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Re-commissioning Energy Conservation Measures in Supermarkets: An UK Case Study

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Abstract

Considering the UK's ambitious carbon emission reduction target (i.e. reducing CO_{2e} emissions by 80% below 1990 levels by 2050), it is evident that energy conservation measures in food retail buildings can substantially contribute in meeting this goal. Supermarket buildings in particular are complex energy systems that require careful study to make sure they perform in a sensible manner. Retail pressure on quick store delivery makes commissioning teams prone to mistakes and therefore, despite stores being newly built or refurbished, their systems are not ideally set up. This circumstance makes buildings underperform by excessively consuming energy which is a detriment in terms of costs and carbon emissions. The objective of this paper is to disseminate the energy savings that can come from low cost re-commissioning measures linked to best operating practices; this is achieved by gathering insights from the monitoring of refrigeration, HVAC, and lighting systems. A case study in a 3,300 m^2 UK supermarket showcases the energy performance of these systems before and after measures are implemented. The trials conducted have the feature of being holistic by working closely with store staff and contractors. Results show store energy use in Year 2 improved by 20% against its benchmark (Year 1); consequently reducing the carbon footprint and energy bills of the building. Furthermore, the learning's are transferable and have quick payback periods; thus making clear a large potential exists in reducing energy bills of retailers while simultaneously contributing to carbon mitigation in the UK.

Keywords – Low cost energy conservation in buildings, Monitoring based commissioning, Re-commissioning, Supermarket energy efficiency

1. Introduction

Supermarkets are one of the largest single-end users of energy in the UK consuming approximately 3% of the UK's electricity, while contributing to the country's greenhouse gas (GHG) emissions by 1% [1]. Considering the challenge of climate change in conjunction with the UK's ambitious carbon emission reduction target (i.e. cutting GHG emissions by 80% below 1990 levels by 2050 [2]), it becomes evident that energy conservation measures in food retail businesses can substantially contribute in meeting such goal.

However, the energy performance of UK retailers has to be assessed in the context of their market. Total sales through UK grocery outlets were estimated at $283.4 billion (USD) in 2013, marking an increase of 3.7% compared to 2012 and are projected to be $343.9 billion (USD) in 2018 [3]. With four major "players" in the market with more than 10% market share each (Tesco, ASDA, J Sainsbury, WM Morrison) the industry is fiercely competitive [4]; moreover, their estate expansion plans imply that competitive pressures will not decline. This fact combined with tight operating margins (2% to 6% in 2004/05 [5]) increases the pressure to deliver new stores in tight timelines. Consequently, the installation of energy systems and their commissioning is prone to mistakes – inadvertently making buildings use more energy than what is actually required [6].

The term commissioning refers to the process of ensuring that building systems perform according to their design specifications and deliver the energy performance stated by manufacturers [7]. This process also includes setting up systems adequately to fulfil end-user requirements, while also making the most of equipment energy saving features.

In particular, supermarket energy systems tend to underperform due to:

- Improper equipment installation, degradation or incorrect control sequences [8];
- Metering related issues with calibration and damage [9].

Due to the factors above, proper commissioning is considered to be the single most cost-effective way to reduce energy use and as a result costs and greenhouse gas (GHG) emissions in the built environment. However, even though recently commissioning practices have gained popularity, they are still not utilized to their full potential as building hand overs are usually not a very rigorous process [7].

The objective of this paper is to showcase the energy savings that can be achieved via low cost re-commissioning measures that are directly linked to best operating practices; this is achieved by gathering knowledge through the monitoring of refrigeration, HVAC, and lighting systems. The paper is organized as follows: Section 2 contains a brief description of the energy and carbon emission breakdown of a supermarket. Section 3 outlines the benefits of monitoring energy use and indoor and ambient conditions in a supermarket. Meanwhile, details of the supermarket that was used for the case study are presented in Section 4 along with the results of energy saving measures for refrigeration, HVAC and lighting systems. Section 5 provides context to the research findings by showcasing the energy saving potential across the UK if doors on chilled and frozen cabinets are installed across food retail buildings. Section 6 summarizes main findings and details further work.

