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ENERGY PERFORMANCE CONTRACTING – IS IT TIME TO CHECK THE SMALL PRINT?

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Abstract

Energy Performance Contracting has been suggested as a key strategy to increase energy efficiency retrofits of existing building stock: reducing the uncertainty of returns on the investment by guaranteeing the level of energy savings that will result and thus making energy efficiency investment significantly more attractive. However, in order for this potential to be realised, investors need to have confidence in the level of protection offered by the guarantee.

This study explores the consequences of alternative approaches to measuring and verifying savings due to a lighting retrofit project in a hypothetical UK school. It finds that the hours of lighting use can significantly affect the final savings. In most cases a significant increase in gas consumption is seen which is ignored by several of the measurement options leading to the potential for a loss of confidence in the value of the savings guarantee if a more transparent approach is not taken by the contractor.

1. INTRODUCTION

Despite having been a subject of interest for 4 decades and assertions by successive UK governments that energy efficiency is fundamental to achieving the UK's carbon reduction commitments, e.g. [1], many studies have identified a gap between the total number of energy efficiency projects where savings would exceed investment costs and those actually undertaken. [2], [3]. While some commentators have suggested that this is can be explained as a rational choice based on the option value of delayed investment [4];[5], others point to the conflict between the upfront investment in the energy efficiency measure and the long term, potentially risky, savings which are required to it [6].

In an Energy Performance Contracting (EnPC), the risk of how the energy efficiency measure will perform is transferred from the client to the provider of the measure. Consequently, EnPC removes much of the long-term uncertainty associated with the investment [7] and, as a result, has been heavily promoted as a mechanism for increasing the uptake of energy efficiency projects [8]; [1].

The literature relating to EnPC is comprehensive in its geographic scope with the majority of commentators highlighting the importance of a robust arrangement for measuring and verifying (M&V) savings achieved as a result of the project. References [9]–[19] explicitly consider the market conditions essential for growth of the EnPC market, with almost all identifying standardised M&V processes as a key market enabler (or, conversely, its absence as a key market barrier). Only two commentators take a different position, with Jensen et al. [9] placing a higher emphasis on trust in the context of Danish municipalities and Sarkar and Singh [10] cautioning against over-complex M&V arrangements as a potential market barrier in developing countries. In addition, a variety of US based studies quoted in Kats et al. [20] provide evidence of greater savings in projects with robust M&V arrangements.

The International Performance Measurement and Verification Protocol IPMVP grew out the US EnPC industry standards [21] and is widely cited as a model for verifying savings achieved under a contract and, although US-based in origin, ten Donkelaar et al. [22] report its use in just under 50% of 100 European projects surveyed. However, it is important to note that IMPVP does not present a detailed process for measuring savings but a framework that can be adapted to fit a wide range of circumstances. In particular, IPMVP contains 4 distinct options for measuring savings each with different measurement boundaries, since many the effects of many ECMs may affect other building systems across these measurement boundaries the total savings measured and thus guaranteed, may vary depending on the option selected.

For the EnPC market to achieve its aim of increasing energy efficiency investments, it is essential that clients have confidence in the level of guarantee offered under the contract since otherwise, the risks of investment will not be considered to be reduced. The potential for differing levels of savings depending on the measurement boundary selected leads to a risk that clients and contractors may have very different expectations of energy savings as a result of the investment in an EnPC with important consequences at an industry level as a result of a lack of confidence in future energy savings guarantees. To date, the literature has sought to explore the market level impacts of standardised M&V approaches as discussed above but has not considered the question of how a standardised M&V approach should be implemented and the unintended effects which might arise. This study seeks to contribute to closing this gap by exploring the case of a lighting retrofit in an archetypal UK school to understand the consequences of alternative measurement options under IPMVP.

