DEFINING AND DEVELOPING AN ENERGY RETROFITTING APPROACH

Mark B. Luther[1] and Priyadarsini Rajagopalan

ABSTRACT

This paper identifies the dilemma faced by the stakeholders of existing buildings in regards to a decision making process for energy retrofitting. This paper also identifies the missing stage viewed as the "integrity audit "which can lead to substantial savings in the area of building operation. The methodology is centered on identifying energy waste first, reducing the overall peak electrical demand and then retrofitting for energy-efficiency. A proposed "integrity audit" leads to the classification of three main energy culprits: the identification of waste, missed opportunities, and rescheduling the operation of equipment use. A case study indicating the financial advantages of applying this methodology for a commercial building are presented. The energy retrofitting strategy is divided into two main categories, namely building control improvements and building component implementation. The payback periods are often within months if not immediate.

KEYWORDS

energy retrofitting, energy auditing, energy diagnostics, building performance, sub-metering, payback period

1 INTRODUCTION: THE GLOBAL PICTURE ON ENERGY USE, CO_2 AND BUILDINGS

The building sector has exhibited great potential for reducing CO_2 emissions (IPCC, 2007). It has been stated globally, that buildings account for up to 40% of our energy end use (WBCSD, 2009). It is estimated that about 27% of building sector emissions come from offices alone (AGO, 1999). With the exponentially increasing forecast of CO_2 emissions: 2.3 Gt in 2004, 8.6 Gt in 2007, to an estimated 15.6 Gt in 2030 (Levine et al., 2007; Urge-Vorsatz et al., 2007), it is interesting to consider the methodologies and pathways towards mitigating this CO_2 increase in our buildings.

The McKinsey report (2008) indicates that the building sector could contribute to a reduction of 49 $MtCO_2$ emissions by 2020 and 60 $MtCO_2$ by 2030. This implies a saving of $125 and $130 per tonne of CO_2 reduction respectively, generating a substantial financial benefit to the economy over the life-cycle of the abatement. Furthermore, a carbon tax and energy mandates in Australia have left building owners in immediate need of solutions requiring a pre-retrofitting assessment for decision-making (Luther, 2013).

[1]School of Architecture and Building, 1 Gherignhap Street, Deakin University, Australia, luther@deakin.edu.au, 0437 005 918mb

The potential for energy savings in the existing building sector is large. In North America, under the aggressive policies scenario, in 2025, overall existing commercial buildings energy use would be 21% less than the current business as usual forecast (Waide et al, 2007). In a report by the Australian Greenhouse Office, it was claimed that over $4.3 billion was spent on operating commercial and industrial buildings (GBCA, 2002). Since this report, a doubling in energy costs has occurred, increasing this amount to over $8 billion. No doubt, systematic energy management techniques are required if we are going to target this problem to achieve significant results. The pathway to identifying and implementing energy solutions for all buildings will help transform the way energy resources are utilized, through a better understanding of human and environmental systems end use and new technologies (Luther, 2013).

2 ENERGY RETROFITTING

2.1 Benefits and Challenges

There is a large body of research on building retrofits available in the public domain. However, existing buildings continue to be upgraded at a very low rate. For instance, existing commercial building stock is currently being retrofitted at a rate of approximately 2.2% per year (Olygyay and Seluto, 2010). A reasonable level of retrofitting would be in the order of 10% of building stock (Deloitt , 2009). Studies suggest that the reasons for this are risks of failure, overestimation of energy savings, increased payback period, and interruptions to operations. Different retrofit measures may have different impacts on associated building sub-systems due to various interactions; hence, the selection of the retrofit technologies becomes very complex (Ma et al., 2012). Nevertheless, there are claims of benefits to the economy, where energy retrofitting is viewed as a huge business boom to job security. In the Melbourne CBD alone there is an estimate of $1.2 billion dollars of business related to energy retrofitting over a 5–7 year period (Deloitt, 2009). The benefits to infrastructure also need to be realized if energy retrofitting is to occur on a larger scale. Peak electrical demand has been rising over the past ten years while actual energy consumption remains relatively steady. Peak demand represents the maximum load on a section of network or generation plant over a defined time period e.g. maximum demand may occur between 3pm and 6pm in a specific location. An analysis of peak electricity demand in a sample of Sydney office buildings (both base and tenant loads) by Sinclair et al.(2010) found that HVAC accounted for 57% of peak demand, while lighting, office equipment and lifts contributed 19%, 12% and 8% respectively of peak demand. It is clear that HVAC energy consumption is the most significant determinant of a building's peak load. The overall peak demand load reduction with respect to a building's energy bill, as well as its reduction to the infrastructure (supply) load to the region, needs to be considered.

