ANALYSIS OF THE APPLICABILITY OF THE UK NATIONAL CALCULATION METHODOLOGY TO ENERGY EFFICIENCY FINANCE OF NON-DOMESTIC BUILDINGS: A CASE STUDY APPROACH

Esfand Burman[1], Judit Kimpian [2] and Dejan Mumovic[3]
[1] Centre for Urban Sustainability & Resilience, University College London
[2] Research & Development Division, Aedas Architects
[3]Bartlett School of Graduate Studies, University College London
(Contact: esfandiar.burman.10@ucl.ac.uk)

ABSTRACT

This paper provides a brief overview of the Green Deal, the UK Government flagship programme to finance energy efficiency improvements in buildings at no upfront cost, and the modifications made in the National Calculation Methodology (NCM) to make it applicable to the Green Deal for non-domestic sector. A case study approach is used to assess whether NCM can model a number of energy efficiency measures that are qualified for the Green Deal with reasonable accuracy. It is suggested that CIBSE TM22 tool could be used to overcome methodological issues related to calculation of auxiliary energy use in the NCM. A framework for calibrating thermal models and analysing the uncertainty associated with estimated savings in energy finance projects is also introduced and applied to the case study.

INTRODUCTION

The Energy Act (2011) includes a provision for a framework to finance energy efficiency, called 'The Green Deal', whereby private companies offer consumers energy efficiency improvements to their properties at no upfront costs, and recoup payments through savings achieved on energy bills. The Green Deal is focused on energy efficiency measures that yield *expected* financial savings greater than the repayment costs attached to the utility bills; this is called the Golden Rule (DECC, 2010). Given all uncertainties associated with actual operation of buildings, the financial viability of the Green Deal is dependent on actual savings being reasonably in line with expected savings. As thermal modelling software packages are used to calculate expected savings, it is important to assess the capability of the existing methods and tools to predict energy performance of buildings with reasonable accuracy. In the UK non-domestic sector, the National Calculation Methodology (NCM) was developed following inception of the Energy Performance of Buildings Directive (EPBD) to calculate energy performance of buildings. Simplified and dynamic calculation tools developed based on the NCM have been predominantly used for the Building Regulations compliance calculations under standardised operating conditions, and for production of Energy Performance Certificates. These calculations are based on comparisons between the calculated energy performance of a building and the energy performance of notional or reference buildings, depending on the assessment type. The relativist nature of these calculations has often sidelined questions about capability of NCM to project total energy performance of buildings with precision (CLG, 2011, p.13):

"*The basis on a comparison minimises argument about how well the absolute carbon emissions are predicted by different NCM-compliant methods, because both the proposed and notional buildings are subject to the same calculation approach. Instead it concentrates on achieving improvements compared with the previous regulations.*"

However, the same calculation methodology is now being used for the Green Deal in the non-domestic sector subject to a number of revisions. The aim of this paper is to compare the methodology that underpins the Green Deal with an established methodology used for energy efficiency finance to assess the capability of the NCM to project total energy performance with reasonable accuracy, and explore improvement opportunities.

APPROACHES TO THERMAL MODELLING CALIBRATION

Energy performance assessments carried out with thermal models are often based on uncalibrated modelling. However, as energy efficiency finance ultimately deals with actual performance of properties, it is necessary to link theoretical energy performance projections derived from software to actual operation. Three approaches to thermal calibration are briefly reviewed in this section.

The Green Deal Approach: The user develops a baseline model following one of the two NCM-compliant routes: Simplified Building Energy Model (SBEM) or Dynamic Simulation Method (DSM). The main difference being that SBEM uses monthly averaged weather files and indoor environmental parameters, whereas DSM is based on hourly simulation. The following specific actions are then taken to update the baseline building for Green Deal applications (BRE, 2012):

- **Tailoring:** the user can change the standardised operating conditions assumed under the NCM to enable a closer definition of the building (e.g. occupant density, occupancy schedule, equipment gains, temperature set points and ventilation rates).
- **Management Scores:** a set of questions will be asked from the user to establish the management and maintenance regime for all regulated energy end uses within the building. Consequently a number of multipliers are derived that will adjust the outcomes of the modelling process to accommodate the effect of building management.
- **Normalisation:** finally, actual data on annual consumption per fuel and the reliability of the data are used to calculate a normalisation factor that will be applied to the modelling results.

