and possibly increased comfort. Typically, there is lack of interdepartmental cooperation (He et al., 2015) and these levels need to be clearly identified in order to motivate all parties involved and exploit all the available resources (Kong et al., 2012).

8.1.2. Modelling challenges

The water-energy nexus has been considered in only a few studies (such as Li et al., 2009; (Berman et al., 2012), and a greater focus on water savings measures, as well as on long-term national urban water efficiency improvement planning, is required (GHD, 2006). When ranking different retrofit options, combinations of alternatives should be evaluated (USDE, 2012a) and the integrated water and energy savings considered, since gains in energy efficiency can result in improved water efficiency and vice versa (Xylem, 2012). The building should be seen as a system, composed of several individual components: if one of these components is replaced with an efficient one (e.g., a pump) but the next component in the sequence (e.g., a boiler) is still not efficient or with a lower capacity, then the entire system will be inefficient (Xylem, 2012). There is also difficulty in accessing, tracking and reporting on energy and water use data (USDE, 2012b), and more emphasis should be placed on the M&V part of the project as a means to reduce uncertainty, improve model predictions and thereby the building owners' (and lenders') trust in the contractors.

8.1.3. Financial barriers

It has been shown that ECM not requiring retrofit reached only 6.5% annual savings in building energy consumption compared to 49.3% from retrofitting options with significant capital investment (Alajmi, 2012). However, the lack of such initial capital investment (Rhoads, 2010) and high upfront costs (USDE, 2012b) pose major limitations to the implementation of large retrofit projects. Consumers in every sector of the economy usually emphasise initial costs rather than operating costs in their decisions, and in the energy/water sector this leads to the choice of inefficient systems (Hirst, 1991). In addition, electricity costs are often only a fraction of the total building cost for the landlord, thus reducing the interest in energy efficiency (Young, 2015), although the cost of electricity in countries such as Australia has doubled from 2008 to 2015 and this should lead to more interest in retrofitting (Young, 2015). Moreover, also long payback periods and the often unclear division of benefits between stakeholders create limitations for the expansion of this market (Rhoads, 2010; Kong et al., 2012). A long payback period is a particular issue when a split incentive situation is in place and tenants have short leases, and thus they only partially benefit from the retrofit solution; in these cases, more complex solutions are needed to accrue costs/benefits to future tenants (Rhoads, 2010). For instance, one solution could be to begin rolling out retrofit measures with short payback periods, and then fund larger, longer-term retrofits through the achieved savings; this can be often set up as a revolving loan fund (Rhoads, 2010).

Additionally, non-monetary benefits are often disregarded: for instance, not only water/energy savings, but also the added value of the property should be considered (Popescu et al., 2012), as well as reduced insurance premiums (Young et al., 2012). Limited data are available to factor in this benefit; nevertheless, a number of studies in the US and Europe have confirmed that the market value of retrofitted buildings increased by 13.5% for green buildings compared to non-green buildings (Pivo and Fisher, 2009) and up to 6.6% for buildings with high energy efficiency labels (Brounen et al., 2009). Further, the increased property value is an immediate investment return and should be regarded as such by the stakeholders: in a number of projects, such as the refurbishment of the Empire State Building, additional owner expenditure was motivated by the expectation of increased occupancy and rents and simultaneously the reduced total costs of occupancy (Rhoads, 2010).

8.1.4. Regulatory barriers

Existing policies are often poorly designed, and with unnecessary regulatory barriers and subsidies distorting the energy market (DIS, 2015). They offer the same benefit for different retrofitting options, leading to different water/energy/environmental benefits. For instance, in 2007 the Italian government introduced incentives providing a tax deduction benefit of 55% of the capital cost of any intervention on existing buildings leading to a reduction in carbon emissions, but later analyses established that a significant number of the adopted retrofitting options were not the most energy-efficient (Sardella, 2016). In order to improve policies, reduce community resistance and raise awareness, relevant stakeholders should be engaged in the development of guidelines and policies, as was done in Hong Kong with the Building Energy Efficiency Ordinance.

Also, the execution and supervision of newly introduced regulation is often limited (Kong et al., 2012), and in general, there is insufficient regulatory and financial support (He et al., 2015), or if there is, the multiple financing options are difficult to navigate (USDE, 2012b). He et al. (2015) state that due to lack of supervision and proper regulations, often projects are designed, built and run by under-qualified people, leading to lower than predicted savings. Also, often it may take several years for an energy or water conservation project to be funded, and as the cost of waiting can be very high, it could be preferable to pay slightly more in financing costs instead of delaying the project (Tetreault and Regenthal, 2011). Even when an approach, such as the use of an ESCO, has proven to be an efficient solution, there are no agreed frameworks (such as in EU) for ESCO and general contractor collaboration, meaning that energy and water retrofits are seen as a by-product for major construction companies, and therefore not many specialise in this sector (Zhivov et al., 2015).