2.2 The Problem—Retrofitting Strategy Culprits

Presently, there are a great number of energy retrofit technologies readily available in the market. However, the real energy problem is often concealed through sales representation of products offering a panacea to energy management and reduction, thus misleading property managers and owners. While it is not disputed that such products are in fact needed and can be of benefit, they are often installed and provided at the wrong stage in a structured retrofitting strategy. Furthermore, as innovative technologies and energy efficiency measures for buildings are well known, the main issue is to identify those that will prove to be the most effective and reliable in the long term (Asadi et al., 2012). Often, there are too many strategies available and that can make the decision-making process confusing.

Reviews of actual savings in real buildings show a wide discrepancy in delivered savings, with many projects delivering savings well under 10% of pre existing energy costs, far short of predicted savings and barely discernible within the noise of utility bills, while other projects successfully deliver savings of 40% and more (Shapiro, 2011). Common problems include neglecting certain improvements which mean weak improvement scope, non life cycle cost, lack of consideration of the latest retrofit strategies etc.

This paper considers existing strategies for retrofitting commercial buildings and applied this methodology to the retrofitting of several Australian buildings. However, the approach may not be limited to Australia only, and it is possible to apply this methodology elsewhere. The objective is to furnish facility managers with cost effective, staged, and practical retrofit technologies in order to continuously improve their building stock for long-term performance.

3 PREVIOUS STUDIES

3.1 Tools developed for energy retrofitting

Many researchers have proposed different methodologies for energy assessment. Some of the studies focus on energy savings whereas others look at overall retrofitting for the whole building site. Junghans (2013) proposed a Facilities Energy Efficiency (FEE) model for a strategic approach for energy efficiency for a municipality's entire building stock. In the "analysis of building" stage, a wide range of parameters like location, procedures for operation, and usage, as well as the building conditions and its current technical standard are covered. Rey (2004) developed a structured multi-criteria assessment methodology for renovating office buildings which simultaneously takes into account environmental (energy consumption), sociocultural (thermal and visual comfort) and economic (cost) criteria. Xu et al. (2012) analysed key performance indicators for the sustainability assessment of building energy retrofitting in hotel buildings in China. The KPIs can help decision-makers to identify an optimal solution between alternatives, which presents the maximum sustainability performance.

Few studies have proposed methodologies for pre-retrofitting of commercial buildings. Jones and Bogus (2010) propose a 'decision process' for energy-efficient retrofits. Here a qualitative analytical approach is considered, patterns and relationships of energy use are identified. Flourentzou et al. (2002) developed a user friendly building diagnosis and decision making tool, TOBUS for office buildings. The tool uses a structured diagnosis scheme to deal with the entire complex process of office building refurbishment or retrofit with respect to deterioration, functional obsolescence of building services, energy consumption and indoor environmental quality. Kaklauskas et al. (2005) developed a method of multi-variant design and multiple criteria of a building refurbishment's analysis. This methodology enables analysts to form up to 100,000 alternative versions to determine the strongest and weakest points of each building's refurbishment project and its constituent parts. Juan et al. (2010) developed an integrated decision support system to assess existing office building conditions and to recommend an optimal set of sustainable renovation actions, considering trade-offs between renovation cost, improved building quality, and environmental impacts. Most of these tools focus on one particular item, neglecting others. An auditing survey is rarely mentioned and as a result, a staged approach, discussing before and after the usage of the application tool is missed. In most of the studies, energy performance is calculated from the building input parameters. However, the problems in equipment operations cannot be identified without a detailed assessment of how the equipment operates for a representative period of time. In addition, it is very important to analyse the load profiles and compare them with outside weather in order to identify the baseline. On the other hand, Doukas et al. (2009) developed an intelligent decision support model based on the systematic incorporation of Building Energy Management System (BEMS) data such as loads, demands and user requirements. The authors mention that the BEMS operational data of a building are in many cases just recorded without being further processed and analysed in terms of assisting the selection of possible energy saving measures. The decision support unit which is the core of the model, performs a sequence of evaluation processes on the proposals via experience data through BEMS and external parameters. This is a comprehensive tool, but relies on the accuracy of the BEMS data, hence flaws in the operations cannot be identified without actual monitoring of the equipment. Moser (2013) states that when some systems fail they can go unnoticed for years just like a malfunctioned economizer system which is typically an 'invisible' issue. It is to be noted that appropriate design and construction is only part of delivering energy efficient performance. Ongoing maintenance is another, if not more important component.