2. Energy Systems in a Supermarket

Approximately 70% of the energy used in UK supermarkets is in the form of electricity; satisfying the needs for refrigeration, HVAC, lighting, food preparation and other auxiliary services. Usually, natural gas compliments the remaining amount of energy demand in the form of space heating and hot water [1]. The breakdown of supermarket's electrical energy use is [10]: refrigeration: 40% to 50%, HVAC: 20% to 30%, lighting: 15% to 25%, other (Bakery, rotisserie, etc.): 10% to 15%.

The energy use in supermarkets has an adverse impact on the environment mainly in the form of GHG emissions, measured in equivalent carbon dioxide (CO_{2e}) and commonly referred to as carbon emissions or carbon footprint. Emissions due to energy use that is not generated on-site are classified as indirect, such as grid electricity [11, 12]. On the other hand, direct emissions come from energy generation on-site (e.g. heat) or refrigerant gas leakage. For UK retailers, even though electricity is around 70% of the total energy consumption, it accounts for 80% to 90% of the energy-related emissions because it comes from a more carbon intensive source (e.g. coal and gas fuelled power plants) [13].

3. Energy Monitoring and Sub-metering in Supermarkets

Metering of energy use is an essential part of the monitoring and targeting process that leads to effective energy management. The status quo for most commercial buildings is the installation of energy supply billing meters in order to identify a building's performance; commonly known as MPANs (Metering Point Administration Number). Nevertheless, a total aggregated measure of building energy use does not provide sufficient granularity in order to determine where energy is consumed.

In the UK, Part L2 of the Building Regulations [16-17] calls for energy meters so that the building operator can assign at least 90% of the estimated annual energy consumption of each fuel to the various end-use categories (e.g. lighting, heating, ventilation etc.). For buildings with a total floor area greater than 1,000 m^2, the regulation requires enabling automatic meter readers (AMR) with data logging included. AMR systems provide building operators with an effective way of managing data remotely in digital form; a much more practical mechanism than taking manual meter readings [9]. Metering schemes require at least half-hourly metered data for it to be considered adequate to characterize performance [18]; a healthy interval must be established according to end-user needs.

In addition to energy sub-metering, sensors such as temperature and humidity could also be connected to building energy management systems (BEMS). This is a valuable way of investigating energy consumption as it provides context to the energy data being logged [19] and it can provide many benefits once analyzed [14-15]; such as:

- From the facility manager perspective, it provides detailed information on energy use patterns that can help determine the effectiveness from energy conservation measures;
- Historical energy performance can assist stakeholders in their effort to design and operate cost-effectively systems in new or refurbished buildings.

4. Case Study

In this paper, the results of the energy saving strategies led by Imperial College and applied by contractors in an UK store are presented. The store has a sales area of 3,300 m^2 and its opening hours are from 8 am to 10 pm on weekdays and Saturday, and from 10 am to 4 pm on Sunday. The store is fitted with conventional refrigeration and HVAC control systems, Danfoss and Trend; respectively. Innovative building design features in the store include: double glazed windows in the shop front, reflective white polished floor, and multiple circular sun pipes in the ceiling. Such measures were implemented to enhance the dimming capabilities of the lighting system. Furthermore, the electricity and heat demands were metered for each service; hence giving transparency as to where the energy was used in the building.

By using the monitoring system installed in the supermarket it was possible to gather energy data for the first year of the store's operation, namely from 1st March 2011 to 1st March 2012, defined as Year 1. This period corresponds to the time after original commissioning of the systems was done, but before any energy saving measures were implemented. The breakdown of energy use of the store in its first year is shown in Table 1.

Table 1. Energy use breakdown for case-study supermarket in Year 1.

	Consumption (kWh)	**Share of Total**
Electricity		
Refrigeration	745,330	28%
Lighting	517,698	19%
HVAC	193,833	7%
Bakery & Hot Food	253,966	10%
Other	78,693	3%
Total Electricity	1,789,570	67%
Heat		
Total Heat (Boiler)	877,410	33%
Total Demand	2,666,980	100%

The energy breakdown above allows the targeting of the most energy intensive areas of the store and assists in the design of effective energy saving strategies. This data was used to create benchmarks both for the store's total energy use as well as for its subsystems.