This updated model will then be used to calculate energy performance of the building before and after the proposed energy efficiency measures and determine expected savings.

When fuel consumption data is based on meter readings, the reliability of the data is assumed 100% and a normalisation factor is defined as follows:

$$Ni = \frac{Zi}{Yi} \qquad (1)$$

Where Zi is the actual energy consumption and Yi is the calculated energy use before accommodating the proposed energy efficiency measures in the model. The expected total performance of the building after improvement works would then be calculated as follows:

$$Zli = Ni \times Yli \qquad (2)$$

Where Yli is the outcome of thermal modelling process including the effect of the proposed improvement works, and Zli is the expected energy consumption after improvement works. The expected energy saving would then be the difference between Zi and Zli.

The underlying principle of this method is an assumption that the normalisation factor before and after introduction of the proposed energy efficiency measures would be identical. This assumption will only hold true if the NCM is capable of modelling all energy efficiency measures qualified for the Green Deal with reasonable accuracy. Furthermore, no criteria is set for the accuracy of thermal models in relation to actual energy consumption. The implications of these will be investigated in this paper.

BS EN 15603 Approach: This energy performance of buildings standard includes a procedure for validation of the building calculation models (BS EN 15603, 2008, pp. 32-34). The aim of this procedure is to gain higher confidence in a building calculation model by comparing the outcomes with actual energy consumption data, and ensure there is *reasonable consistency* between calculated and measured energy performance. No specific criteria are provided in the standard to define reasonable consistency and, therefore, this should be determined on a case-by-case basis. This procedure includes an uncertainty analysis based on confidence intervals of input data and energy performance. This means more than one year of actual energy data is required for this type of validation. Under this procedure, validation is carried out based on annual energy performance. This might be deemed sufficient for validating energy ratings produced in building certification schemes. However, unless special attention is paid to trends of energy use (e.g. day vs. night energy use, and seasonal variations), relying on annual calibration alone is often not sufficient to predict energy behaviour of a property (EVO, 2012, p.29). Most researchers use hourly, daily or monthly calibration methods to ensure higher consistency between modelled and measured data for energy saving projects (Haberl and Bou-Saada, 1998; Ahmad and Culp, 2006; Raftery et al., 2011; EVO, 2012).

ASHRAE Guideline 14 Approach: This Guideline provides detail instructions for Measurement of Energy and Demand Savings in buildings including a whole building calibrated simulation approach (ASHRAE, 2002). This approach is widely used in the US for energy finance projects. It also underpins *Option D: Calibrated Simulation* included in the International Performance Measurement and Verification Protocol (EVO, 2012).

ASHRAE Guideline 14 offers two calibration methods: hourly and monthly calibration. The IPMVP recommends the monthly method to strike the right balance between the effort put in the modelling process and accuracy achieved (EVO, 2012, p.31). Monthly calibration method uses 12 months of utility bills that are based on metered data. The measurement period must reflect the steady mode of operation and not, for example, early few months of occupancy when a building is subject to fine-tuning and occupants are still learning how to operate their building. The calibration criteria used are based on Coefficient of Variation of the Root Mean Square Error (CVRMSE) and Normalised Mean Bias Error (NMBE) that are defined as follows (ASHRAE, 2002):

$$\text{CVRMSE} = 100 \times [\textstyle\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 / (n-1)\ ]^{1/2} / \bar{y} \qquad (3)$$

$$\text{NMBE} = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{(n-1)\times\bar{y}} \times 100 \tag{4}$$