3.2 Retrofitting Methodologies

The client needs a pathway to energy management, provided by an independent (non-product) based team. Furthermore, it has been proven time and again that this is a process, requiring continuous analysis and feedback to management. Energy management is not satisfied by a one-off fix-it-all approach and requires client participation and commitment.

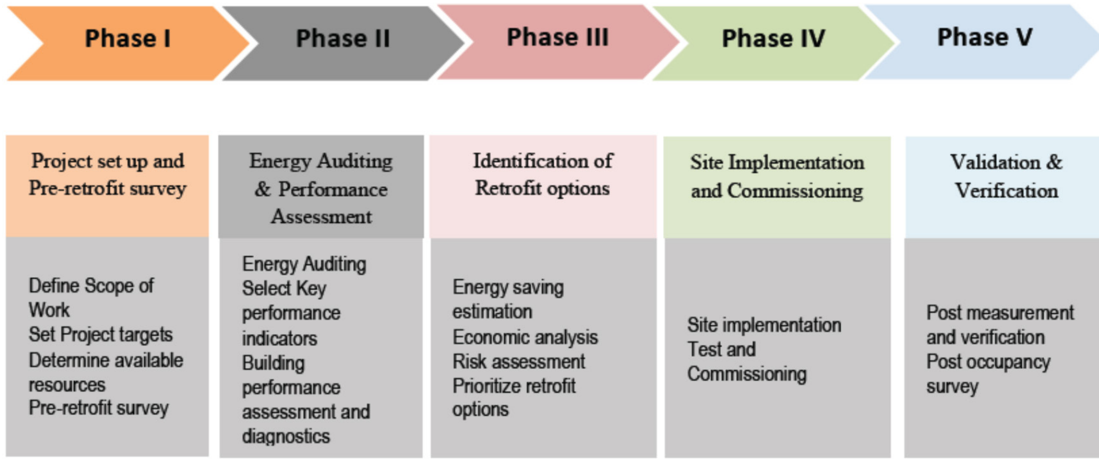
3.2.1 A Staged Approach to Energy Retrofitting

Several organizations are attempting to provide pathways and a staged approach to energy retrofitting in Australia. Table 1 shows two key approaches. In particular, it is useful to consider these criteria, their definitions, as well as suggested order. Origin Energy and Low Carbon Australia have produced the staged approach (Origin Energy, 2011). On a similar scale, the University of Wollongong (Ma et al., 2012) has put together their strategy towards energy retrofitting, suggesting five stages (see Figure 1). The intent in both of these staged methods is similar, however detail is lacking as to how these investigative processes take place.

TABLE 1. Key phases to energy retrofitting.

	Origin energy, 2011	Ma et al., 2012
Stage 1	Understand the business case objectives and qualify its suitability	Defining the scope of work, setting targets and a pre-retrofit survey
Stage 2	Perform on-site assessment of selected buildings or sites	Energy auditing, selecting performance indicators, and building performance assessment & diagnostics
Stage 3	Provide detailed energy-saving reports—quantifying savings of kWh and CO_2 with cost estimates	Identifying options: saving estimates, economic and risk analysis
Stage 4	Implement guaranteed Energy Saving Measures (within +/– 20% of target)	Implementation and commissioning
Stage 5	Deliver a complete Measurement & Verification Report: verifying savings	Validation and verification

FIGURE 1. Key Phases in a Sustainable Building Retrofit Programme (source: Ma et. al., 2012).



