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Characterisation of the Multi-dimensional Performance Risks Associated with Building Energy Retrofits

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Abstract

The potential of the built environment to contribute in reducing societal carbon intensity has been well established. The EU Energy Efficiency Action Plan 2011 posits that buildings offer greater potential than any other area of activity, noting they account for *ca*. 40% of final energy consumption.

There are three broad strands of performance metrics that are applied to decision-making in building energy retrofits, *viz*. energy savings, financial return and more recently, reduction of carbon emissions. Best practice involves consideration of these metrics on a whole life basis using approaches derived from methodologies such as life cycle cost analysis (LCCA), and life cycle assessment (LCA).

However, obtaining satisfactory (not to mention optimal) choices requires acknowledgement of a number of different performance risks associated with these lifecycle metrics and necessitates the development of approaches to reflect them in the decision-making process.

This paper contributes to the required discussion by examining conventional approaches to assessing building energy retrofits and by identifying and exploring a number of performance risks.

Keywords: building energy retrofit; lifecycle; performance risks; whole life carbon.

Introduction

Energy efficiency has become a priority for governments and businesses globally due to rising prices, geopolitical concerns and climate change. Reducing energy consumption saves money, enhances energy security and reduces environmental impacts [1]. As buildings account for the largest share of energy demand, equating with *ca*. 40% of final energy consumption in the EU, they are seen as having the greatest potential for reducing energy consumption of any single domain [2].

Buildings have very long operational lives and as a consequence display a low turnover, with 80% of current European buildings predicted to be still in use in 2030 [3]. This means that while it is important to design, construct and commission new buildings to high standards of energy efficient, this alone will not be enough to meet the reductions in energy consumption expected from the built environment. In addition, a significant programme of energy retrofitting of existing building stock will be required [4].

In the context of this envisaged significant increase in retrofit activity, it is important for the most effective use of funds that investment alternatives be effectively prioritised, selected and planned before installation and that their efficacy be assessed post installation. To achieve this there is a need for evaluation approaches to not only consider key performance metrics but also reflect the risks inherent to them.

Measuring Performance

Selecting energy efficiency measures *i.e.* choosing the right combination of technologies or systems to retrofit to an existing building can be difficult. There are many stakeholders with an interest in the energy retrofit of buildings each with different objectives [5] *e.g.* building owners may be focussed on increased value; building managers on reduced running costs *etc*.; occupants on comfort and utility; environment agencies on reduced carbon emissions; municipalities on reduced fuel poverty, economic development *etc*. Notwithstanding these different viewpoints, traditionally building energy retrofit options have been evaluated primarily on the basis of predicted energy and associated cost savings.

However, the significance of anthropogenic greenhouse gases to climate change [6], has led to an acknowledgement globally that substantial reduction in the carbon intensity of economic and industrial systems is required [7]. The efforts to stabilise atmospheric greenhouse gases have resulted in carbon emissions reductions becoming a significant additional driver in building energy retrofit programmes. Consequentially measurement of an intervention's impact on carbon emissions is increasingly being added to consideration of energy and financial implications and terms such as carbon savings, carbon neutral *etc*. have gained currency in energy-efficiency buildings discourse [8], [9].

An important consideration is that buildings are responsible for energy consumption, financial cost and carbon emission generation throughout their lifecycle not just during its use phase (so-called operational energy and carbon) [10], but also in all the activities that contribute to by the construction, upkeep and demolition of the building. This energy and carbon is said to be embodied in the building and can be divided into a number of categories, v*iz*.

- The initial embodied energy (or carbon) *i.e*. arising from the manufacture of building materials and construction of the building, including design and project management activities [11];
- The recurring embodied energy (or carbon) added though maintenance, renovation *etc*. of the building including replacement of components [12];
- The end-of-life embodied energy (or carbon) associated with the deconstruction, recycling and demolition activities selected for the building when its useful lifespan is over [13].

However, as embodied energy and carbon were not historically deemed significant over the lifespan of a building – typically it would have been expected that approximately four-fifths of the whole life energy (& similar quantity of carbon) would be within the operational phase [14] – decision-making for energy retrofits has previously disregarded non-operational energy (and carbon) implications.

