Retail Building Thermal Efficiency Improvement through an Enhanced Re-Commissioning Framework

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ABSTRACT

End-use energy efficiency is recognized as a predominant contributor to achieve UK carbon reduction target that is still far from reach today. The opportunity in retail buildings is apparent, especially supermarkets that account for 4 $MtCO_2e$ of total UK carbon footprint. This paper outlines an enhanced re-commissioning (Re-Cx) framework that aims to mitigate supermarkets with poor energy performance, known as "cold-stores". The framework delivers a holistic approach with four critical strategies – Identification, Monitoring, Rectification and Prevention in sustaining supermarket thermal efficiency throughout its operational lifecycle. This includes a comprehensive store characterization to identify "cold-store", key performance indicators (KPIs) proposal for supermarket thermal efficiency monitoring, a cost-effective fault indication flowchart development for "cold-store" rectification, and the introduction of a novel Re-Cx and maintenance integration approach to prevent "cold-store" in a sustainable manner. A case study is carried out on 350 stores from one of the biggest UK supermarket chains. Seven "cold-stores" are identified from the comprehensive store benchmarking and characterization analysis. These results are also validated through the proposed KPIs. Moreover, a comparison between EnergyStar Re-Cx strategies and the supermarket maintenance procedures found 80% of the Re-Cx measures could be integrated into the maintenance activities. This ascertains the feasibility of the suggested integration approach. In a nutshell, this framework brings a new perception to retail Re-Cx regime, which can be implemented to effectively identify, monitor, rectify and prevent "cold-stores".

INTRODUCTION

The present global carbon emission level is projected to rise above 40Gt on business-as-usual (BAU) basis by 2030 (Birol 2009). In order to sustain global warming within 2°C increase, the International Energy Agency (IEA) has introduced the '450 Scenario' framework, which outlined key policy-based Carbon Dioxide (CO_2) abatement measures. End-use energy efficiency is identified as the biggest contributor from this framework that accounts for more than half of the CO_2 reduction opportunities. As a result, various building energy efficiency regulations and policy frameworks have been established in the UK, which have also led to the emergence of many new energy saving and low carbon technologies.

The UK retail food outlets, which account for approximately 4 $MtCO_2$ equivalent emissions per year (Tassou 2011), are also directly impacted by this efficiency revolution. Many new stores have benefited from government regulatory incentives and advanced technologies integration in their building design to achieve optimum energy efficiency. However, the existing stores are lagged from making significant progress due to numerous reasons. Many of these buildings were not commissioned appropriately due to tight schedule for new store delivery in the competitive market environment (Acha et al. 2013). This has also led to various chronic system efficiency gaps that may not be rectified in regular maintenance activities

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(Wang et al. 2013). One of the common examples is the undesirable "cold-store" phenomenon, where a store consumes significantly higher energy for heating than other equivalent stores or is not able to deliver the desired space temperature. This poor energy performance store not only disrupts occupant thermal comfort, which includes staff productivity and customer shopping experience, but also impacts its operating cost. Moreover, process to identify the most cost-effective non-domestic building retrofit measures remains a huge challenge (Ma et al. 2012). Although Re-Cx with comprehensive energy audits is one of the common approaches, it may not always be executed in a systematic manner (CIBSE 2003).

It is evident from above arguments that there is a need to enhance the Re-Cx of retail buildings as part of the continuous effort to reduce UK carbon footprint. Although lighting and heating are the two most energy intensive services in a typical UK retail building (Carbon Trust 2012a), re-commissioning heating system is often far more complicated than lighting system. Hence, this research focuses on addressing supermarket with poor energy performance through an enhanced Re-Cx framework with 4 cost effective and sustainable strategies – Identification, Monitoring, Rectification and Prevention. Firstly, supermarkets are characterized and benchmarked for "cold-store" identification based on diverse building and environmental perspectives. Secondly, quantitative key performance indicators (KPIs) are designed with statistical process control methodologies to monitor supermarket thermal efficiency and comfort in a continuous manner. This not only improves the typical approach of relying on unsatisfactory store ambience feedback from customer and staff that could be very subjective, but also ensures a "cold-store" is fixed promptly in order to minimize energy wastage. Thirdly, a cost-effective fault indication flowchart is established to simplify the conventional storewide Re-Cx processes that are costly and time consuming. This eases "cold-store" rectification by focusing only on the identified faults. Lastly, an innovative Re-Cx and maintenance integration approach to proactively optimize system efficiency is introduced as a long-term resolution to achieve sustainable energy performance.