4.1 Approach to Energy Trials

For the case study, a monitoring-based re-commissioning approach was adopted as illustrated in Figure 1. Re-commissioning in this work takes the definition from ASHRAE: “identifying ideal operational strategies so existing buildings perform as energy efficient as possible” [20]. This process starts by gathering building information via electrical and mechanical drawings, equipment specifications and monitoring systems. Benchmarking, the second step in the process, allows the comparison between the examined building’s energy performance and the evaluation of energy saving measures that will be taken in the following steps. The following step concerns auditing the building and reviewing performance. In the fourth step, the energy saving measures are identified, discussed, agreed with stakeholders, and applied. Lastly, after time has elapsed measures are evaluated.

The trials started during spring of 2012 and have not negatively impacted store trading nor staff and customer comfort. Due to their success, they are now considered business as usual for the supermarket. The result period showcased here is from 1st December 2012 to 1st December 2013, and defined as Year 2, this is because most of the trials were operating in conjunction by late 2012.

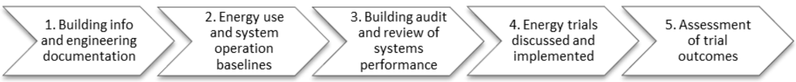

Fig. 1 Monitoring based retro-commissioning flow chart.

4.2 Refrigeration Trials

The refrigeration system, being the major consumer of electricity, is where the largest potential for actual savings lies. The energy saving measures applied are described next.

Temperature setpoint drop: The first energy saving measure that was investigated is not directly related to the refrigeration system, but indirectly influences its energy consumption. The sales floor temperature setpoint was lowered from 19˚C to 18˚C during trading hours and from 19˚C to 16˚C during non-trading hours to reduce warm air infiltration into cabinets.

Cabinet night blinds: Doors on refrigerated cabinets can reduce the system’s energy use, while also improving the ambient climate of supermarkets [21]. However, perception that they might negatively affect store sales prevents its implementation. Instead, an alternative approach was taken that involved the use of night blinds during non-trading hours; thus reducing warm air infiltration to cabinets. This initiative despite not having an impact on trading, affects the replenishment activities taking place during these times. In order to ensure that the store’s employees would comply with the use of night blinds, the authors worked in collaboration with store management. Weekly updates on blind use were provided. Figure 3 shows pack energy use, severely dropping demand as soon as blinds are used (first four nights). Otherwise, if the energy profile shows a less steep gradient when store closes it indicates staff did not pull down blinds on time.

Suction pressure optimisation: By working closely with the store's refrigeration controls contractor a suction pressure optimisation scheme was introduced. This software feature adapts the suction pressure of the refrigeration packs depending on system load; therefore making substantial energy savings while also reducing compressor wear and tear [22].

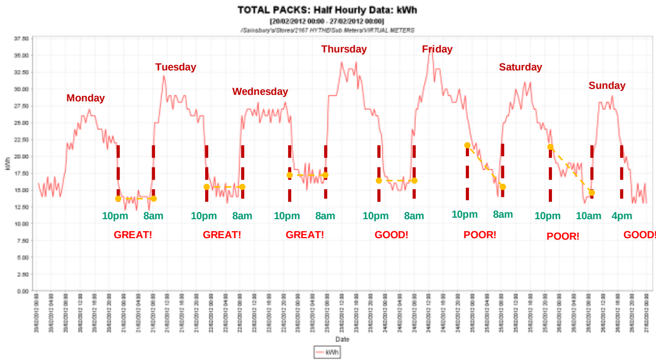

Fig. 2 Pack energy use allows stakeholders to see if night-blinds are being used effectively.

4.3 HVAC Trials

In this section, enhancements on the operation of HVAC and boiler systems are described. Although energy reduction was the main goal, careful consideration was needed to avoid adversely impacting store activities. The energy saving measures applied based on research are explained next.

Variable Speed Drive (VSD): In a conventional HVAC system, fans are designed to operate at constant speed regardless of load. However, if a VSD scheme is used, the fans have the capability to speed-up or slow down according to temperature and pressurisation needs; as was the case in the supermarket assessed. The air handling units (AHUs) were originally commissioned to account for peak demand periods and thus fan speeds were reduced accordingly to sensible values.

Temperature setpoint drop: see Section 4.2 for further information.

Boiler set point drops: the set point of the hot water flow for space heating was modified from 85°C to 82°C. This change aimed at decreasing the energy use of the boiler by lowering the temperature that is supplied to the AHUs. Similarly, the set point of the hot water system was dropped from 70°C to 65°C to further reduce energy use.