This leads to the need for proper certification systems, not only for buildings, but also for the professionals involved in retrofitting projects. Only qualified assessors should carry out audits and other activities leading to the release of a water/energy certification (IEA, 2010): quality assurance and control during all phases of the project must be guaranteed to reduce risks and increase effectiveness (Zhivov et al., 2015). Without clear and consistent auditing/inspection protocols, different assessors with different perceptions can lead to an estimated energy performance that differs by up to 25% (Poel, 2007). In certain countries, such as China, there is a shortage of qualified institutes providing assessment and certification of energy performance (He et al., 2015), thus the creation of an accreditation system for professionals interested in releasing energy and water efficiency certifications would not only create transparency, but also represent an economic opportunity to create employment in this particular market. As an example, in Ireland a cost-neutral certification scheme was realised, where assessor registration fees and certificate charges cover all the necessary administrative costs (IEA, 2010). It is recommended that property owners introduce a number of roles in their organisational structures, such as a senior management position focusing on water and energy conservation (Rhoads, 2010).

8.2. Recommended strategies

This review has led to a number of strategies to improve the current retrofit rate of public buildings in Australia. Recommendations are summarised as follows:

1. *Create defined energy and water regulatory policies*: create strong, enforceable legal standards to underpin change; in particular:
   a. Mandatory standards and codes regarding water and energy efficiency, M&V and audits; to be developed by engaging relevant stakeholders.
   b. Mandatory labels and certificates.
   c. Introduction of benchmarking rating systems and improvement of existing ones (e.g., NABERS).

2. *Enhanced water and energy monitoring, data collection and auditing protocols*: the use of smart metres can overcome uncertainty issues through a more detailed end-use analysis and thus a more thorough understanding of energy/water consumption. Sub-metering is less relevant than in the residential sector, but could be considered in particular multi-tenant government buildings if not installed yet. It can be made mandatory. Sample periods must be also long enough (POWER, 2010) and clearly identified in the regulatory framework.
3. *Implement financing schemes combined with energy/water savings insurance mechanisms*: a revolving loan scheme whereby ESCOs can easily obtain low-interest loans, combined with mandatory training and certifications of professionals, seems to be a winning strategy as it carries a low risk for the owner, who can also avoid high capital investments, and would lead to a quality-oriented scheme with qualified people seeking state-of-the-art retrofit work to maximise their earnings. However, some other minor financial schemes should be developed to create a dynamic, versatile financing environment. It is recommended that Australia follows the UK's Green Investment Bank example and create a new statutory body armed with many financing tools to be deployed on a case-by-case basis to bridge the financing gap (O'Connor and Chenoweth, 2010) in the retrofitting industry. This agency should be staffed by professionals with in-depth finance and technological knowledge. This would lead to job creation, as it has occurred in Germany, and to the development of a professional sector focusing on retrofitting work. Germany, the UK and the US provide good examples of comprehensive regulatory schemes that facilitate the funding and proper execution of retrofit projects. Procurement should be sustainable in order to minimise environmental impacts, which would have otherwise an indirect cost.
4. *Government implementation of retrofit programme awareness-raising and capacity-building initiatives*: the government needs to invest in general public information campaigns (CB, 2010) and specific professional training. The potential for insurers to enter this market must be explored: some companies in the US offered discounts to people undertaking courses in energy efficiency, or to architects/engineers for specialised training (Mills, 2003).
5. *Development of enhanced retrofit guidelines*: implemented practices need to enable assessments that can better incorporate input parameter uncertainty, non-economic benefits, and predictive maintenance for optimised timing of these interventions: M&V should be extended to monitor factors leading to the quantification of non-monetary benefits.
6. *Modelling retrofit project options systematically*: there needs to be greater sophistication in the assessment of interactions between different building service components; that is, there is a need to consider the building as a system. For example, consideration should be given to water efficiency measures and their interaction with energy savings through the water-energy nexus.