2. THEORY AND CALCULATIONS

2.1 Measurement and verification of energy savings

IPMVP [21] sets out 4 methods for measuring energy savings, summarised below:

IPMVP option	Calculation of Savings	Measurement Boundary
Option A: savings determined by field measurements of the key performance parameter(s) which define the energy use of the ECM's affected systems. Parameters not selected for field measurements are estimated.	Engineering calculation of energy use pre and post –ECM installation from measurement of key parameter(s) and estimated value(s)	Defined by calculation (may not encompass all aspects of ECM)
Option B: All parameter measurement Savings are determined by the field measurements of the energy use of the ECM-affected system.	Short-term or continuous field measurements of energy use pre and post EMC installation	ECM affected - system
Option C: Energy use measured at the whole or sub-facility level	Analysis of whole facility energy use pre and post ECM installation. Techniques such as regression analysis used for routine adjustments	Whole facility
Option D: Calibrated simulation. Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility.	Energy use simulation, calibrated with hourly or monthly utility billing data.	Whole facility

Table 1 IMPVP measurement options

Options A, B and C are illustrated conceptually in figure 1 below:

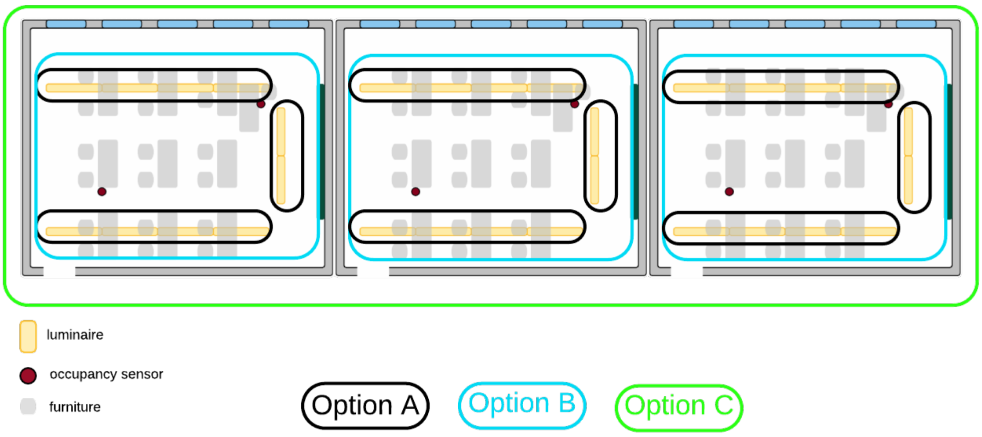


Figure 1: IPMVP measurement boundaries for a school lighting retrofit

2.2 The case study project

A lighting upgrade project was selected as the test case to explore the impact of applying the different measurement approaches since industry surveys consistently show lighting upgrades to be the most popular ECM, with 80% of respondents to a recent survey reporting that it had been included in their project [23]. Since operating hours are considered to be well-known, Option A of IPMVP is typically used to measure savings with the hours of use being estimated and the power consumption of light fittings pre and post installation being measured [21]. The building type selected for the case study was a UK secondary school since schools account for 15 % of UK public sector carbon emissions [24]. In addition, the tenure of school buildings is generally long in comparison with other building types removing a key barrier to investment [12], [25].

A probabilistic approach was selected to explore the impact of changing measurement boundaries due to the large number of different sources of uncertainty inherent in these relatively complex projects. The inherently non-symmetric nature of returns in guaranteed savings EnPC projects which arises from the fact that ESCOs bear the costs of lower savings than anticipated but do not benefit from higher than expected savings, makes a probabilistic approach even more important to gain a full picture of uncertainties [26] [27].

An initial building energy model of an archetypal secondary school was created in EnergyPlus [28] using the DesignBuilder [29] user interface. The archetype was based on the DfE's baseline designs for a 1200 place secondary school [30].

2.3 Parameter screening

The large number of potential variables in the dynamic simulation of a multi-zone building results in a trade-off between coverage of the potential variables and run time particularly in the case of a stochastic modelling approach [31]. Consequently, a screening process was needed following construction of a building energy model.

Following creation of the baseline energy model, a long-list of variables was created from a review of the literature pertaining to the identification of significant variables in building energy models. [31]–[38]. This was used to identify categories of significant variables.

- Fabric – thermal properties of the building fabric
- Systems – efficiency of the building systems
- Operation – temperatures and hours of operation, ventilation strategy
- Occupancy – numbers of occupants and their contribution to heat gain.

Building geometry, orientation and location were identified as potentially important parameters but excluded as they are capable of being well defined, and thus make little contribution to the uncertainty around energy consumption. Weather and climactic conditions were excluded as these are typically covered by contractual adjustment mechanisms.

In total, 69 parameters were identified. Each was assigned a range of ± 20% of its base value and Morris's [39] method for screening variables as extended by Campolongo et al. [40] was used to identify those which had the most significant impact on energy consumption.