4.4 Lighting Trials

Research was conducted to optimise the programming code that controlled the dimming light system in the store and summarized here [23].

Changing lux level set points: taking advantage of the digital dimmable technology being used by the ballasts, a detailed curve explaining the relationship between lux levels and power use was determined. The ability to identify power reduction potential as a function of lux output allowed us to conduct trials that gradually reduced light intensity from 900 to 650 lux.

*Relocation of sensor*s: when lighting use was benchmarked it became evident that the lights did not dim as effectively as the technology allowed it to. After conducting an audit, it was determined that some light sensors were misplaced during commissioning. By working with contractors the sensors were relocated and the system began performing according to specification.

5. Results

Savings from store systems are presented first. This was conducted by plotting daily energy use against influential parameters; as suggested by [24]. For example, external temperature was taken when assessing refrigeration, HVAC, and heating use while sunshine hours were used for lighting load.

Figure 3a depicts the refrigeration pack performance in the store before and after the trials. It can be seen that, for the same external temperature, energy use was reduced substantially in Year 2. Regarding HVAC, Figures 3b and 3c, respectively, compare the energy use of AHUs and the boiler system. Energy used by AHUs has reduced drastically to almost half irrespective of temperature. Meanwhile, heating demand in Year 2 was reduced significantly particularly for colder days, when space heating is required most. Figure 3d is the daily lighting consumption against sunshine hours. It is clear in Year 1 energy consumed by lighting does not correspond with changing sunshine hours, confirming daylight dimming was ineffective. In contrast, during Year 2, not only was daily energy reduced but also a negative correlation between energy demand and sunshine hours can be seen.

Table 2 displays the energy demand of store systems in Year 2, while Figure 4 compares how each energy system in the supermarket performed on a ‘like for like basis’. Savings reveal the substantial benefits low-cost strategies can achieve. Although not included in this study, energy consumed by bakery & hot food areas increased due to extended cooking times in Year 2. Meanwhile ‘Other’ load (office areas and other ancillary services) slightly increased. However, an explanation cannot be given as this area is not sub-metered. Total electricity demand was down 16%. Heating demand was reduced 28%, despite Year 2 being colder. This shows how inefficient the heating was in its first year. Nonetheless, it should be noted that despite a significant drop in total energy use (20%), the share each system has on store demand remains roughly unchanged from Table 1.

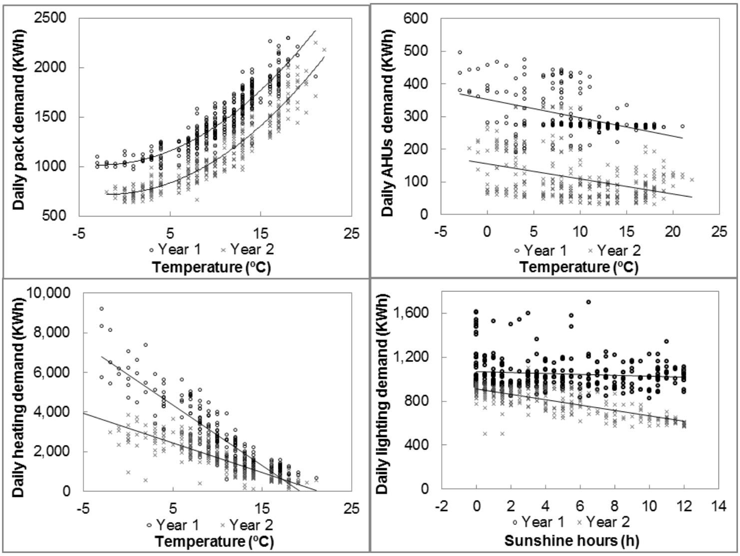

Fig. 3 a, b,c,d – Energy use comparison for various systems between Year 1 and Year 2.

Table 2. Energy use breakdown for case-study supermarket in Year 2.