The paper is structured in four sections. It begins with an introduction that includes the background, motivations, objectives and accomplishments of this research. This is followed by the methodologies applied for the proposed enhanced Re-Cx framework. The results, findings and discussions from case studies with actual UK supermarket chains data are detailed in the third section and followed by a conclusion of the research.

METHODOLOGIES

Identification

Supermarket stores with poor energy performance are identified through a comprehensive characterization and benchmarking analysis across 350 sample stores. This is carried out by first analyzing all factors that directly influence the energy consumption for heating of a store. These include store size, business trading hour (BTH) and weather impact. Sample stores with size ranged from 5k to 100k ft^2 (465 to 9,290 m^2) are analyzed in this research. Supermarket BTH varies across the estate depending on retail analysis, customer demand, location and other business needs. Thus, it should be taken into account as one of the main direct influence factors. In terms of weather impact, heating degree day (HDD) with a baseline of 15.5 ^0C (60 ^0F) is applied as a measure of intensity and duration of cold weather that directly impacts store energy consumption for heating.

Apart from these direct influence factors, key building properties such as its location, HVAC design model, heating technology, age and type of store are also examined in this research. Store location is classified into four regions, namely North, East, South and West of the UK. As for store HVAC design model, it is categorized based on the standard design model used across the supermarket chain. They are 30k, 60k and 90k models, which are different in cooling/heating capacity and determined based on store size i.e. a standard 60k model is designed for all stores with size ranged between 45k to 75k ft^2 (4,180 to 6,968 m^2). Heating technology also varies between stores, which includes gas boiler, Combined Heat and Power (CHP), Ground Source Heat Pump (GSHP) and biomass boiler. Efficiency gap of these heating technologies that affects store energy usage for heating is benchmarked in this analysis. Age of store is assessed to understand aging effects over store heating performance. It is categorized into three groups, namely less than 10 years,

between 10 to 30 years and more than 30 years. In terms of type of store, this is determined based on the store investment activities, which include competitor impact, refresh, refurbishment, extension, new built and existing store.

Monitoring

Two KPIs are proposed to improve the monitoring strategy. The first KPI uses heat demand control chart to monitor and control building heating systems operation so that they are operated at their full potential with minimum wastage. To develop a heat demand control chart, residual of actual versus predicted graph is plotted on a control chart with upper and lower control limits (UCL and LCL) based on the standard deviation, σ to designate the normal energy consumption range for heating a store (Carbon Trust 2012b). These control limits are based on the expected performance fluctuation as expressed in equation (1). The N in equation (1) denotes the distribution sample size, x_i is a specific value in the distribution and μ is the mean of the distribution as expressed in equation (2). The control limits are determined by multiplying the computed standard deviation with a risk factor in accordance to the performance fluctuation as compared to a reference store. It is also worth noting that the control chart developed in this paper allows benchmarking across stores with various perspectives by normalizing their energy consumption for heating with store size and BTH.

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \mu)^2} \quad (1)$$

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i \quad (2)$$

The second KPI applies Psychrometric chart to understand the performance of HVAC systems and thermal comfort of a store. Dry bulb temperature and relative humidity readings of a store with desired time interval are plotted on Psychrometric chart as a continuous trend. These two air properties are selected as they are commonly monitored on BMS systems. They can be used to monitor the changes of store ambient condition. ASHRAE Standard 55 comfort zone is applied to specify the acceptable indoor thermal comfort condition on Psychrometric chart. The plots for a store with good thermal comfort should fall within the comfort zone. Otherwise, it alerts BMS operator or facilities manager to investigate potential system faults. This prevents the degraded thermal comfort from impacting customers shopping experience.