2.4 Parameter definition

Important parameters identified by the screening process are shown in table 2 below.

Parameter	**Parameter range pre-retrofit**	**Parameter range post-retrofit**	**Source**
Lighting gain:	Classroom: 12 – 21 W/m^2 Offices: 12 – 14 W/m^2 Halls: 12 -13 W/m^2 Ancillary: 8 – 10 W/m^2	4.4 W/m^2 (SD 0.22) 5.4 W/m^2 (SD 0.27) 5.7 W/m^2 (SD 0.27) 3.1 W/m^2 (SD 0.16)	[41][42][43]
Heating set back temp.	13 – 20 °C	Unaffected	[44][45]
DHW boiler efficiency	84% (SD 1.5%)	Unaffected	[46][47]
Ventilation temp.	24 – 29 °C	Unaffected	[48]
HW boiler efficiency	84% (SD 1.5%)	Unaffected	[46][47]
Heating set point temp.	15 – 25 °C	Unaffected	[45]
Equipment gain – ICT rooms	21– 51 W/m^2	Unaffected	[49]
Equipment gain – classrooms	2 – 18 W/m^2	Unaffected	[41][45]
Infiltration	0.625 ach^{-1} (SD 0.1875)	Unaffected	[41][24]
HW & DHW Boiler schedule	5 to 11hrs per day (weekdays)	Unaffected	[45]
Lighting schedule	6-24h per day (weekdays)	6-14h per day	[45]
Equipment schedule	8-24h per day (weekdays)	Unaffected	[45]

Table 2 Values for important parameters, pre- and post-retrofit

3 types of probability distributions were assumed for these inputs as shown in table 3 below.

Distribution	**Rationale**	**Inputs**
Normal	dominated by variation in physical characteristics spread is small relative to value	Boiler efficiencies Infiltration Lighting gains (post-retrofit)
Discrete	user determined inputs constrained by model format	On/off times (actual operational hours follow a roughly normal distribution)
Triangular	dominated by lack of knowledge of existing installed components spread is large relative to value normal distribution would underweight extreme values	Lighting gains (pre-retrofit) Equipment gains

Table 3: input parameter probability distributions.

2.5 Definition of baseline energy consumption

700 samples were drawn from the input distributions defined for each parameter and

randomly associated to form 700 distinct model settings. The parameters were assumed to vary independently of each other. This may not be the case for all parameters but insufficient data was available to allow co-variances to be calculated. JEPlus[50] was used to manage parallel simulation runs. Simulation results with 50, 100, 200, 500 and 700 runs were tested for convergence but extreme values did not show convergence. Consequently, 700 runs was selected as a practical limit based on overall run time (approx. 36hrs).

2.6 Calculation of post-ECM energy consumption

The ECM explored consisted of 2 parts: relamping, modelled as a reduction in lighting gains and lighting controls, modelled as a change in the lighting hours. Since lighting hours is a derived variable, this was modelled through changing the on/off times for lighting.

The parameter sets for the baseline energy consumption runs were grouped into 4 quartiles based on the total daily lighting hours. These 4 groups are assumed to represent underlying patterns of use that would not be affected by this particular ECM. To reflect this, after resampling for the parameters affected by the ECM, total daily lighting hours were recalculated and the adjusted parameters sets were assigned to the original 4 groups based on total daily lighting hours. Parameter values are shown in table 2.
Option A savings were calculated by assuming a baseline figure of 2000 annual lighting hours with the exception of offices which are assumed to have a baseline of 2500 annual lighting hours [42]. 2000 hours per annum equates to 10.5 hours of lighting per day (UK statutory school year is 190 days). Post retrofit, a 20% reduction in lighting hours is assumed as a conservative estimate based on manufacturers' claims [51]. No allowance is made for uncertainty in these estimates to reflect standard practice.

Option B results are based on the lighting energy consumption calculated by Energyplus. Option C results are based on the whole facility electricity and gas consumption calculated by Energyplus.

3. RESULTS

IPVMP Option	Change in Annual Electricity Consumption	Change in Annual Gas Consumption
Option A	-7.2×10^{11} J	Not included
Option B	$- 8.6 \times 10^{11}$ J	Not included
Option C	$- 8.7 \times 10^{11}$ J	4.1×10^{11} J

Table 4: Energy saving calculated based on different IPMVP options

The 3 different measurement boundaries inherent in the 3 IPMVP options result in different headline figures for the overall energy savings. Option A understates the electricity saving with respect to Options B&C while the increase in gas consumption which is ignored in Options A and B can be seen to be almost 50% of the electricity saving. However, it can be seen from figure 2b below, that this increase in gas consumption is partly masked by the inherent variability of the gas consumption.