End use		**Consumption (kWh)**	**Change (%)**	**Total Share**
Electricity	Refrigeration	604,245	-19%	28%
	Lighting	423,228	-18%	20%
	HVAC	113,705	-41%	5%
	Bakery & Hot Food	274,410	+8%	13%
	Other	80,308	+2%	4%
	Total Electricity	1,495,896	-16%	70%
Heat	Total Heat (Boiler)	627,360	-28%	30%
Total Demand		2,123,256	-20%	100%

In addition to energy reduction, energy and environmental engineers are also focused on reducing CO_{2e} emissions and operating costs. As shown in Table 3, the carbon reduction on electricity was 130 tonnes. There was no saving from heating as the store uses biomass fuel, which has zero emissions according to DEFRA [12]. Under the CRC scheme, at \$20 tCO_{2e} (USD), the total emissions saved during the second year of operation equate to \$2,600 (USD). Meanwhile, savings on the electricity bill amount to almost \$50,100 (USD), while the heating bill was reduced by over \$26,700 (USD). As the results can attest the sound practices of running buildings as best as they can is a rewarding effort that reduces operating costs and mitigates emissions.

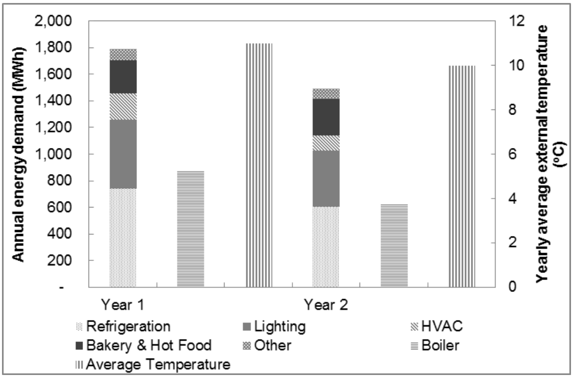

Fig. 4 Case-study supermarket 'like for like' energy use comparison for Year 1 and Year 2.

Table 3. Energy use breakdown for case-study supermarket in Year 2.

	Electricity		**Heat**	
	Emissions (tCO_{2e})	**Bill ($ USD)**	**Emissions (tCO_{2e})**	**Bill ($ USD)**
Year 1	796	298,858	0	97,685
Year 2	666	249,815	0	69,846
Savings	130	49,043	0	27,839
Change (%)	-16.4%	-16.4%	0	-28.5%

6. Discussion

As the results from the case-study show, large energy savings are within reach of supermarkets if a concise effort is made; in particular in the refrigeration system which is the biggest electricity user. Since the use of night blinds offers substantial savings, this fact begs the question what would be the impact from installing glass doors on chilled cabinets across UK supermarkets? This initiative is not new as it has been advocated by academic and industry organisations before [25-28]. Although the payback period for retrofitting doors can be short and it would seem the sensible thing to do, there has been much reluctance from retailers due to fear of losing sales and annoying customers. However, recent research shows that this fear could be overstated [29]. This aesthetic prerogative is costing businesses not only energy but also makes them more carbon intensive.

In addition to energy savings the advantages of closed cabinets are many and these include: warmer chilled food aisle environment would improve the comfort level for shoppers and staff, prolonged food quality due to less cabinet temperature variation, and a reduced load on store heating. However, not everything is positive and some caveats can become troublesome if not addressed; such as: up-skilling facility management teams on cabinet maintenance and an increased space cooling demand during periods of warm weather.

To illustrate the potential benefits doors on fridges can bring to the UK a simulation of savings was conducted and is presented next for discussion sake. Studying the energy savings from the case-study provides insights into the potential impact from doors. This is because when cabinet night blinds are pulled down, they essentially mimic the presence of a door; reducing hot air infiltration and hence loads on packs.

Two methods were used to deduct the energy impact of doors. In the first method, the savings that doors could provide were deduced from analysing "non-trading" half-hourly energy data before and after the night blind engagement program began. Energy use was compared against external temperature, as it is the main driver of packs energy use across the year (see Section 4.2). Pack demand is roughly two thirds when the "Blinds" scenario is compared to "BAU"; as seen in Figure 5. There is an overall energy benefit of 32% at 10°C (average external temperature).

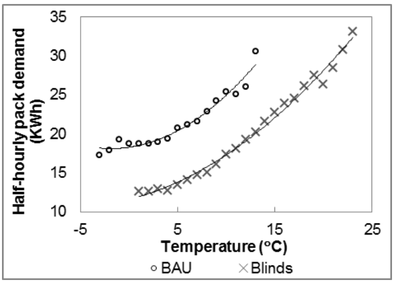

Fig. 5 Pack energy use versus external temperature during non-trading hours in BAU and Blinds scenarios.