Rectification

"Cold-store" can be caused by various defects in heating systems as well as building envelope. Thus, it is essential to fully understand the root cause before a "cold-store" issue can be addressed in a timely and cost effective manner. An effective corrective action to rectify a "cold-store" by using a HVAC fault indication flowchart is developed in this research. It is designed based on comprehensive building system interactions to systematically identify various energy performance gaps of HVAC systems and building envelope. The two KPIs discussed in the Monitoring section are applied as key decision factors in the flowchart to initiate the isolation process. HVAC subsystems and building components that are considered in the flowchart include temperature and space sensors, building management system (BMS) control set points, air volume control components, dampers, heating coil valves, boiler systems, pressure sensors, exhaust fans, air curtains, building envelope etc. All these components are mapped in the flowchart in a logical manner based on the overall system interaction. The flow begins with inspection on HVAC subsystems components and follows by the building components as detailed in Figure 6.

Prevention

A novel preventive action to mitigate "cold-store" by integrating Re-Cx measures into building planned and preventive maintenance (PPM) standard operating procedure (SOP) is developed in this research. This enables proactive

resolution in identifying and rectifying potential thermal efficiency gaps during regular maintenance routines as opposed to conventional Re-Cx activities, which are usually carried out in five to ten years interval. Besides that, it also minimizes the impact of Re-Cx activities over supermarket business operation. The new approach carries out each Re-Cx measure in accordance to the relevant maintenance activities instead of the entire Re-Cx process that might take weeks or months. Figure 1 summarizes the process developed in this research to integrate Re-Cx measures into existing maintenance regimes.