3.2.2 Energy Management Process & Performance Improvement

Somewhat in contrast to the above methods, the American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE, 2011) suggest a feedback loop in their energy management approach (see Figure 2). The diagram illustrates ASHRAE's view on energy management, which is not to be confused with others who are defining a retrofitting process. What is important to notice between the two (retrofitting and energy management) is that energy management requires a feedback or cyclical process under continuous review of the implemented strategy. This concept does not appear to be present in most energy retrofitting projects where the before and after effects are closely evaluated. More recently, this continuous loop process has been recognized by other organizations endorsing energy retrofitting and

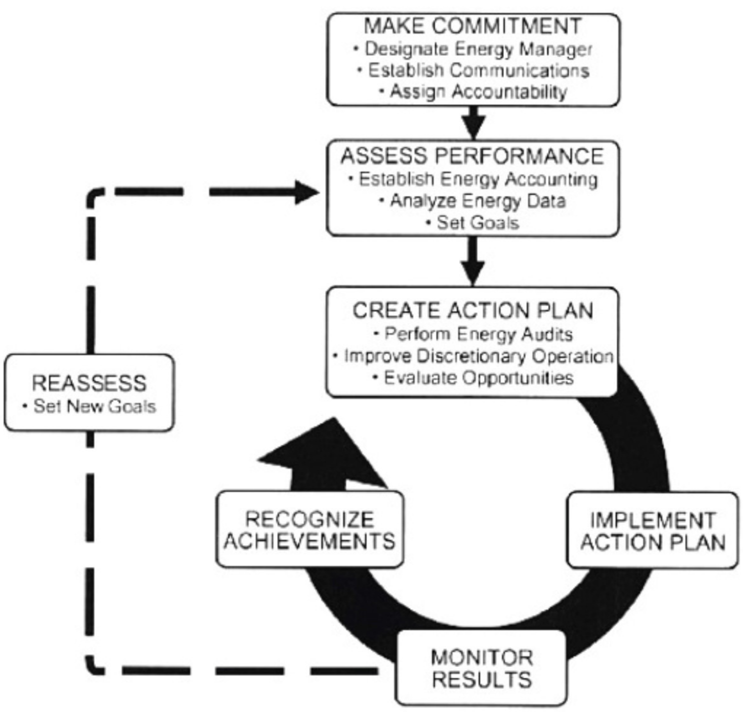


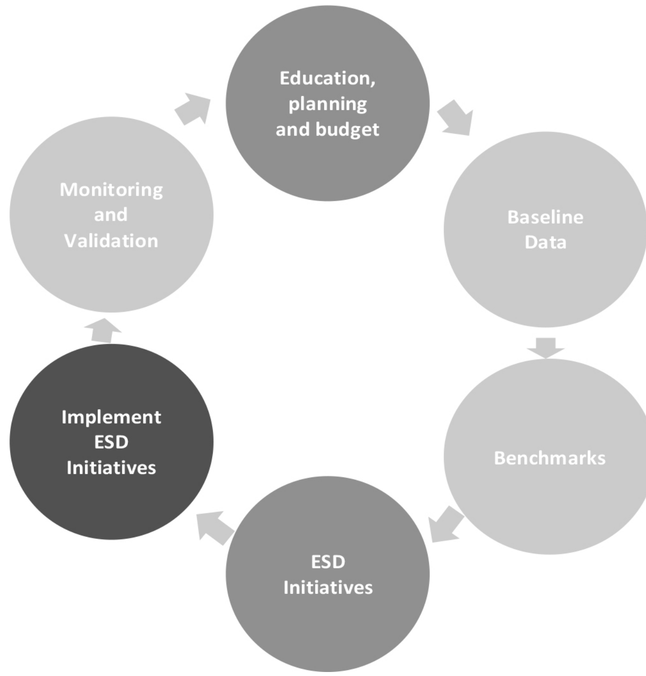
FIGURE 2. Energy Use and Management (source: ASHRAE, 2011).

environmental processes for buildings, such as by Sustainability Victoria, Australia as shown in Figure 3. Again, an overview process is indicated with minimal detail on what occurs within each stage.