Where:

y_i : measured monthly gas, electricity or other fuel use

$\hat{y}_i$: monthly gas, electricity or other fuel usage derived from thermal modelling

$\bar{y}$: average monthly gas, electricity or other fuel usage for the measurement period

n: number of data points (n=12 for calibration based on 12 months of data)

Detail operational information should be collected during site surveys and by measurements to calibrate a thermal model. For each fuel type, CVRMSE of 15% or better and NMBE of 5% or better must be achieved for calibration. Once the baseline model is calibrated, the effects of the proposed energy efficiency measures could be estimated with the model. The uncertainty associated with energy savings derived from modelling are linked to the calibration accuracy via the following equation (ASHRAE, 2002):

$$U = t \times \frac{1.26 \times CVRMSE}{F} \times \sqrt{\frac{n+2}{n \times m}} \tag{5}$$

Where:

F: percentage of the baseline energy use that is saved according to the calculation

m: number of data points in post retrofit analysis (m=12 for monthly method)

n: number of data points in the baseline period (n=12 for monthly method)

t: t statistic found in statistics textbooks. For 68% confidence level, t=1

U: uncertainty in calculated energy saving expressed as a percentage of the savings

Maximum level of uncertainty derived from equation 5 must be no greater than 50% of annual reported savings at 68% confidence level.

Finally, it should be noted that this calibration framework requires full 8760 hourly simulation software packages. This is a stark contrast with the Green Deal framework and precludes monthly calculation methods such as SBEM from being used for energy finance projects. This approach is used for the case study investigated in this paper.

METHODOLOGY

A case study was used to assess whether a DSM software package compatible with the NCM could model the energy efficiency measures that qualify under the Green Deal. The calibration method proposed by ASHRAE Guideline 14 was also tested on this building. A secondary school in London was selected for this study. The authors carried out post-occupancy evaluation on this building and collated detail information about the as-built specification and performance, actual operating conditions, and measured energy performance. The school was completed in 2010 and includes a number of energy efficiency measures such as Ground Source Heat Pumps (GSHP), demand-controlled ventilation, heat recovery, refined zoning arrangements to optimise energy performance, and high performance building fabric. These are all qualified measures under the Green Deal framework for non-domestic buildings (DECC, 2012). If the calibration criteria set out in ASHRAE Guideline 14 were achieved it could be concluded that the NCM is capable of modelling these energy efficiency measures with reasonable accuracy.

The main objectives of this investigation were as follows:

- To assess the capability of the NCM to estimate the performance of specific energy efficiency measures with reasonable accuracy, and the implication of this assessment for The Green Deal,
- To demonstrate how ASHRAE Guideline 14 could be used for energy finance projects using tools and methods applied in the UK.

To this end, the following actions were taken:

- An NCM compliant calculation engine, IES Apache, was used for thermal modelling. The miscellaneous loads that could not be modelled within the software package such as external lights and lifts were estimated using CIBSE TM22 Energy Assessment and Reporting Methodology (2006).
- Information collated from post-occupancy evaluation informed the modelling process.
- Actual total performance for the building was established based on latest utility bills and metered data.
- The outcomes of the model were compared with the monthly utility bills.
- ASHRAE Guideline 14 criteria were used to check if calibration was achieved.
- Actual annual performance was also compared with the modelling results. Sub-metered data was used to compare individual energy end-uses in addition to total performances.
- Where the modelled energy associated with specific end-uses was not close enough to the measured data, the root causes were investigated. TM22 tool was used to estimate these end-uses and compare with the outcomes of thermal modelling.
- ASHRAE Guideline 14 criteria were used to check whether the adjustments made to the energy end-uses that had not been predicted within the software package could lead to reasonable consistency between the calculated and measured performance.
- Finally, the information and insight gained from post-occupancy evaluation were used to compile a package of improvement works. The expected savings and associated uncertainties were analysed using ASHRAE Guideline 14 principles.

Figure 1 shows images of the case study school extracted from its thermal model.