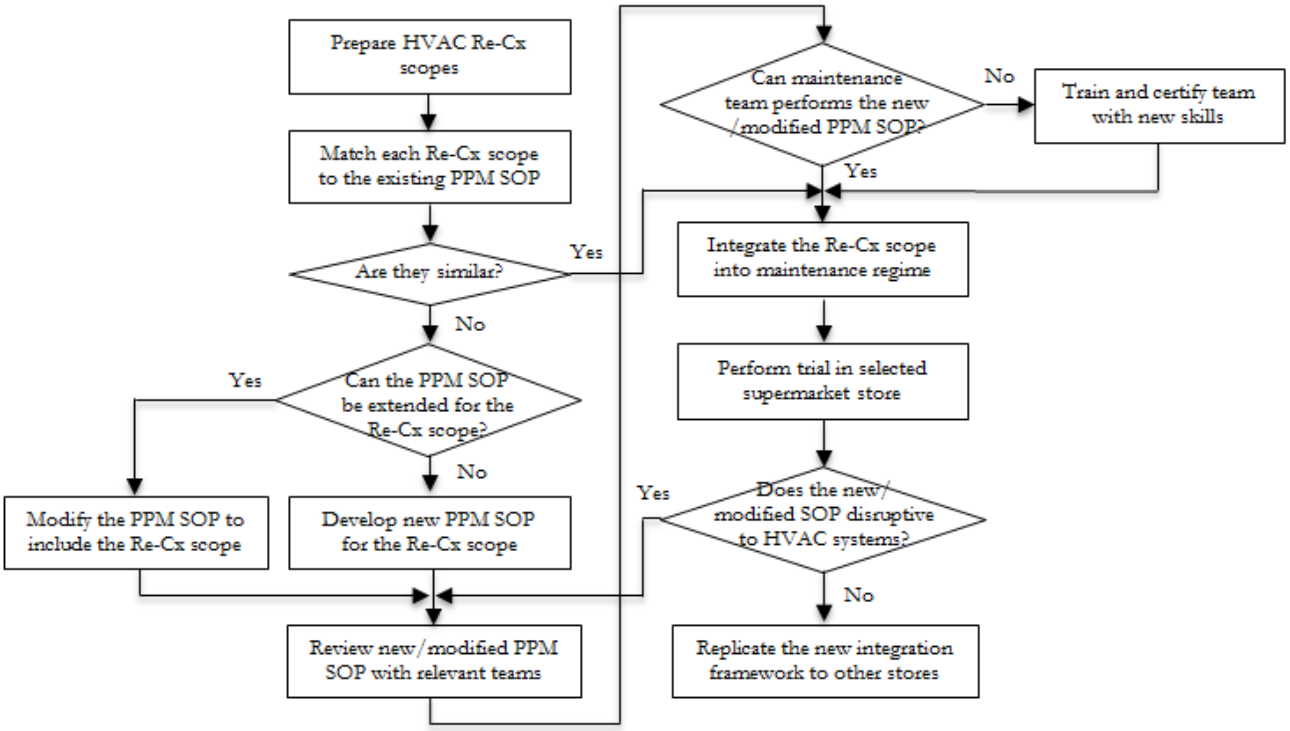


Figure 1: The Re-Cx-maintenance integration framework

RESULTS AND DISCUSSIONS

Characterization and Benchmarking

350 supermarket stores are characterized and benchmarked in accordance to the methodologies outlined in the Identification section on page 2. The characterization of store energy consumption for heating based on store sizes, BTH and HDD are illustrated in Figure 2a – 2c. Most of the outliers for Figure 2a are due to longer BTH or higher local HDD as compared to other stores with equivalent size. Similar signature is observed in Figure 2b, where besides the outliers, energy consumption for heating a store with equivalent BTH i.e. 4,400, 4,700, 5,000 and 5,300 hours varied significantly due to their differences in store size and local HDD. The unexpected flat distribution observed in Figure 2c is also found to be due to the outliers with longer BTH and bigger store size. Thus, it can be concluded that store energy consumption for heating should be normalized by its store size and BTH for store benchmarking purpose across the estate. This provides a more insightful energy performance comparison and could also prevent inaccurate interpretation of distribution outliers.