But, as the building stock becomes less energy intensive in their operations, through more efficient designs of new builds and upgrading of existing buildings, the relative importance embodied energy & carbon is increasing and becoming more difficult to ignore [15]. This viewpoint is increasingly found in building energy discourse [16] and the importance of considering whole life energy (and by extension carbon) was recognised in the IPCC fourth assessment report, which argues that the embodied energy in building materials needs to be considered in addition to the operational energy in order to reduce total energy use by buildings [17].

The use of complementary methodologies taking a lifecycle perspective of these three performance metrics enable the consideration of the cost, energy and carbon trade-offs of potential options on a whole life basis, including:

- *Life Cycle Costing* (LCC) to calculate the net present value of all relevant costs (*e.g*. retrofit, maintenance, repair, replacement, energy, recycling, disposal and residual value) throughout the life span of the building [18], [19];
- *Life Cycle Energy Analysis* (LCEA), a derivative form of Life Cycle Assessment (LCA) to calculate total lifecycle energy consumption associated with the building [20];
- *Whole Life Carbon* (WLC), calculated through LCA methodologies giving the total carbon emissions generated over the life of a building (including those from non-energy processes) [21].

The move towards a lifecycle perspective highlights the importance of the lifecycle calculation methodologies, the results of which will form the basis of decision-making. The following sections characteristic a number of performance risks that affect the quality of calculations of these metrics.

Energy Efficiency Performance Risk

Rickard *et al.* define investment risk in energy-efficiency upgrade projects, as the down-side risk that the energy-efficiency upgrade will produce less than the expected return on investment over a given period [22]. Although expressed in financial terms, this return on investment can be thought as in respect of any desired performance metric. Howarth and Sanstad observed that both businesses and households routinely pass up on energy efficiency investments that offer better than market returns, showing a substantial implicit discounting of such investments, indicative of perceived risk [23].

Mathew *et al.* sought to develop a quasi-actuarial system pricing of energy efficiency projects in effect developing risk profiles for such projects. In the course of this work they identified two principle broad categories of risk *i.e.* (i) the inherent uncertainty of the estimated savings, due to various unknown or unknowable factors that affect the actual savings; and (ii) potential inaccuracies in the way savings are measured [24]. This two types of risks are in keeping with the ideas of Rickard *et al.*, who similarly divided energy efficiency project risk into *underlying factors i.e.* variables such as weather, energy prices, energy-efficient product failures, hours of operation, maintenance *etc.* and *calculation biases* used to predict the savings [22].

Mills *et al.* in noting, that there is no secret in the uncertainties of savings estimates and that there are many factors with the potential to inhibit performance, identified five categories of energy efficiency project risk *viz.* economic *e.g.* fuel costs; contextual *e.g.* data on facility; technology *e.g.* equipment lifetime; operational *e.g.* degradation of savings; and measurement & verification *e.g.* modelling errors [25]. – The first four of these correspond Mathew *et al.'s* first category 'savings-estimate' and the fifth to their second category 'measured-deviation'.

Thompson, in attempting to provide for appropriate discounting of energy efficiency investments, commented on a number of specific risks applicable to such projects (each of which could be said to belong to Mathew *et al.'s* first category 'savings-estimate'), including: future price of energy; performance of new technology; performance of existing equipment as it ages; take-back effect of occupants using some of the energy savings to increase their comfort [26].

Distinguishing between the underlying factors, which add uncertainty to potential savings and the potential inaccuracies or biases in modelling the potential savings is useful global approach to considering energy efficiency project risks. In addition, the specific performance risks identified by commentators such as Mills *et al.,* Thompson *et al. etc.* contribute to the understanding of risks involved in such projects. This paper posits that in the context of the evolving whole life evaluation of energy efficiency projects, there is a need to explore the performance risks in an integrated manner considering whole life energy, cost and carbon. Therefore, a number of risks, which have the potential to affect one or more of these aspects of performance, are commented upon below.

1. Technological risk

Many of the technologies and solutions offering energy conservation and energy efficiency are relatively new and so unproven. The possibility of underperformance from such unproven solutions is not inconsiderable. In many ways perhaps this is the most obvious risk, and one identified by many commentators [22], [24] and yet the performance specification offered by the suppliers is commonly accepted and used in assessment of potential solutions. Life cycle calculations of all performance aspects (including LCC, LCEA & WLC) involving unproven technologies carry substantial uncertainties [27] regarding actual equipment operational performance. Such uncertainty will affect the meaningfulness of the results if not addressed in a credible manner.