There is some common ground among the previous retrofitting and energy management methodologies. In summary, most seem to advocate the following:

- An initial commitment to the scope of work and understanding of the business case.
- Understanding the baseline through initial analysis and through an auditing process, resulting in benchmarking the performance against similar projects.
- Developing an action plan with strategies, realizing energy retrofitting potential savings, prioritizing strategies and risk recognition.
- Implementation of a strategy followed by monitoring and validation.
- Setting new goals: results of a feedback loop.

FIGURE 3. Environmental Building Performance Improvement Process (Davis Langdon for Sustainability Victoria, 2013).



4 A PROPOSED PRE-RETROFITTING ASSESSMENT

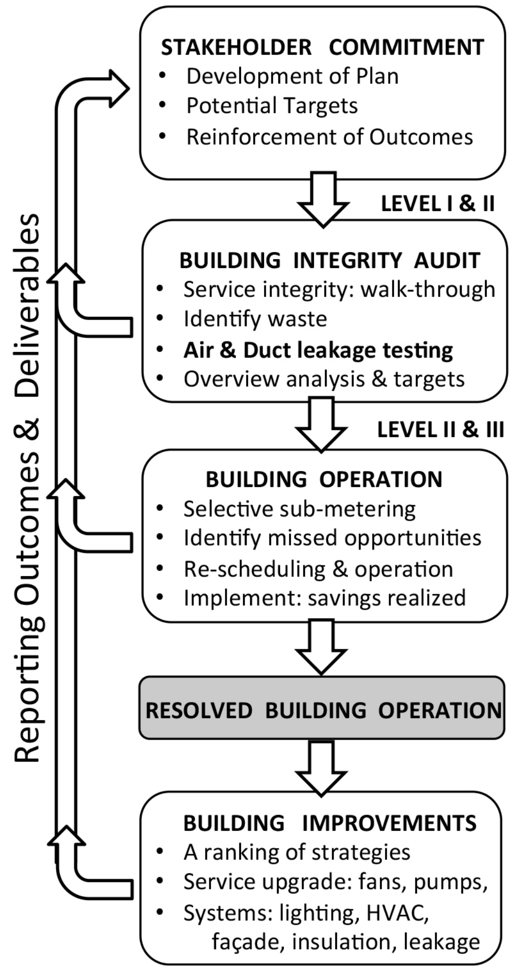
A pre-retrofitting methodology is proposed in this paper into four sections (Figure 4) and involves a "building integrity audit" which is elaborated on in the following sections:

1. Development of a building performance retrofitting management plan and its commitment.
2. A "Building Integrity Audit": comprising a comprehensive overview of building services, energy systems and building fabric, mechanical and occupant schedule, control and then identifying energy waste.
3. Pre-retrofitting Energy Management: understanding the, scheduling, control, and energy use through sub-metering:
4. Implementing a staged and ranked approach to retrofitting the building services, systems and fabric.

4.1 Development of a building performance retrofitting management plan

Jones and Bogus (2010) indicate the importance of a 'decision process' for energy-efficient retrofits. This initial stage engages the client in planning a schedule of ongoing energy management and retrofitting. The key is to obtain client commitment and consent to a suitable staged process and procedure for the proposed project. Timelines need to be drafted and approved; induction and access to the premises need to be granted for the next stages. In addition, an alliance needs to be formed between the building management and the energy management team. Furthermore, the processes, methodologies and business case need to be explained to all stakeholders. Although this may appear to be a minor step in the overall process of energy management and retrofitting, it is probably the most significant stage. It is essential that the whole management team is engaged in the decision-making process to establish a program that is not a one-off project.

FIGURE 4. A Proposed Methodology to Energy Retrofitting.