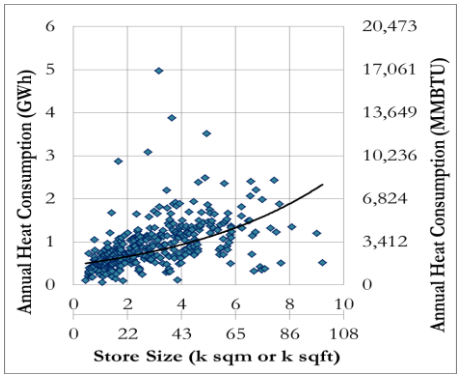


Figure 2a: Heat consumption by store size

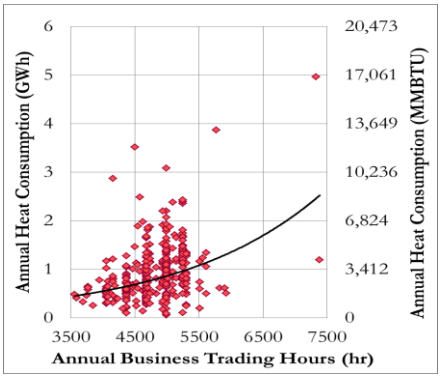


Figure 2b: Heat consumption by BTH

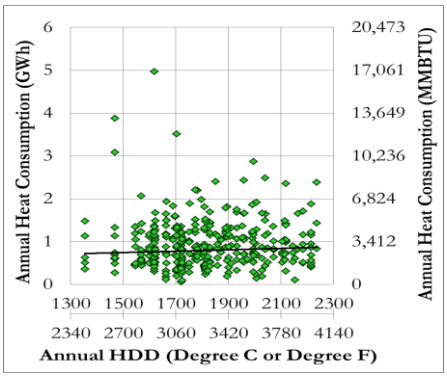


Figure 2c: Heat consumption by HDD

The subsequent characterizations are carried out based on store energy intensity for heating by its location, HVAC design model, heating technology, age and type of the store. It is found that stores located at north of UK experienced higher HDD as compared to those at south as shown in Figure 3a. Besides that, energy intensity for heating is observed to decreases with bigger HVAC capacity design as shown in Figure 3b. This is also in reverse proportional to the store size and thus demonstrates the benefit of economies of scale in store design. From Figure 3c, characterization that benchmarked across different technologies revealed their efficiency gaps which affect the overall store energy consumption for heating. Stores with GSHP are observed to be consuming less energy as compared to other heating technologies. On the other hand, Figure 3a – 3c have also led to the identification of seven outliers that are likely to be "cold stores" that need further investigation. They are all built with 30k HVAC design model and most of them are designed with gas boiler. However, there is no commonality with respect to their location. Apart from that, further characterization with age and type of the stores found no apparent correlation with their energy intensity for heating in general across the distribution. Thus, it can be concluded that the age and type of a store may not be contributing factors for "cold-store" issues.

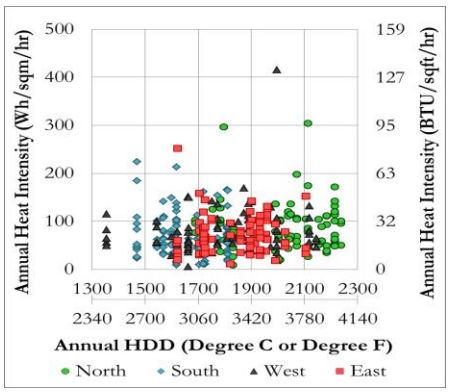


Figure 3a: Heat intensity by store location

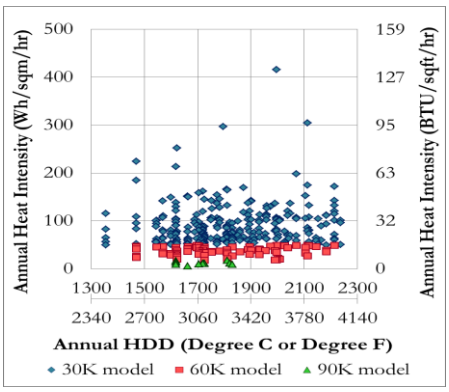


Figure 3b: Heat intensity by HVAC model

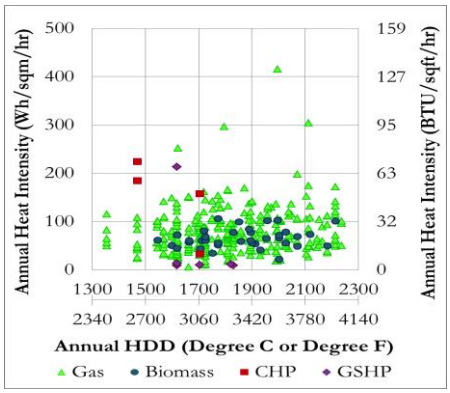
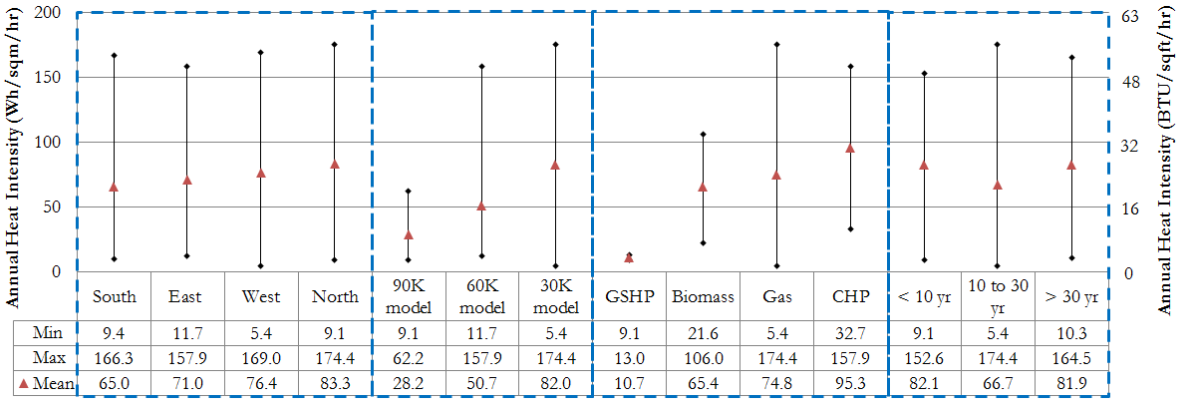