2. Technical risk

A related but separate risk is that the installation and/or commissioning of the chosen retrofit configuration may not be of sufficient quality to achieve the envisaged energy savings with consequential impacts on cost and carbon performance. Alternatively, this work may take additional time and resources to achieve the desired standard resulting in greater costs and increased recurring embodied carbon. The risk is recognised in the EU Energy Efficiency Plan 2011 which noted a shortage of qualified and experienced craft workers for building energy efficiency retrofits and by the decision to establish the 'BUILD UP Skills: Sustainable Building Workforce Initiative' to address the skills weakness [1], [28].

3. Longevity uncertainty

As recognised by Rickard *et al.* among other, the lifespan of the planned energy retrofit may be less than envisaged [22]. This will necessitate replacement equipment and related works, which will mean additional costs, embodied energy and carbon over and above that calculated in the planning stage.

There is a further risk that the building itself will be decommissioned earlier than envisaged, this too will directly impact on the relative significance of the embodied energy and carbon *vis-à-vis* that associated with the operational phase, while also decreasing the amount of money that could be saved.

4. The human factor

While it is not unexpected that users will occasionally use the chosen retrofit configuration incorrectly or less than optimally, there is also the possibility that they will not use it in line with assumptions made pre-installation and therefore impacting on all aspects of performance. Mills *et al.* identified ‘persistence’ of performance as an issue, and linked it partially to occupant behaviour and suggested end-user training and information, occupant incentives *etc.* as possible remedies [25].

The take-back or bounce-back effect of occupants reclaiming some of the predicted energy savings for increased comfort and utility is a recognised phenomenon [26], however if the take-back level is greater than anticipated, this too will result in reduced performance.

Occupants using the retrofitted energy system less effectively (from the point of view of energy consumption avoidance) than envisaged will result in reductions in each of the three performance metrics (energy, cost and carbon) and could have a knock-on effect on other risks and uncertainties such as technological performance, maintenance requirements and longevity of the retrofit configuration.

5. Maintenance

The degree of upkeep required for the solution to achieve the required performance may be greater than anticipated *e.g.* day-to-day maintenance may be more time-consuming, part replacement intervals may be underestimated, costs higher than planned *etc.* As previously stated this extra maintenance could arise as a result of ineffective use by occupants.

Increased maintenance would impact primarily on the costs involved in running the equipment, with additional life cycle carbon and energy associated with additional parts and services. There is also the possibility that extra maintenance could result in additional downtime, with a direct effect on operational energy (and related cost and carbon implications).

6. Energy cost movements

Buildings are a long-life produce and so future predictions of underlying economic factors are also fraught with uncertainty, for building movements in the cost of energy are particularly sensitive, if prices move contrary to assumptions on which the decision-making was made the financial savings which are due to derive from the avoided energy consumption will be substantially changed – thereby changing the lifecycle costing of the project.

Such changes in energy prices may arise as a result of changes in fossil fuels reserves [29]; weather; new technologies; political uncertainties [30]; geo-political competition for natural resources [31], *etc.*

7. Decommissioning risks

The envisaged end of life management of the chosen retrofit technology (or technologies) may prove unfeasible, This may be due to a variety of reasons *viz.* technical (*e.g.* recycling technology does not work as envisaged), financial (*e.g.* costs may be higher than planned), legal (*e.g.* it may not be legally permissible to recycle or dispose of the material in the manner planned) or logistical (*e.g.* envisaged end-of-life process is not available within a reasonable proximity). In such cases an alternative end-of-life strategy will have to be adopted for the retrofit technologies – alternative strategies will have different cost, energy and carbon profiles from the original strategy, which will therefore will directly impact on each of the three performance aspects.

8. Overestimation of carbon savings

The quantity of carbon emission to be saved during the operational phase of the building may be over-estimated due to changes in the carbon intensity of energy sources. Estimates of carbon emissions are typically based upon the carbon factors of the energy sources current at the time of calculation. However, the carbon intensity of electricity from centralised grids is anticipated to reduce throughout Europe and in other developed economies as GHG reduction targets, (supported by international agreements and in some cases legislation) necessitate substantial action by all economic sectors to reduce the GHG emissions from their activities – particularly so in the case of the 'low-hanging' fruit of power generation, see for example the reductions envisaged in the EU Energy Roadmap 2050 [32].