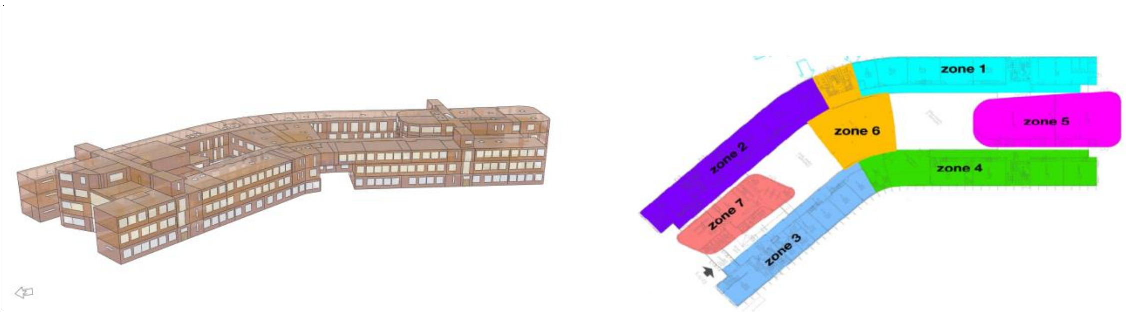

Figure 1 Axonometric view of the case study building extracted from thermal mode (left); Layout plan & HVAC zoning arrangement for the building (right)

The building is a Secondary School located in East London with 14,600 m² total useful floor area. The ventilation strategy is predominantly natural with mechanical ventilation only supplied to the core and ICT enhanced spaces. Ground source heat pumps were meant to act as the lead heating system supplemented by gas-fired condensing boilers. In addition to server room cooling, limited cooling is also provided to ICT enahnces spaces. A detailed metering startegy is installed for the building that allows measurment of all main energy end-uses separately.

The school was designed and procured in accordance with the Building Regulations 2006. The average as-built U value for the external envelope, including glazing, is 0.51 W/m²ºK, and the result of the pressure test following building completion was 4.36 m³/m².hr @ 50 Pa.

RESULTS

Figure 2 compares the sub-metered annual performance of all energy end-uses with the modelling results that are adjusted for miscellaneous loads including lifts and external lights. All end-uses show reasonable consistency except the auxiliary energy. Actual energy use of pumps is almost three times the calculated figure, whereas actual energy use of fans is almost half what is derived from modelling.

The NCM uses default pump power densities based on broad definitions for system type and control strategy. For example, maximum pump power density assumed in the NCM where both Low Temperature Hot Water and Chilled Water loops are present with variable speed pumping is 1.5 W/m² (CLG, 2011, p.83). The installed power density for the heating and chilled water system in the case study building is 3.46 W/m² *excluding* the pumps associated with the vertical borehole closed-loop GSHP installed. It should also be noted that there are other pumps within the system that are not allowed for in the NCM calculations such as cold water booster and cold water circulation pumps. As for fans, the NCM algorithm systematically underestimates energy savings associated with demand-controlled ventilation by assuming variable speed drives only reduce the airflow (CLG, 2011, p.85). However, fans are variable torque machines and the main benefit of variable speed control is specific fan power at part load is substantially lower than full load fan power (Carbon Trust, 2011). It is therefore necessary to carry out a calculation based on actual installed pump and fan powers and their control strategies. TM22 tool was used to address these issues and reconcile auxiliary energy with the metered data.