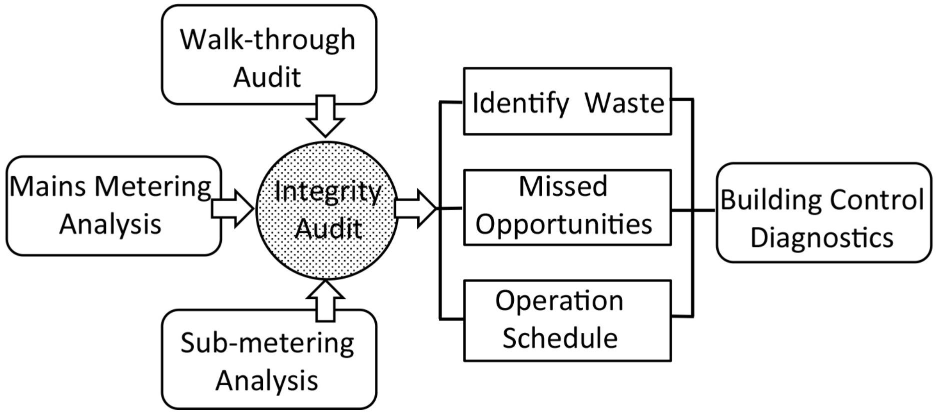


4.2 A Building Integrity Audit

The primary purpose of this audit is to identify areas of energy waste. This stage is comparable to an AS 3598 (2000) Level 2 audit. Note that this auditing system is identical to the ASHRAE: Procedures for Commercial Building Energy Audits (2011). A Level 2 Audit involves more than a walk-through and review of energy bills and can be inclusive of some sub-metering and equipment inspection. We identify this as the 'integrity audit' and indicate that several measures contribute to this stage resulting in defining the 'building control diagnostics' forthcoming outcomes (Figure 5). Analysis of the existing metered data is an integral part of this stage but should occur after an inspection of the integrity of the services. This is followed by an inspection of the existing building services in order to assess the need for further investigation of the building integrity: air leakage rates, duct connection leakage, damper actuators, chiller, pump and fan technology and control implementation, etc. It formulates an understanding of the building zones, their scheduling and operational equipment as well as their commissioning requirement.

In support of the analytical outcome of the existing energy-metered data, an energy-efficiency simulation for the existing building condition can be performed. Energy simulation results in a ranking of energy-efficient strategies in relation to specific building improvements. Simulation of energy-efficient strategy ranking has been found to only partially identify particular building components, since it assumes a flawlessly controlled (no equipment, operational or scheduling discrepancies) building. An additional energy ranking of the building on a national level may also be identified through national benchmarking system such as NABERS (2010) before any retrofitting occurs. A follow-up of these simulations and ratings may occur systematically at various stages throughout the energy management program.

FIGURE 5. The Building Integrity Audit Leading Towards Building Control Improvement.



The concept of this 'integrity audit', an audit which needs to take place before the implementation of any retrofit, is apparently not common. This can be considered as an initial step towards any retrofitting in order to establish the building base case. In conjunction with this stage, a sub-metering strategy should be developed. Together these investigative processes will result in revealing three distinctive (often low cost) retrofitting opportunities as listed below:

- **Identification of waste:** where unnecessary equipment is operating when it is absolutely not required. (example: HVAC systems running throughout the night, or pumps circulating water unnecessarily)
- **Missed opportunities:** realization of energy saving measures that could be implemented through simple sensor control and operational programming (example: bathroom lighting and ventilation responding to passive infrared (PIR) sensors, or the implementation of an economizer cycle)
- **Scheduling and Operation:** review and check if systems are running when not necessary (example. the operation of a chiller 2 to 4 hours before an air handling unit (AHU) is operated; lecture theatres shutting down their HVAC and lighting systems 3–4 hours after their last use).

The recognition and categorization of energy losses as identified above can help in decision-making in the pre-retrofitting stage of projects.

4.3 Pre-retrofitting Energy Management

This next stage investigates building energy use and control, based on sub-metering of specific equipment and areas. It is comparative with a Level 3 AS 3598: 2000 Energy Audit, CIBSE TM-22 and ASHRAE Energy Audits.