Jones used a dynamic model of predicted carbon intensity of the UK electricity grid to compare with using with a steady-state view of emissions and demonstrated that the steady-state approach could lead to over-estimates of operational carbon by much 50% for a new house and 95% for a new school building [33]. Such changes to centralised energy grids mean that buildings will have less operational carbon even if no energy improvements are made. It can be seen that estimating operational carbon by extrapolating data from whole building energy simulation with current carbon intensities leads to erroneous estimations both of quantity and relative importance to the embodied components of whole life carbon emissions.

Conclusions

There are two broad types of uncertainty or risks that apply to building energy efficiency projects [26], [25] – firstly that the assumptions on which performance has been predicted do not hold true and secondly that the way in which the predictions were made are erroneous or contain biases. This paper identified eight specific risks, which have the potential to impact on performance in terms of whole life energy, cost and carbon. Seven of the risks fall into the first category – assumptions *viz.* technological, technical, longevity, end-user, maintenance, energy costs & decommissioning. The eight is a calculation bias, a potential inaccuracy in the way in which future carbon savings are calculated.

Many of the technologies offered by solution providers are novel and as such unproven, this brings a great deal of uncertainty into the assumptions used in the calculation of life cycle metrics. Uncertainty analysis can provide the context to improve use of these metrics. Blengini & Di Carlo, observe that uncertainty analysis, while not common practice, is gaining importance in LCA studies and facilitates clearer interpretation of results [34]. Such uncertainty analysis would involve systematic appraisal of the uncertainties, ranking of importance, and calculation of probability of occurrence thereby providing practitioners with the context in which to present and use results.

There is a calculation bias inherent in using steady state versus predicted electricity carbon intensities. Jones' demonstration of using dynamic models of predicted carbon emissions presents a means of making whole life carbon determination more credible and therefore more useful in selecting energy retrofit options [33].

Further work is required to explore these and related risks in more detail, to incorporate an acknowledgement of the risks in retrofit assessment methodologies, to integrate solutions where available (*e.g.* uncertainty analysis; dynamic models of energy carbon intensities; risk mitigation strategies *etc.*) and to communicate shortcomings where not.

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References

[1] *Energy Efficiency Plan 2011*, Brussels, Belgium: European Commission, 2011.

[2] C. Cheng, S. Pouffary, N. Svenningsen, and M. Callaway, The Kyoto Protocol, the Clean Development Mechanism, and the Building and Construction Sector. Paris, France: United Nations Environment Programme, 2008.

[3] Energy-efficient buildings PPP, Brussels, Belgium: EC DG-Research & Innovation, 2010.

[4] EU Energy and Climate Change Package, Brussels, Belgium: European Commission, 2008.

[5] E. Zavadskas, S. Raslanas, and A. Kaklauskas, The selection of effective retrofit scenarios for panel houses in urban neighborhoods based on expected energy savings and increase in market value: the Vilnius case, *Energy and Buildings*, vol. 40, no. 4, pp. 573–587, January 2008.

[6] S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Eds., Climate Change 2007: The Physical Science Basis. Cambridge UK & New York, USA: Cambridge University Press.

[7] *United Nations Framework Convention on Climate Change (UNFCC)*. http://unfccc.int/

[8] A. Young, C. Perry, and R. Manson, *Briefing: Energy efficiency in buildings, Proceedings of the Institution of Civil Engineers Engineering Sustainability*, vol. 162, no. 3, pp. 127–132, June 2010.

[9] A. Reeves, S. Taylor, and P. Fleming, Modelling the potential to achieve deep carbon emission cuts in existing UK social housing: The case of Peabody, *Energy Policy*, vol. 38, no. 8, pp. 4241–4251, May 2010.

[10] R. Fay, G. Treloar, and U. Iyer-Raniga, Life-cycle energy analysis of buildings: a case study, *Building Research & Information*, vol. 28, no. 1, pp. 31–41, January 2000.

[11] G. P. Hammond and C. I. Jones, *Embodied energy and carbon in construction materials*, *Proceedings of the ICE - Energy*, vol. 161, no. 2, pp. 87–98, January 2008.

[12] M. K. Dixit, J. Fernández-Solís, S. Lavy, and C. H. Culp, Identification of parameters for embodied energy measurement: A literature review, *Energy and Buildings*, vol. 42, no. 8, pp. 1238–1247, August. 2010.