A second method was further explored to validate the results obtained from the first method. This method focused on assessing energy savings on holidays when the store was closed and accordingly blinds were pulled down for a whole day. This analysis was done for holidays in different seasons. Figure 6 illustrates the half-hourly energy use for 3 days (07/04/2012 – 09/04/2012) with Easter Sunday in between. By comparing the average trading time energy used on holidays against the day before/after the impact of doors on cabinets can be estimated. On average, a 31% benefit was obtained when blinds were pulled down, similar to the result obtained in method 1. Furthermore, the benefits calculated are consistent with previous studies, suggesting the approach used is sensible [25], [28]. It is worth noting additional pack load from anti-sweat heaters and other door elements were not included in this analysis.

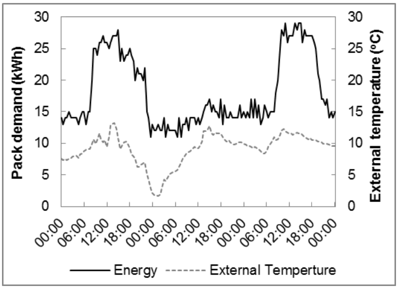

Fig. 6 Pack energy use and average external temperature from 07/04/2012 to 09/04/2012.

Based on the results obtained, it is clear that a very significant amount of energy can be saved on refrigeration by covering open cabinets. In reality, extra energy would be consumed on lighting and anti-sweat heaters due to the use of doors. This fact was assumed to balance out the extra savings that could be achieved as doors are much better at blocking air infiltration than night blinds. Therefore, if refrigeration demand in UK supermarkets is assumed to be 40-50%, doors on cabinets could reduce total store electricity demand by 10-15%. Such a substantial benefit could have significant impact for the UK energy system if the measure was replicated across UK shops. Consequently, this query is addressed in the following high-level exercise.

Taking only the top four UK major food chains, it was assumed 3,000 supermarkets could be fitted with doors [30]. Convenience stores were not considered as fitting doors would be difficult due to short aisle width and higher trading intensity. Taking an average supermarket size (33,000 ft^2) and average annual electricity intensity (70 kWh/ft^2), it was found that these buildings consume about 7.32 TWh per annum of which 2.47 TWh can be attributed to pack demand. Thus, if installing cabinet doors can reduce pack demand by say 33%, a total of 820 GWh/yr of electricity could be saved. This would be the same as shutting down a 93 MW, marginal and usually expensive, coal power plant. Such demand reduction would also mitigate 363 $ktCO_{2e}$, if Defra's 0.445 kgCO2/kWh carbon factor is used [12], equivalent to roughly 0.19% of UK emissions associated to energy supply [31]. Finally, from a business perspective the food retail industry could save CRC costs by $7.18 million USD/yr (at $20 tCO_{2e}), while energy bills (at 0.167 $/kWh) could be reduced by $137 million USD/yr.

7. Conclusion

Supermarket buildings are complex energy systems that operate under a highly competitive environment where the customer is always right; therefore, energy efficiency measures should not compromise shopping experience. This paper focused on how adequate monitoring and in-depth analysis can lead to effective low-cost energy savings for a better management of services through re-commissioning. Taking a case-study of an UK supermarket sensible energy trials were devised and applied with the support of contractors and store management. These trials had the benefit of being conducted once sufficient energy benchmarking data had been collected; thus allowing us to evaluate impacts. Store performance was monitored on a weekly basis to make sure benefits were maintained and to report any unexpected performance to relevant stakeholders. The holistic approach in this work has shown that with adequate monitoring, annual savings in electricity and heat are possible, 16% and 28%, respectively. Best of all is that these energy initiatives are quite straight-forward to replicate. These benefits have also important positive consequences in carbon mitigation and operating costs. If scaled across thousands of supermarkets these energy strategies could yield multi-million annual savings (as the discussion of putting doors on cabinets shows). Rolling-back across the estate these learnings may seem a challenging task, but with adequate resources and a robust project plan the benefits should be achievable with quick economic returns. Further work in this research area should focus on creating robust and reliable tools that can automate reporting of commercial building performance so energy savings can be sustained cost-effectively for prolonged periods of time.

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