Here, a process of specific equipment sub-metering selection is identified. It is unjustifiable, from an economic standpoint, to measure every component. The metering results are partitioned into building operational schedules. Peak loads (kW) and energy waste are also identified. Statistical and analytical algorithms are often tailored and applied to this data to explain anomalies in energy use. Discrepancies in operation, perhaps leading to equipment failures, scheduling, and lack of control are targeted. Once again, the primary aim is to identify and remedy operational energy waste before the building capital retrofitting process begins. The rationale for installing energy meters is twofold: to control energy consumption/costs and to improve equipment energy use and reliability. Intelligent metering systems enable building owners to take advantage of demand management opportunities and to calculate needs based on historical record (Plourdi, 2012).

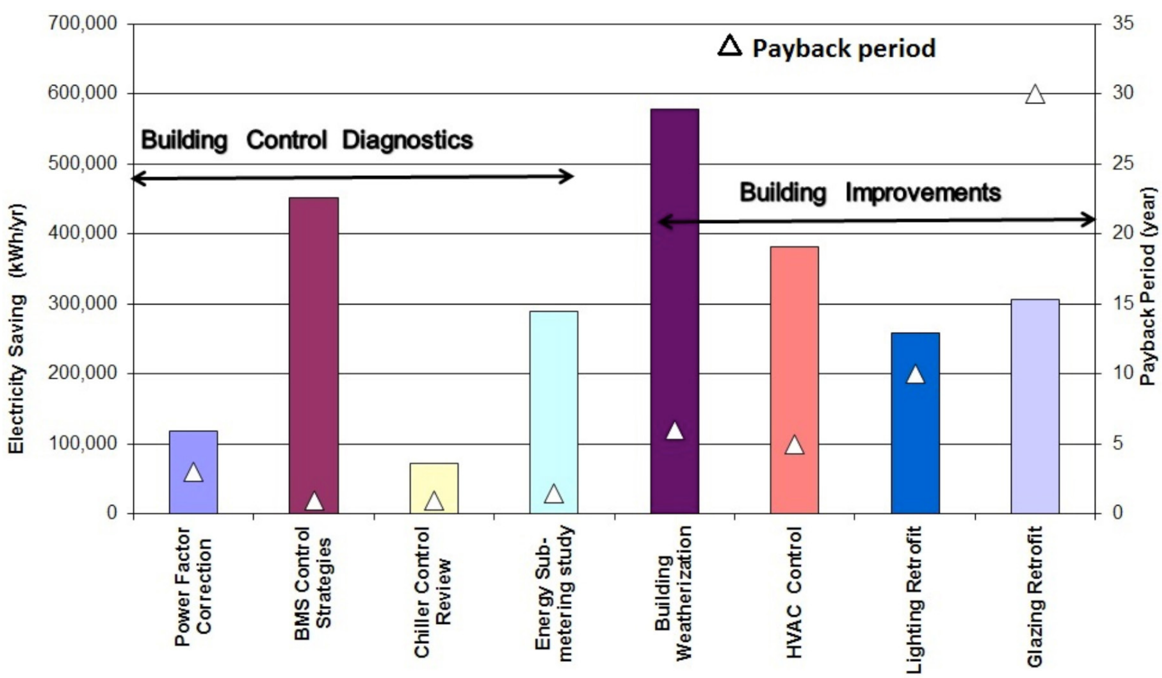
4.4 Implementing a staged and ranked approach to retrofitting

The integrity audit usually requires minimal capital. If there was, it is generally not noticed by the occupants and occurs in a plant room or building management system. The implementation of a systematic approach to fixing, tuning, replacing and/or improving the services and/or building components requires the undertaking of a cost benefit analysis including payback periods as discussed in the next section.

4.5 Strategies and payback period

Figure 6 illustrates evidence of prioritizing specific items in retrofitting for a commercial building selected as a case study. Other projects would take on a similar format. This chart was constructed based on a year of metered data of two main electrical outputs: HVAC with Lifts and Lighting with Power Points. The hourly kilowatt usage over a 24 hour period was studied as well as shutdown periods of the building. These studies together with on-site investigation determined several of the results shown as 'building control diagnostics' (left side) of Figure 6. Studies indicated that auxiliary and mechanical equipment were running 24 hours a day. Alongside these findings, a building energy simulation, utilizing the ENERGY-10 software (Balcolm, 1998) provided a ranking of energy-efficient building improvement strategies. These results comprise the 'building improvements' on the right hand side of the chart. The left hand side of the chart indicates savings from building control diagnostics that were