Figure 3c: Heat intensity by technology

The overall energy performance characterization results are summarized in Figure 4, which describes the mean and range of store energy intensity for heating based on various perspectives. The chart concludes that energy intensity for heating of a store is mainly influenced by store HVAC design model and heating technology. Stores with 90k model or with GSHP consume the least energy for heating as compared to others. Besides that, store location has minimum influence, whilst age of the store has no apparent impact over its energy for heating.



	South	East	West	North	90K model	60K model	30K model	GSHP	Biomass	Gas	CHP	< 10 yr	10 to 30 yr	> 30 yr
Min	9.4	11.7	5.4	9.1	9.1	11.7	5.4	9.1	21.6	5.4	32.7	9.1	5.4	10.3
Max	166.3	157.9	169.0	174.4	62.2	157.9	174.4	13.0	106.0	174.4	157.9	152.6	174.4	164.5
▲Mean	65.0	71.0	76.4	83.3	28.2	50.7	82.0	10.7	65.4	74.8	95.3	82.1	66.7	81.9

Figure 4: Summary of heat intensity based on various characterisations

Key Performance Indicators

Two of the seven "cold stores" identified in previous section, namely Greenwich and Pocklington are selected for benchmarking against a good reference store – Hythe using heat demand control chart as shown in Figure 5a. The control limits (±21.0 Wh/sqm/hr or ±6.7 BTU/sqft/hr) are determined based on Hythe's energy performance fluctuation. The performance variance of both "cold-stores" surpassed the control limits on certain months as remarked on the chart. This demonstrates that heat demand control chart can be implemented to effectively monitor and alert the store manager or energy manager on the potential "cold-store" signature. Besides that, more monthly performance variances of the "cold store" would exceed the control limits if a more stringent risk factor is applied as discussed in Monitoring section. Hence, control limits play an important role in the control chart to signify store energy performance gap. It must be determined accurately to avoid false indications over stores with good energy performance.