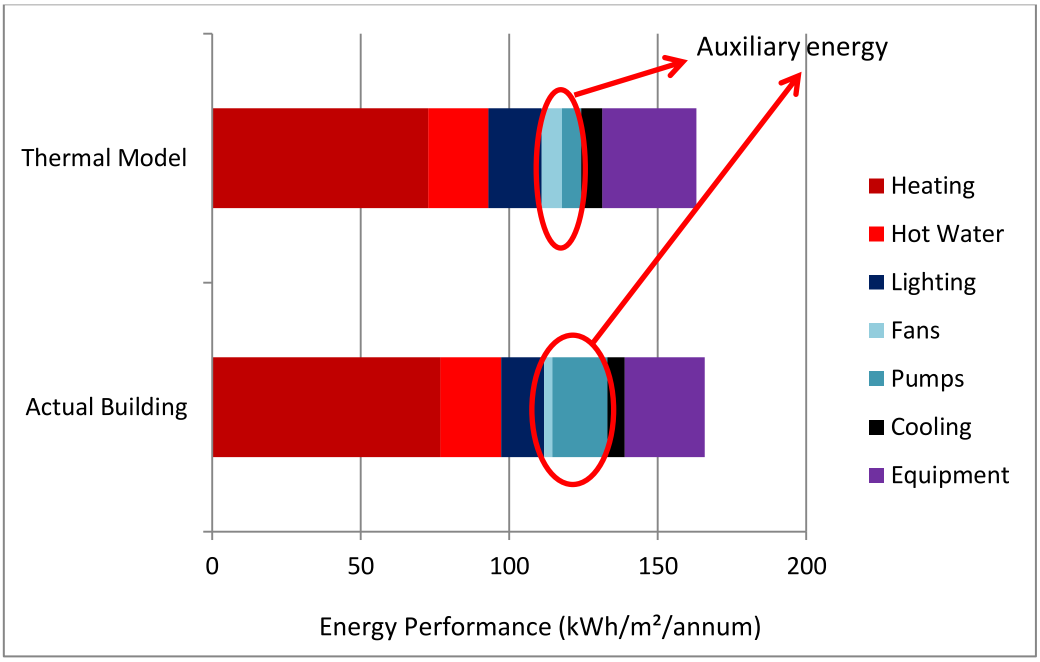

Figure 2 Actual vs. NCM-modelled energy performance of the case study building

Table 1 includes the results of the calibration exercise *after* auxiliary energy use was adjusted accordingly. Achieving monthly calibration for gas energy use was especially difficult due to the complex natural ventilation strategy adopted, and uncertainties associated with the operation of windows. The classroom CO_2 concentrations logged by the Building Management System were used to estimate the air change rates and calibrate the model. While the CVRMSEs are within the acceptable range set out by ASHRAE Guideline 14, these are substantially higher than total annual differences derived for both gas and electricity. This reinforces the argument that thermal modelling calibration based on annual performance alone will not be sufficient for predicting the thermal behaviour of a building in energy saving projects.

Figure 3 compares maximum monthly electrical demand reported by the electricity supplier with the calculated maximum monthly demand. The calculated demand shows reasonable consistency with the actual demand with maximum 10.7% error in October. The graph includes the effect of TM22 adjustments.

Table 1 Calibration results for the case study building

Fuel type	**Monthly calibration: CVRMSE (%)**	**Monthly calibration: NMBE (%)**	**Annual consumption measured (kWh/m²/annum)**	**Annual consumption modelled (kWh/m²/annum)**	**Annual percentage difference (%)**
Gas	14.0%	4.8%	97.4	93.1	4.4%
Electricity	11.4%	-2.8%	68.4	70.1	-2.5%