FIGURE 6. A Series of Energy-Efficient Strategies and their Payback Periods.



not identifiable through the software program but through analytical inspection of metering results. This includes power factor corrections, BMS and chiller control as well as an energy sub-metering study. The right hand side shows savings from retrofitting strategies such as building weatherization (air leakage), HVAC optimisation, lighting and glazing retrofitting. Together, both provide realistic parameters of energy savings vs. simple payback to be considered in a retrofitting decision-making process.

It should be noticed that the first four items, namely power factor, BMS, chiller control and sub-metering, belong to a category of 'building control diagnostics' which is not conventionally embedded into energy simulation software. The remaining four strategies, to the right, are in fact outcomes of energy simulation. HVAC control generally implies a range of factors such as scheduled use, high C.O.P. equipment, efficient variable speed drive (VSD) fans, and the implementation of economy cycles.

The payback period remains the single most significant factor among any retrofitting approval or implemented strategy (Ma et al., 2012). It should be noted that Figure 6 represents a combination of two separate investigations one 'building control diagnostics' the other 'building improvements'. A simple payback period was applied to both. The adaptation of this simple payback methodology to eight different retrofitting categories is perhaps the limitation of this case study. A payback that is solely based on energy savings alone is misleading and is often not completely correct. For instance, the glazing strategy indicates a 30 year payback, which has several flaws regarding its payback evaluation. It does not take into account other benefits such as comfort, spatial (floor area) gains, and operational time reduction in achieving HVAC set-point temperatures as well as infiltration reduction, all of which affect the productivity levels of the users and improved performance of the space. Furthermore, a glazing retrofit is a noticeable capital improvement on the property and undoubtedly will increase the energy performance rating of the building as well as the asset itself. If the building undertakes an energy benchmarking improvement and achieves a higher rating, it may very well display a shorter payback period (value-adding) than indicated by a simple payback method.

Note that the 'building control diagnostics' section in Figure 6 are entities almost solely related to direct energy payback. They are not items that the users of the building come in contact with or can experience directly, such as a new lighting system. Yet, these are the categories which are often overlooked by enthusiastic energy auditors who suggest product retrofitting solutions first (Shapiro, 2009). In fact, it is the reporting of the service system, or lack of it, which often highly influences peak demand occurrences.

Therefore, with respect to responding to the building operation, improved mechanisms of measurement and reporting are needed. It is essential that the salient energy consuming devices be individually monitored, associated with 'fault finding' measures, and effectively reported. Meters also eliminate guesswork and save time by quickly pinpointing problems (Plourde, 2011).

5 CONCLUSION

Amongst the significant literature published in the area of energy management, auditing and retrofitting, a comprehensive and rigorous methodology appears to be missing in many Australian Buildings. Several existing pathways, listed at the beginning of this paper, require further detailed development. It is acknowledged that there are rigorous methods to conduct energy metering analysis alone and they have not been discussed here as this is an introductory paper, giving an overall view on the energy retrofitting approach. The methodology proposed in this paper establishes the need for an 'integrity audit' involving identification of waste, missed opportunities and scheduling as well as reports on the state of the building service equipment. The evaluation process is centered on identifying energy waste first, reducing the overall peak electrical demand load and then retrofitting for energy-efficiency. The financial advantages of targeting this for a commercial building have been presented, yet, further improvements are required in this area. The pathways to accomplishing this energy reduction may be of interest to building owners and facility managers who may not want to implement all of the strategies proposed, but rely on a decision-making process related to energy-savings, payback periods and value for money. Furthermore, on a regional and individual building level, these energy improvements have the potential to reduce peak demand load, placing less strain on the power supply infrastructure. This methodology has limitations with respect to an overall life-cycle-costing, incorporating improved comfort and value adding to the building.

There are many existing tools and software that can aid in the continuing process of energy retrofitting and assessment. Though these tools can offer a significant role in the process of retrofitting, they are not the definitive replacement for 'integrity auditing' and sub-metering analysis.

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