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Life cycle cost and carbon footprint of energy efficient refurbishments to 20th century UK school buildings

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Abstract

This study presents a method for assessing energy efficient refurbishment options for schools in the UK. The method accounts for life cycle effects on cost and carbon emissions since refurbished buildings will last for many years.

Four schools are identified as representative of school archetypes built in the UK during four distinct periods in the 20th century. The schools are used as a base for simulation of the effects of energy efficient refurbishment of building fabric and heating plant. All possible combinations of the selected measures are simulated. Simulated energy savings are then compared between the four school buildings, demonstrating how physical characteristics of the schools affect the available savings. Simulating combinations of energy efficiency measures allow analysis of interaction effects between measures, and reveals some positive and some negative interactions. A regression model of energy savings in the four schools is also developed.

Simulated energy savings are then used as inputs for a life cycle assessment model. Life cycle indicators considered are marginal life cycle cost and marginal life cycle carbon footprint. These metrics are used to rank the energy efficiency measures on net present value and life cycle carbon footprint saving, both individually and in combination with each other.

Carbon payback is shorter than financial payback in all scenarios, and all measures and combinations of measures repaid the carbon invested in them. Positive net present value is less common, and frequently depends on air tightness improvements also being achieved.

Keywords: Building energy simulation; Life cycle cost; Life cycle carbon footprint; Refurbishment; Energy efficiency

1. Introduction

Public sector buildings in England were estimated to have emitted 20.1 $MtCO_2e$ in 2009/10, equivalent to 9% of UK emissions from buildings (Gill Bryan et al., 2011; CCC, 2012). Of this total, schools were responsible for 3.0 $MtCO_2e$ (Gill Bryan et al., 2011). The government's carbon management strategy for the school sector sets a target to cut school's current emissions from energy use by 53% by 2020 (DCSF, 2009). Although some of this saving will come from newly-built schools, retrofitting existing buildings is one of the most cost-effective ways of reducing emissions (Enkvist et al., 2007).

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This paper considers four school buildings as case studies, each representative of an archetype commonly built in the 20th century. The objectives are to identify viable thermal energy retrofit measures (ERMs), to explore how these ERMs interact with each other, and finally to reveal the physical characteristics of schools which can predict the viability of ERMs and packages of ERMs. This paper compares the life cycle carbon footprint (LCCF) and life cycle cost (LCC) of improving existing schools. Understanding how refurbishment work undertaken today will affect future generations requires taking a life cycle approach, since the buildings of today will last for many years.

It is important not to conflate the economic assessment of LCC with environmental life cycle assessment methods such as LCCF since they are different tools (Gluch and Baumann, 2004). However both are useful to decision makers where environmental impacts are a concern. It is of particular importance to recognise where the two objectives are in conflict as a decision maker must then decide how to balance competing objectives.

Previous studies have used dynamic energy simulation to estimate the financial viability of ERMs in non-domestic buildings, mainly offices. Some of these studies have looked at LCC or payback period analysis of the ERMs (Beccali et al., 1997; Hestnes and Kofoed, 2002; Chidiac et al., 2011a,b). Other studies have looked at some or all of embodied carbon, embodied energy and LCCF of energy efficiency measures in non-domestic buildings, but most are concerned with improving the design of new buildings (Buchanan and Honey, 1994; Kofoworola and Gheewala, 2009; Scheuer et al., 2003).

2. Case studies

Schools built in the late 19th and 20th century account for the majority of existing schools in the UK. Prior to the late 19th century most schools were built to provide elementary education through monitored teaching to children of workers in industrial cities. Most adopted local vernacular styles (Harwood, 2010) and there was no unified style which we would recognise as a typical school (Ringshall et al., 1983).

The Education Act of 1870 brought a great change in the UK education system. The state became the primary sponsor of schools for compulsory education up to the age of 10–12. All designs had to meet the strictures of the Education Department for site, plans and cost approval and thus, schools with standardised design were built. Buildings from this era were repetitive, constructed mainly in red brick with large timber sliding sash-windows for naturally-lit classrooms and halls. Typical designs feature up to a 3- or 4-storey superstructure with separate classrooms around a central schoolroom or hall, and a covered play area (see Fig. 1).

In the early 20th century, the outbreak of war saw a freeze on development, and the inter-war economy of the 1920s and 1930s was effectively bankrupt. This period also saw criticism of previous school designs on the grounds of poor daylighting, ventilation and hygiene. The open air school movement grew from the influence of continental European schools where corridors were singly-loaded with classrooms allowing better ventilation, day lighting and a southerly orientation. The more formal central hall plan began to change in favour of more asymmetric groups of classrooms separated by function, usually of one- or two-storeys, although the case study building is a larger four-storey building (see Fig. 2).

Post-war increases in school populations and the need to repair and replace obsolete and war-damaged buildings necessitated The Education Act of 1944, which brought immense changes in the objectives of education. New education methods and user needs demanded new buildings, and new functions coincided with new architectural forms. Also, cost-consciousness required architects to seek economic building methods (Ringshall et al., 1983). In order to maximise teaching space, inner circulation was reduced. As a result the architecture evolved as doubly-loaded corridors with classes on either side, restricting options for window orientation and cross ventilation. Buildings from this era were mainly flat concrete roofed, prefabricated concrete or lightweight brick structures with large steel single glazed windows and deep plans with less importance given to orientation (see Fig. 3).

A new building archetype was developed during the late 20th century, featuring a central atrium. These designs were generally limited to double storey height. The atrium, usually glazed from the top was used to trap solar energy on cold days and distribute that heat in the form of warm air into classrooms set off to the sides. This atrium also acted as an additional space built at low cost. During summer, the atrium acted as a solar chimney collecting hot air and exhausting it at the top. The classrooms also started having roof skylights to improve daylighting and allow for stack ventilation (see Fig. 4).

Four school buildings have been selected for this study as representative of these four archetypal 20th century school types. Their characteristics are presented in Table 1–5.

3. Methods

3.1. Goal and scope

The intention is to explore LCCF and LCC implications of retrofit options for a range of school typologies. The goal is to establish which retrofit measures and combinations of measures result in the greatest overall reduction in the LCCF and LCC.

The functional unit used is 1 m^2 of the schools' gross internal area (GIA). Although the life cycle inventory (LCI) and life cycle impact assessment (LCIA) are conducted on each school as a whole, results are normalised by GIA in order to be able to compare the results of this study with each other and with those in future studies.