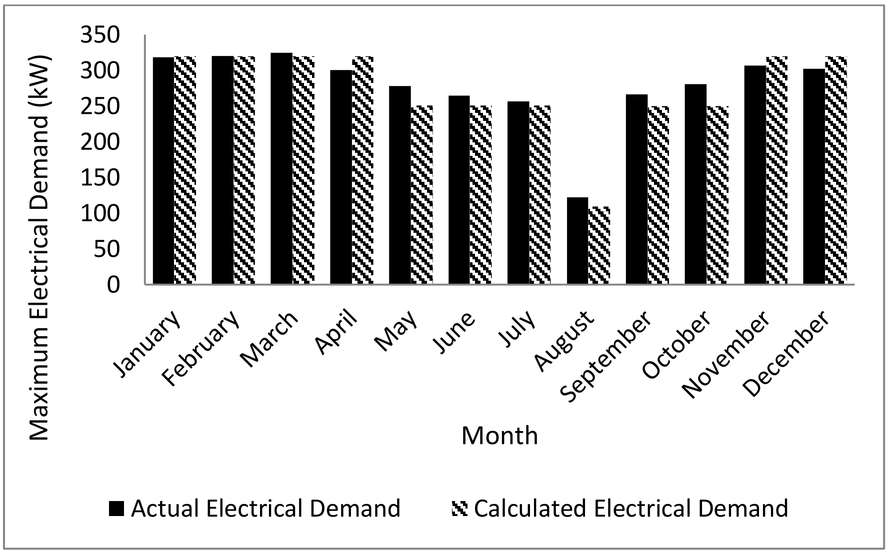

Figure 3 Maximum monthly electrical demand: Measured vs. Calculated

One of the findings of the post-occupancy studies was that a number of motorised vents installed for cross ventilation of the classrooms and corridor doors that open to the school's courtyard were stuck open during winter. The quick response from the maintenance contractors, before repairing the malfunctioning vents, was to increase the low temperature hot water flow temperature to 80 °C to overcome the associated heat loss. As ground source heat pumps are not effectively operational at this temperature, this led to isolation of the GSHP system. Consequently, gas consumption went up and was substantially higher than what would be expected from a new build school. Furthermore, post-occupancy studies revealed that there were incidences that heating set points could not be achieved at a number of classrooms and the ground floor corridor in winter due to high air change rates. The simulation results also confirm that high air change rates in the building in winter may lead to heating demands higher than installed capacity for less than 1% of annual hours.

Overall, the results derived from the hybrid TM22-Thermal model reasonably match actual operation. Table 2 includes a list of energy efficiency measures that could be adopted to address the operational issues and optimise the building's energy performance. Although financial analysis of the cost and monetary saving of these measures is beyond the scope of this paper, it is worth noting that all these measures are relatively low cost and could be easily implemented following a seasonal commissioning. The amount of expected savings derived from the calibrated model is indicative of huge improvements that could be achieved by fine-tuning new buildings in early stages of post-occupancy. An opportunity that is too often missed. The expected savings also meet the uncertainty criterion of ASHRAE Guideline 14.

Table 2 Energy Efficiency Measures proposed for the building, expected savings and uncertainty analysis

Proposed Energy Efficiency Measures (EEMs)	• Repair the motorised vents used for natural cross ventilation that are stuck open to minimise heat loss in winter. • Adjust the control settings to ensure GSHPs are always the lead heating system and gas-fired boilers are only used to supplement GSHPs (reduce the LTHW flow temperature to 50°C). • Address the issues associated with isolation valves to ensure heating and ventilation zones that are not occupied can be hydraulically isolated; optimise the operational schedules set up for HVAC systems to reflect actual occupancy pattern. • Refine the lighting zones within the circulation and common areas and adjust the optimum control settings for daylight and presence detection sensors (sensitivity and time offs).	
Expected energy saving (%)	Gas: 41% of the baseline performance before improvement works	Elec.: 11% of the baseline performance before improvement works
Uncertainty (%)	Gas: ± 13% of expected saving at 68% confidence level	Elec.: ± 41% of expected saving at 68% confidence level