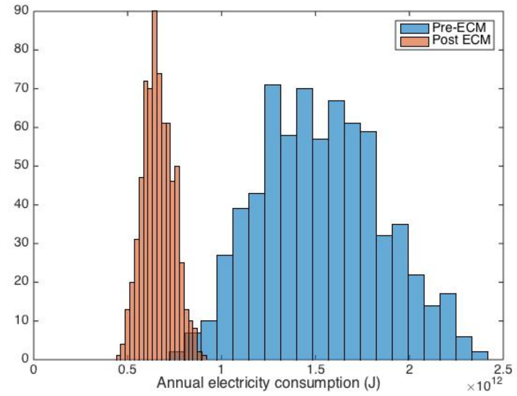


Figure 2a: Annual electricity consumption

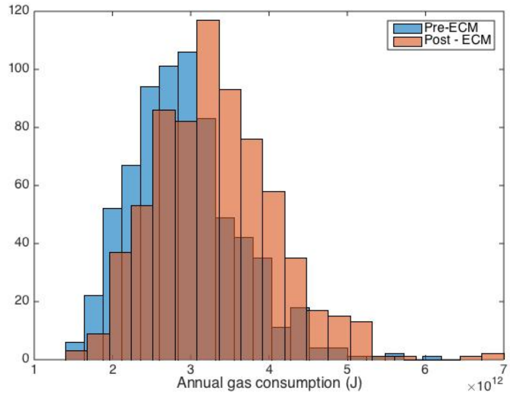


Figure 2b: Annual gas consumption

4. DISCUSSION

The underlying assumption of using Option A for calculating lighting energy savings is that the hours of lighting use are well known. However, the literature suggests that this is not the case with technical and operational challenges meaning that there is very limited research into number of hours of lighting in school buildings [51], [52]. In addition, research in other building types suggests that hours of lighting use can vary very significantly from the assumed operational hours of a building, with Bruhns for example, reporting a survey of office buildings in London found 20-30% of lighting hours occurred at weekends and overnight [32]. Stratifying the outputs by the total number of daily lighting hours shows very different results for the different strata of lighting hours. As can be seen in figure 3 below, if existing lighting hours were already low then the expected savings will not be achieved, while savings can be significantly exceeded if the original lighting hours were particularly high.

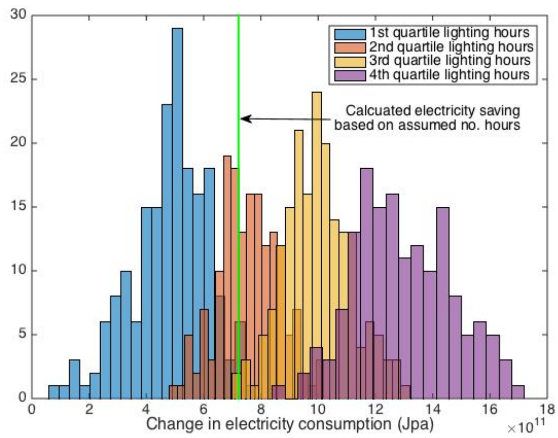
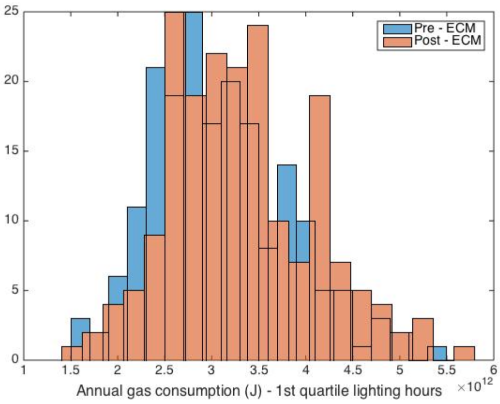
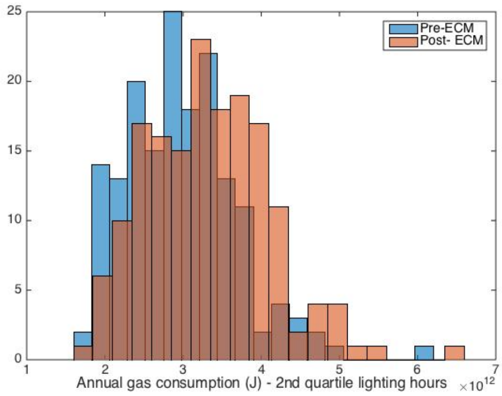