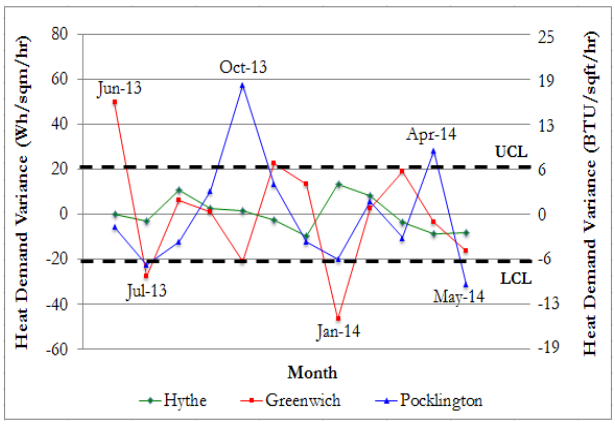


Figure 5a: Heat demand control chart

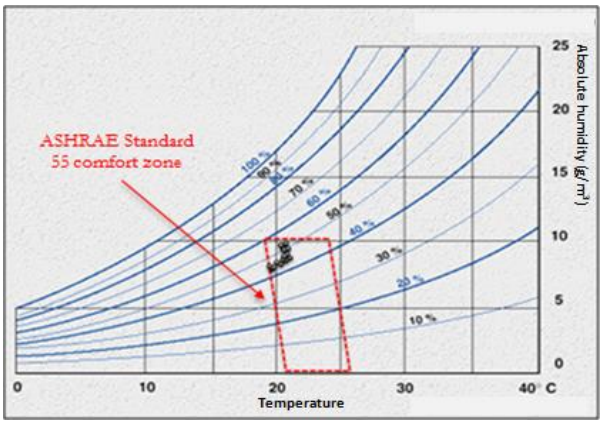


Figure 5b: Psychrometric chart

Apart from that, the space temperature and humidity data from another good reference store – Leicester are plotted and analysed on Psychrometric chart as shown in Figure 5b (1 g/m^3 = 6.24x10^{-5} lbs/ft^3). It is observed that the indoor thermal comfort of this store falls within ASHRAE Standard 55 comfort zone most of the times during winter. The trend marginally exceeds the comfort zone towards the mid-night, which is acceptable as it occurs during non-occupancy period. However, the comfort zone should be revised for summer months. This method can be used to quantify indoor thermal ambient in a more precise manner as compared to intuitive human feedback. Besides that, a continuous plot on the

Psychrometric chart allows any changes of store thermal comfort to be notified easily. This enables appropriate corrective action to be taken in a timely manner.

Fault Indication Flowchart

A fault indication flowchart as shown in Figure 6 is developed in this research with all the major interrelated components of HVAC systems and building envelope. It can be applied to isolate the most probable root cause of potential energy performance gap objectively. The flowchart begins by checking the status of the two KPIs presented on page 3. Both KPIs are mutually exclusive and thus they must both be checked to conclude an indication of healthy energy performance. Once the KPIs trigger a fault signal, the relevant HVAC systems and building envelope components are inspected in accordance to the sequence in Figure 6. However, different stores may have varying HVAC systems and building envelope design. Thus, the flowchart must be designed in accordance to the store specifications and reviewed with all the relevant parties.