DISCUSSION

The NCM was not primarily developed to calculate *absolute* energy performance. Normalisation is one of the key concepts introduced in the Green Deal framework to make NCM applicable to energy finance projects. The success of this concept is dependent on the NCM's capability to model energy efficiency measures qualified for the Green Deal with reasonable accuracy. This is not achieved in case of demand-controlled ventilation. The algorithm underpinning this ventilation strategy assumes a linear relationship between the airflow and fan power whereas the fan cube law holds that fan power is proportional to the cube of its speed and airflow. While the cube law offers an ideal theoretical relation that does not take into account operational losses, there are a number of empirical equations that reflect fan power variation against its speed with reasonable accuracy, including the empirical equation offered by ASHRAE Standard 90.1 (ASHRAE, 2004, p.179). It should also be noted that the minimum airflow allowed in the NCM for demand-controlled ventilation based on gas sensor is 62% of the maximum airflow (CLG, 2011, p.68). Carbon Trust recommends airflows as low as 30% of the maximum airflow to take advantage of the huge saving potential of variable speed fans (Carbon Trust, 2011, p.11). The difference between the linear equation used in the NCM and more accurate non-linear equations would be even larger at lower speeds. This can seriously compromise the accuracy of the NCM to estimate savings achievable from a well-designed demand-controlled ventilation system. Mechanical ventilation does not constitute a large proportion of electricity use in the case study building. However, the NCM-modelled fan energy being almost twice what it should be is indicative of the magnitude of error expected where demand-controlled full mechanical ventilation is supplied.

Using default and fixed pump power densities regardless of the length of heating index run, actual specification, and building specific context can also lead to large errors as confirmed in this case study.

While it is important to address these methodological issues within the NCM, this study shows that other tools and methods could help overcome the shortcomings of the NCM in projecting absolute performance. For example, the hybrid TM22-NCM method used in this study for auxiliary energy is also endorsed by CIBSE new publication TM54 for other electrical end uses (CIBSE, 2013).

The problems related to normalisation in the Green Deal could be compounded by other factors such as the uncertainties associated with defining management scores for regulated loads. Therefore, it is vital to have a robust framework to link calculated performance to actual performance directly. Furthermore, such framework must entail methods for uncertainty analysis.

The method used in this paper underpins the International Performance Measurement and Verification Protocol (IPMVP) that has been widely used for financing energy efficiency projects worldwide. This investigation shows a hybrid TM22-NCM method can be used to establish absolute performance and subsequently estimate the savings from proposed energy efficiency measures using the ASHRAE/IPMVP approach. Calibrating a thermal model often requires considerable amount of time and effort. However, the information obtained and insight gained from the building specific context will inform any improvement work. The risk of making important investment decisions based on default figures, simplified assumptions, and standard management scores, can make any extra work at the early stages of energy finance projects worthwhile.

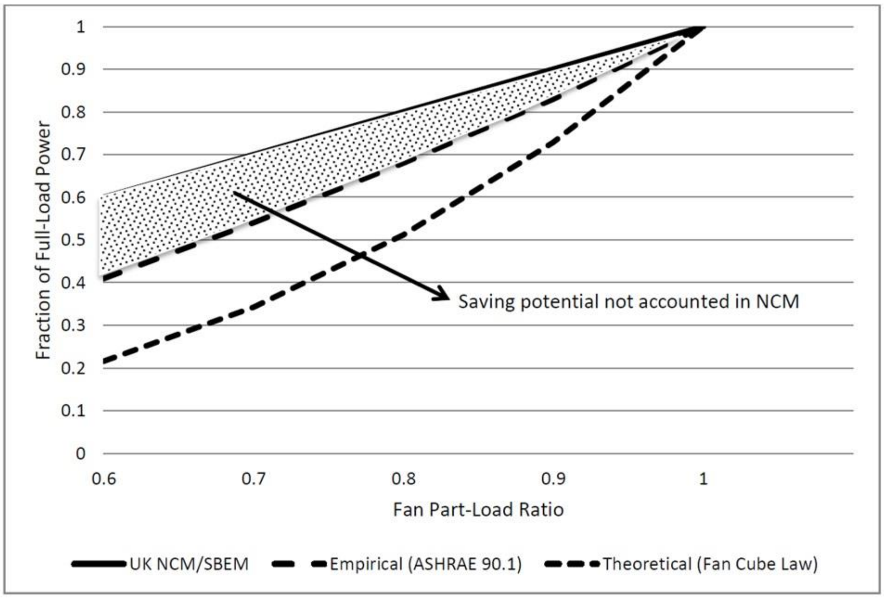

Figure 4 Demand-controlled ventilation saving potential not accounted in NCM

CONCLUSION

It is the early days for the Green Deal and few projects have followed its framework in non-domestic sector. While there is an on-going debate about the financial and legal aspects of this scheme, it is important to recognise the significant role estimating the energy savings plays in the whole process.