Figure 3: Electricity saving grouped by hours of lighting use

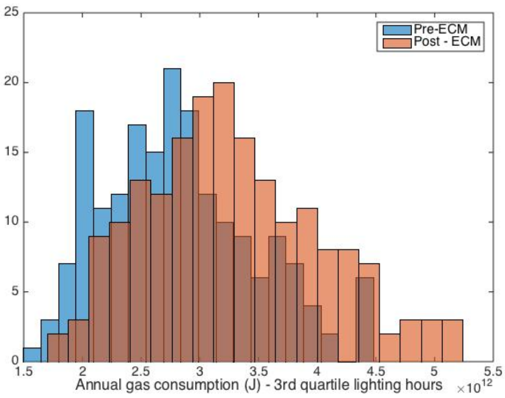
Inefficient lighting can make a significant difference to heat gains in a building and may off-set some heating requirements (the “heating replacement effect”) if there is a high level of coincidence between hours of lighting and hours of heating. The heating replacement effect is well-documented in the literature [52]; this work puts that knowledge into a new context - the stochastic analysis of the impact of it on risk-bearing within EnPC. These effects are typically assumed to be small and are routinely ignored. However, in the context of a naturally ventilated building this is not necessarily a valid assumption. This assumption is particularly open to challenge in schools where the 6-week summer holiday will result in a higher number of coincident hours than in buildings used year-round. Figures 4a-d show the changing gas consumption as a result of the lighting upgrade for the different strata of lighting hours. In all cases the gas consumption is increased. As lighting hours increase, the difference becomes particularly marked with the highest strata of lighting hours seeing an average 15% increase. This is particularly significant in light of plans announced in the 2016 budget to encourage schools to increase the length of the school day [53].



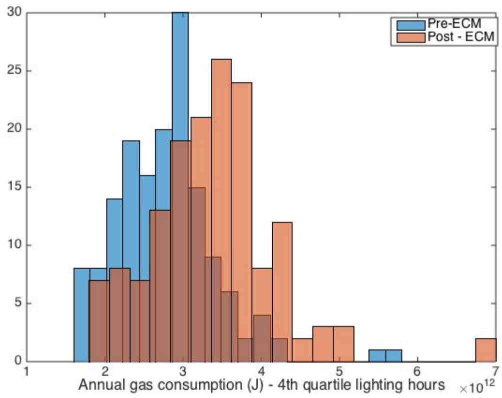
(a) – 1st quartile lighting hours



(b) – 2nd quartile lighting hours



(c) – 3rd quartile lighting hours



(d) – 4th quartile lighting hours

Figure 4 (a)-(d): gas consumption pre- and post retrofit

While the net effect of a lighting upgrade will be a reduction in the energy consumption of the school, the actual savings may be quite different from those that were guaranteed. A client who has been guaranteed a saving, but finds that almost half of the saving has been eroded by an increase in another utility which is not covered by the guarantee is unlikely to place much confidence in the guarantee in future, nor to recommend the procurement approach to their peers.

The choice of M&V option is typically driven by cost and other practical constraints. However, in 73% of the 700 samples explored in this study, the change in gas consumption exceeded the 10% threshold required under IPMVP for measurement at the whole building level. In reality, it is likely that the low profit margins available [54] would make contractors unwilling to accept the risks of a whole building measurement of gas consumption but given the underpinning importance of confidence in the level of guaranteed savings it is vital that contractors are more transparent about the choices of measurement option and the broader consequences of each ECM.

5. CONCLUSIONS

Lighting retrofit projects offer the opportunity to significantly reduce the electricity consumption of existing buildings. However, this will be partly offset by an increase in gas consumption. Energy Performance Contracts rely on a guarantee of savings to create an incentive for investment in energy efficiency but in some cases clients could see gas bills rise significantly even though the guaranteed saving has technically been achieved. This effect will be greater for clients with higher overall hours of lighting use. If this risk is not clearly explained to clients it is likely to lead to a loss of confidence in the concept of energy performance contracts as a whole.

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