In addition, similarly to Geng et al. (2015), with a limited amount of building information, if enough data are available for different locations (e.g., climate, expected changes) and buildings (e.g., floor area, initial technology and energy/water consumption), there is potential for Australia to run a holistic simulation/ranking tool based on a large dataset of different buildings in different locations, and to assess, among a wide range of options, the best range of water/energy retrofitting alternatives given certain input conditions. This is a realistic possibility for Australia, since the Government is creating a large database merging existing data from different sources (DIS, 2015). Such a tool should assess 'sustainability as a whole' (i.e., economic, social, environmental costs/benefits) and deal with uncertainty related to climate change, for instance. Once a limited number of retrofit options are identified at a national level as being the ones with the greatest large-scale implementation potential, this will allow for the facilitated design of the best ad hoc financial policies and accelerate the spread of the retrofitting market.

9. Roadmap to an improved retrofit rate of Australian public buildings

Fig. 1 illustrates the complex dynamics and interactions involved in setting up a supportive environment for accelerating the current retrofit rate for public buildings in Australia. Key elements of this supportive environment include an appropriate regulatory framework, accessible financial mechanisms, mandatory energy/water efficiency certification and auditing requirements coupled with professional accreditation, and finally adequate guidelines and awareness for retrofit project opportunities. For example, to illustrate one pathway to an improved retrofit rate for public buildings, if a revolving fund mechanism was created that facilitated the acquisition of money for accredited contractors then the total project budget could be enriched not only through reduced interest rates, but also with the registration fees of assessors and contractors. Those accredited organisations following strict retrofit project procedures defined by the government, would in turn have easier access to finance for further retrofit projects, since the government and financial backers would be confident of returned capital through life cycle operational savings. Therefore, such an environment would imply a reduction in risk and loan repayment security, which would ultimately promote the initiation of further retrofit projects to be initiated by public building asset custodians. The whole system would lead to: (1) a constantly increasing budget to fund retrofit projects through registration fees and repaid loans with interests; (2) job creation, with the development of a new category of professionals specialising in a growing retrofitting market; and (3) an increase in the retrofitting rate, leading to reduced energy and water consumption, as well as environmental and social benefits.

The core drivers of the system presented in Fig. 1 are summarised in Fig. 2, which illustrates a roadmap to accelerate the retrofitting rate of public buildings in the current Australian context. In addition to the revolving loan fund, it is important to also provide alternative financing systems, based on different payback periods and capital