The framework proposed for the Green Deal and method used to estimate savings are based on a calculation methodology that was not primarily developed to calculate absolute energy performance. Therefore, it is necessary to assess the capability of this tool, and address any shortcoming that may exist in modelling energy efficiency measures that qualify for the Green Deal.

This investigation revealed that the NCM systematically underestimates the savings achievable from demand-controlled ventilation by assuming a linear relationship between airflow and fan power that defies the fan Cube Law and empirical evidence.

Using default and fixed pump power densities can also cause significant errors in projecting auxiliary energy use.

A hybrid TM22-NCM approach is suggested to overcome the shortcomings of the NCM related to specific electrical loads. It was demonstrated that such a hybrid approach could be used to calibrate a thermal model with actual building performance under the framework of ASHRAE Guideline 14/IPMVP. Lessons learned from these protocols that could feed in to energy finance projects in the UK are: their reliance on dynamic simulation only instead of monthly averaged methods used in calculation engines such as SBEM, hourly and monthly calibration methods instead of annual calibration method, and the framework adopted for analysing the uncertainty associated with projected energy savings.

ACKNOWLEDGEMENT

The Engineering and Physical Science Research Council (EPSRC) of the UK supported this study through an Engineering Doctorate programme. The post-occupancy evaluation was also funded by the Technology Strategy Board (TSB).

REFERENCES

Ahmad, M. and Culp, C., 2006. Uncalibrated Building Energy Simulation Modelling Results, HVAC&R Research, V12, N4, pp1141-1155.

ASHRAE 2004, Energy Standard for Buildings Except Low-Rise Residential Buildings, ANSI/ASHRAE/IESNA Standard 90.1-2004, ASHRAE Inc., Atlanta, USA.

ASHRAE, 2002, Guideline 14, Measurement of Energy and Demand Savings, ASHRAE Inc., Atlanta. USA.

BRE, 2012, NCM modelling guide Green Deal Development Edition, Draft document available at www.bre.co.uk [accessed on 07.02.2014].

BS EN 15603, 2008, Energy performance of buildings – Overall energy use and definition of energy ratings, British Standards Institution.

Carbon Trust, 2011, Variable Speed Drives Technology Guide, CTG070, Carbon Trust, UK.

CIBSE, 2013, TM54 Evaluating Operational Energy of Buildings at the Design Stage, The Chartered Institution of Building Services Engineers, London.

CIBSE, 2006, TM22 Energy Assessment and Reporting Methodology, The Chartered Institution of Building Services Engineers, London.

Department for Communities and Local Government (CLG), 2011, A Technical Manual for SBEM, UK Volume, available at www.ncm.bre.co.uk [accessed on 07.02.2014].

Department of Energy and Climate Change (DECC), 2012, Which energy efficiency improvements qualify for Green Deal Finance?, available at www.gov.uk [accessed on 07.02.2014].

Department of Energy and Climate Change (DECC), 2010, The Green Deal, A summary of the Government's proposals, available from www.gov.uk [accessed on 08.04.2014].

Efficiency Valuation Organisation (EVO), 2012, International Performance Measurement and Verification Protocol, available at www.evo-world.org [accessed on 07.02.2014].

Haberl, J.S., and Bou—Saada, T.E., 1998, Procedures for calibrating hourly simulation models to the measured building energy and environmental data, Journal of Solar Energy Engineering, 120(8), 193-204.

HM Government, 2011. Energy Act, available at www.legislation.gov.uk [accessed on 07.02.2014].

Raftery, P., Keane, M., and Costa, A., 2011, Calibrating whole building energy models: Detailed case study using hourly measured data, Energy and Buildings, 43(2011), 3666-3679.