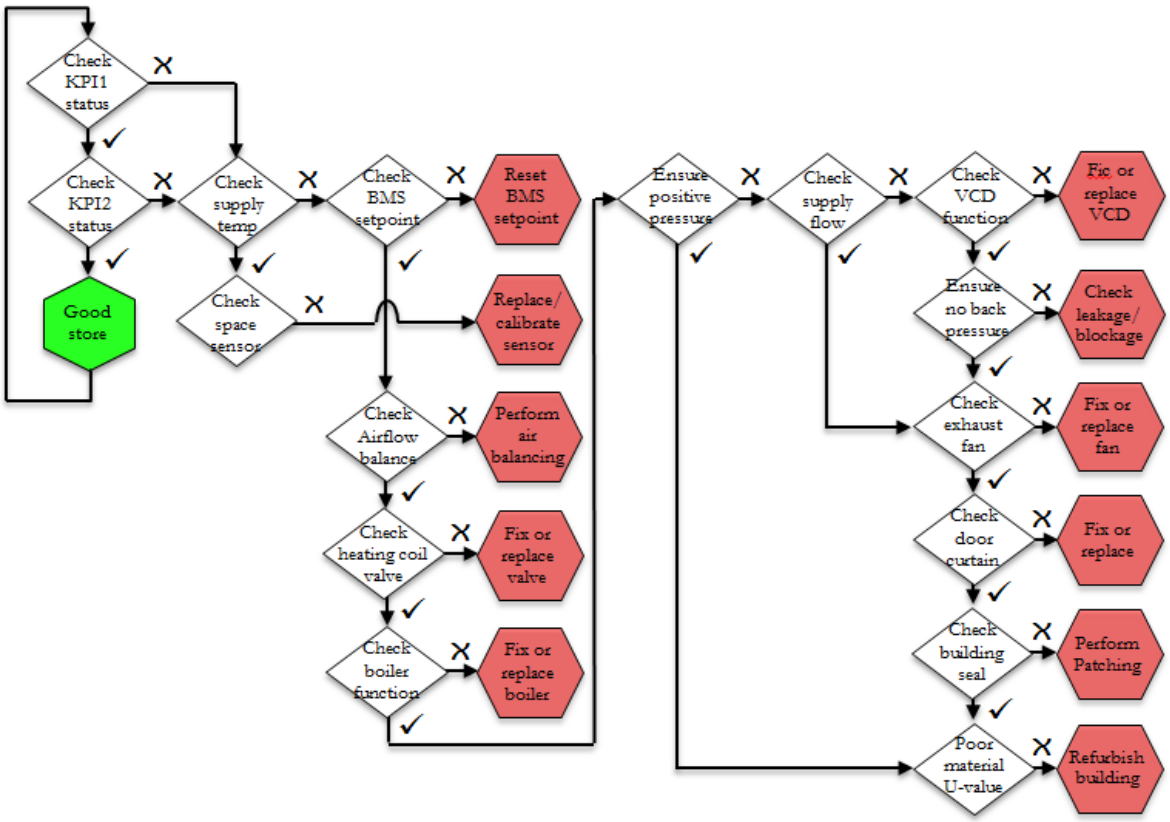


Figure 6: The fault indication flowchart

Re-Cx and Maintenance Integration Approach

A case study is carried out with EnergyStar HVAC Re-Cx strategies (Energy Star 2014) and actual supermarket maintenance SOP to analyze the practicality of this integration approach. Among the 32 Re-Cx measures from EnergyStar, 14 scopes are found similar to the maintenance SOP, which are practical to be integrated. 12 are observed with the integration potential through the current SOP extension without major changes. However, 6 are found not presently available in the SOP. Thus, new scopes in the maintenance regime need to be established and reviewed in accordance to the

methodologies outlined in Figure 1 before the integration takes place. The findings are summarized and illustrated in Figure 7. It can be concluded that 81% of the Re-Cx scopes are feasible to be integrated into the maintenance SOP to prevent "cold-store" issues. Besides that, it also shows that HVAC Re-Cx strategies have close commonality with its maintenance regimes, which can be redundant. This provides an integration opportunity that not only save cost and improve overall systems efficiency, but also make a better use of internal technical resources and expertise. However, the 19% of new scopes that require trainings for maintenance team may incur additional cost in this implementation. Nevertheless, the returns from the potential savings and system efficiency improvements are worth the investment.

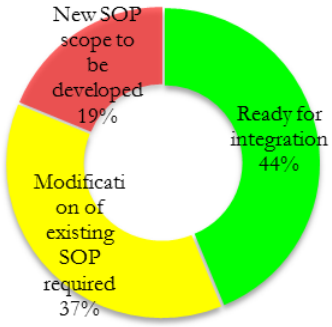


Figure 7: Case study results

CONCLUSION

This research has delivered an enhanced Re-Cx methodology for retail buildings. It provides a complete sustainable resolution to address "cold-store" issue from identification to monitoring, rectification and prevention. The characterization analysis concludes that store HVAC design model and heating technology are the two key factors with greatest influence to supermarket energy consumption for heating. This can be a useful reference for management in making investment decision for future store development. Moreover, the recommended KPIs are validated with actual supermarket data and proven to be robust in monitoring store thermal efficiency and comfort as opposed to ambiguous human feedback. The enhanced Re-Cx framework developed in this research also establishes a systematic fault indication flowchart with the capability to isolate root cause of various energy performance gaps. This helps the facilities management team to carry out rectification by focusing only on relevant system issues whilst simplifies the overall HVAC Re-Cx process. Apart from that, the novel Re-Cx and maintenance integration framework not only prevents "cold-store" issue in a sustainable manner, it also brings numerous benefits as discussed. The practicality of this proposal has also been validated through a case study with EnergyStar HVAC Re-Cx strategies. Nevertheless, this research can be extended in the future by carrying out a return of investment analysis in order to quantify its monetary benefits and to strengthen its business prospect.

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