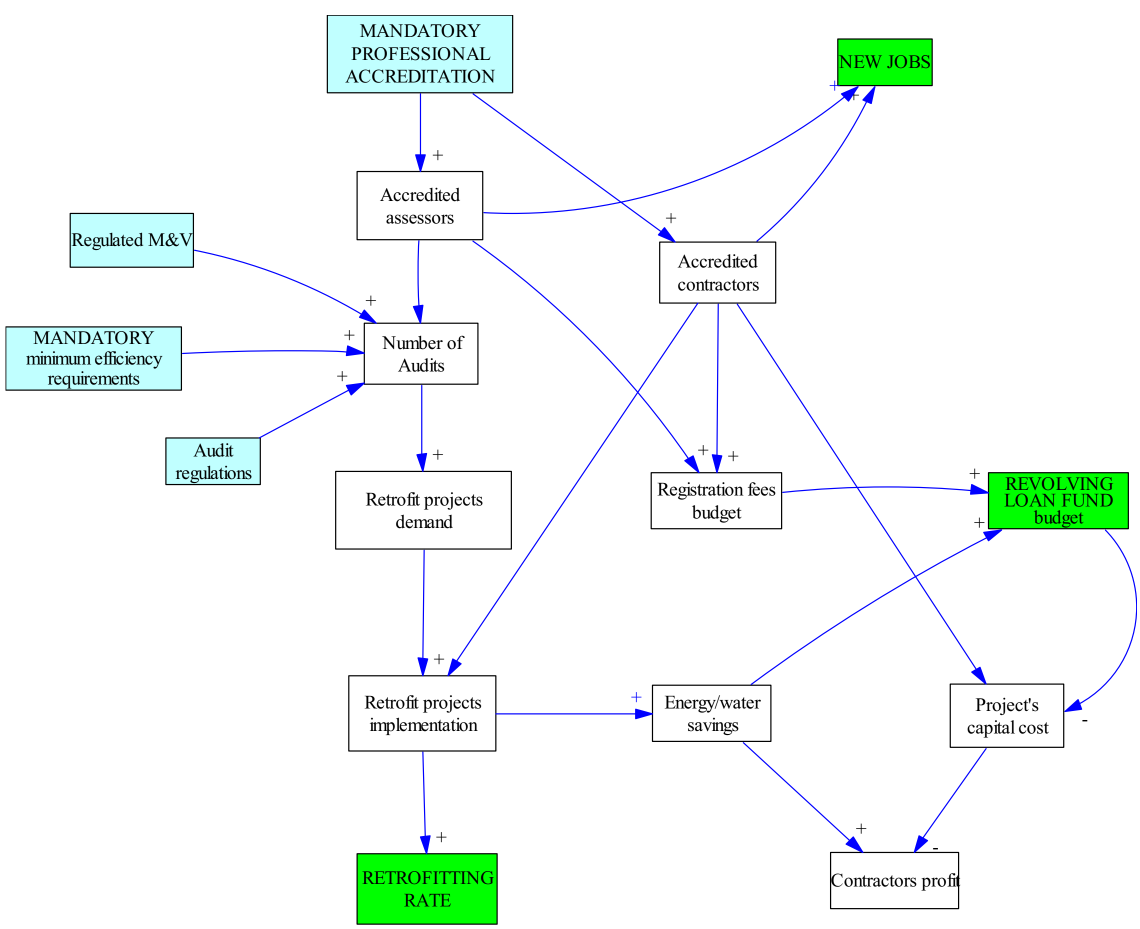

Fig. 1. Retrofit project path model conceptualisation showing the effects of financial, M&V, auditing and regulatory mechanisms.

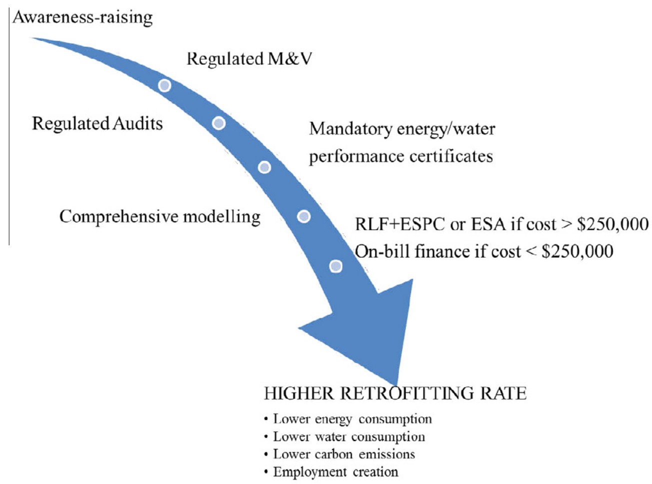

Fig. 2. Roadmap to an improved retrofit rate of Australian public buildings.

investment. Based on this review, it seems that for small projects (i.e. <$250,000), on-bill finance is the best option while for larger projects, Energy Service Agreements (ESA), or ESPC combined with a revolving loan fund for easier access to finance for ESCOs, are more appropriate. It must be emphasised how these finance mechanisms have been so far focusing on energy retrofits, but they should be adapted and applied to water-savings projects too.

10. Conclusions

In this paper we have presented an overview of the processes involved during a water/energy retrofitting project, along with a number of international examples. Despite a growing interest, widespread research, and several guidelines and regulations being available, the research has identified a number of impediments to the development of a growing retrofitting industry sector in Australia. With respect to financing mechanisms, a number of current barriers were identified (e.g., split incentives issue, high upfront costs, etc.), and current domestic and international best practice examples of financial mechanisms and policies were analysed. The best Australian example to date was the energy upgrade financing scheme in Melbourne titled the '1200 Building', which had reasonable success. Internationally, the most successful financing mechanism appears to be the revolving loan fund system, which could be adapted to the Australian context. This mechanism, combined with EPC procurement approaches, has been shown to be successful in other countries (e.g. USA). German and United Kingdom financing and regulatory strategies, which adopt a combination of different financing options to suit different retrofit opportunities, have also been successful. As discussed herein, Australia has the opportunity to adapt best practices internationally to derive a supportive building retrofit sector. A significant gap identified in this study, is the lack of consideration for the water-energy nexus in retrofit project assessments internationally (i.e. discrete independent assessments of water and energy is normal practice); the water-energy nexus needs to be a key feature of any Australian framework.

In conclusion, the implementation of the herein recommended framework would lead to an increased rate of water/energy retrofitting in Australian public buildings, which also provides a number of economic, social, employment and environmental benefits.

Acknowledgements

This research project was supported by the Sustainable Built Environment National Research Centre (SBEnrc) in Australia. The collaborative industry partners to the project include the Queensland Government (Department of Housing and Public Works), Western Australian Government (Department of Commerce, Building Commission, Sustainable Building and Department of Finance), and Aurecon. Research partners include Swinburne University, Griffith University and Curtin University. We are grateful for the support provided for this project.

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