[13] Y. Yohanis and B. Norton, Life-cycle operational and embodied energy for a generic single-storey office building in the UK, *Energy*, vol. 27, no. 1, pp. 77–92, 2002.

[14] T. Lane, Our Dark Materials, *Building Magazine*, no. 45, pp. 1–5, 2007.

[15] S. Sturgis and R. Gareth, Redefining Zero, London, UK: RICS Research, 2010.

[16] E. Ayaz and F. Yang, Zero Carbon Isn't Really Zero: Why Embodied Carbon in Materials Can't Be Ignored, *DesignIntelligence*, 01-Sep.-2009. [Online]. Available: http://www.di.net/articles/archive/zero_carbon/. [Accessed: 15-February-2012].

[17] B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, and L. A. Meyer, Eds., Climate Change 2007: Mitigation of Climate Change. Cambridge UK & New York, USA: Cambridge University Press, 2007.

[18] J. Kneifel, Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings, *Energy and Buildings*, vol. 42, no. 3, pp. 333–340, March 2010.

[19] S. Fuller, Life-Cycle Cost Analysis (LCCA), *Whole Building Design Guide*, 26-Jun.-2010. [Online]. Available: http://www.wbdg.org/resources/lcca.php. [Accessed: 09-January-2012].

[20] G. F. Menzies, P. F. G. Banfill, and S. Turan, Life-cycle assessment and embodied energy: a review, *Proceedings of the ICE - Construction Materials*, vol. 160, no. 4, pp. 135–143, January 2007.

[21] B. P. Smith, Whole-life carbon footprinting, *The Structural Engineer*, 2008.

[22] S. Rickard, B. Hardy, B. Von Neida, and P. Mihlmester, The Investment Risk in Whole Building Energy-Efficiency Upgrade Projects, presented at the *ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, Washington DC, USA, 1998, pp. 307–318.

[23] R. B. Howarth and A. H. Sanstad, Discount rates and energy efficiency, *Contemporary Economic Policy*, vol. 13, no. 3, pp. 101–109, 1995.

[24] P. Mathew, J. S. Kromer, O. Sezgen, and S. Meyers, Actuarial pricing of energy efficiency projects: lessons foul and fair, *Energy Policy*, vol. 33, no. 10, pp. 1319–1328, July 2005.

[25] E. Mills, S. Kromer, G. Weiss, and P. A. Mathew, From volatility to value: analysing and managing financial and performance risk in energy savings projects, *Energy Policy*, vol. 34, no. 2, pp. 188–199, January 2006.

[26] P. B. Thompson, Evaluating energy efficiency investments: accounting for risk in the discounting process, *Energy Policy*, vol. 25, no. 12, pp. 989–996, 1997.

[27] E. G. Hertwich, M. Aaberg, B. Singh, and A. H. Strømman, Life-cycle assessment of carbon dioxide capture for enhanced oil recovery, *Chinese Journal of Chemical Engineering*, vol. 16, no. 3, pp. 343–353, 2008.

[28] M. Laskari, Sustainable Building Workforce Initiative, BUILD UP Skills. [Online]. Available: http://www.buildup.eu/training-schemes/23855. [Accessed: 14-June-2012].

[29] N. A. Owen, O. R. Inderwildi, and D. A. King, The status of conventional world oil reserves—Hype or cause for concern?, *Energy Policy*, vol. 38, no. 8, pp. 4743–4749, 2010.

[30] A. Torello and F. Robinson, Moscow Curbs Supplies of Gas Across Europe, *Wall Street Journal*, 04-Feb.-2012. [Online]. Available: http://online.wsj.com/article/SB10001424052970203711104577200852563136204.html. [Accessed: 09-April-2012].

[31] D. Zweig and B. Jianhai, China's Global Hunt for Energy, *Foreign Affairs*, vol. 84, no. 5, pp. 25–38, 2005.

[32] Energy Roadmap 2050, Brussels, Belgium: European Commission, Dec. 2011.

[33] C. Jones, Embodied Carbon A Look Forward - Sustain Insight Article: volume 1, Bristol, UK: Sustain Ltd., 2011.

[34] G. A. Blengini and T. Di Carlo, The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings, *Energy and Buildings*, vol. 42, no. 6, pp. 869–880, 2010.