Energy-led refurbishment of non-domestic buildings: Ranking measures by attributes

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Abstract

Purpose

In the context of the energy-led refurbishment of traditionally-constructed non-domestic buildings, the purpose of the work was to identify the attributes that professionals consider to be important in the selection of energy performance improvement measures, and to establish their relative importance.

Methodology

A questionnaire-based Delphi exercise was carried out in order to draw up a set of attributes agreed among a small panel of experts. Subsequently a paired comparison questionnaire was completed by the experts to establish the relative importance ascribed to the attributes.

Findings

22 assessment attributes, relevant to different stages in the building's life-cycle, were agreed as important by the expert panel. Measures fell into one of three broad groups, expressed on a weighting scale of 0-100, such that the sum of the weights of all 22 measures was 100. Measures of relatively high importance (7-9%) included capital cost, potential energy and carbon savings, financial payback and impact on the building's vapour permeability. Measures of medium importance (4-5%) were impact on internal air movement, loss of significant original building fabric, impact on internal layout, appearance and occupant

comfort, environmental impact and availability of grants or subsidies. Eight further measures were ranked of low importance (2-3%).

Originality/value

This paper is the first attempt to draw up a ranking order of the attributes of energy performance improvement measures, applicable to non-domestic buildings. It confirms that more attributes must be considered by professionals with decision-making responsibility than merely cost, energy performance and payback on investment, and suggests that policy instruments targeting or incentivising a single or a restricted range of attributes risk failure to deliver the desired improvements.

Keywords

Refurbishment, non-domestic buildings, assessment, professionals

Introduction

Against a global context of reducing CO_2 emissions, the UK Government has set a target of 80% reduction from 1990 levels by 2050 (DECC, 2008). Since about 40% of the UK's energy use and CO_2 emissions is associated with existing buildings (Carbon Trust, 2009), and 18% of this is from the non-domestic sector (CIOB, undated), refurbishment has a major role to play in achieving these reductions. Buildings of traditional construction are considered to be hard to treat (Roaf et al, 2008) and these are defined as those built before 1919, with solid walls constructed of mass masonry, originally single glazed and without insulation materials built into the fabric, and likely to have high air infiltration levels. This traditionally constructed non-domestic property type is commonly seen in major towns and cities throughout the UK and northern Europe and such buildings typically provide an urban-central location for many organisations. As an indication of the prominence of this type of building, in 1994 in England and Wales 29% of offices and 40% of retail premises (by floor area) were built pre-1918 (Bruhns et al, 2000). This represents 50 x 10^6 m^2 floor area.

Whilst much research, practical and policy advice has focused on the traditionally built domestic sector (for example STBA, 2012; Suhr and Hunt, 2013), by comparison less work has dealt with the non-domestic buildings which are the subject of this paper (May and Rye, 2012). Much of the advice available is somewhat generic (CIBSE, 2007; Baker, 2009; CIBSE, 2013) but some authors draw attention to the particular feature of traditionally constructed buildings: the building fabric readily allows absorption and evaporation of moisture ("breathing"), in contrast to modern construction forms that use largely impermeable materials (English Heritage, 2011; Historic Scotland, n.d.; May and Rye, 2012; Prince's Regeneration Trust, 2010).

BBP (2010) identified five key barriers to the refurbishment of non-domestic property for carbon reduction:

(i) commercial (the landlord and tenant divide);

(ii) roles and processes (a lack of clarity, methodologies and evaluation criteria);

(iii) financial (shortage of capital finance and unattractive payback periods);

(iv) technology (in terms of available technologies and their performance, limitations associated with existing property and skills shortages among industry professionals);

(v) policy (lack of emphasis and support for improvement of existing property).

LCICG (2012) additionally highlighted the fragmented supply chain and lack of necessary skills in the building sector. The European University Institute (2012) commented that the energy-led refurbishment process involves many small actors who often lack the appropriate skills and/or information to take decisions rationally and that education of specialists is vital if they are to act as advisors to property decisions makers.

These property and facility management professionals, who are responsible for making decisions on the energy performance improvement measures (EPIMs) to be adopted, are faced with a range of alternative EPIMs. CALEB (2008) identifies an inordinate focus on highly complex refurbishment / improvement options as a key barrier to improving performance and states that simple and suitable solutions, such as improving fabric thermal performance, are not implemented because decision makers are distracted by higher risk options. Carbon Trust (2010) confirmed this, putting forward a staged approach to building performance improvement, progressing from simple, cost-effective measures to a more expensive integrated approach leading to 2050. Bettle et al (2006) suggest prioritisation of measures additionally from a financial perspective and question whether it is more effective to implement fabric measures to reduce heating demand and fossil fuel consumption or to improve the efficiency of electrical systems to reduce a property's reliance on electricity. However, when viewed from a carbon perspective fabric measures might be more important if the electricity supply has been decarbonised. Roberts (2008) suggests that when building fabric is improved is the best time for HVAC replacement. This implies a whole building approach to refurbishment, which is essential because changes to the fabric can change the demand on building services. This holistic view of building performance helps ensure that the impact of individual improvement measures is considered comprehensively, and is already evident in the domestic sector (Fyhn and Solli, 2012). Prioritising measures within a refurbishment campaign is clearly challenging.

The range of potential EPIMs for non-domestic property is wide (Tarbase, 2010), including, on the demand side:

(i) changes to small power, equipment and lighting (leading to reduced internal gains);

(ii) building fabric measures (insulation, glazing and air infiltration) and

(iii) services measures (heating and ventilation),

and, on the supply side:

(iv) on-site generation of electricity (wind or solar) and

(v) alternative heat sources (such as heat pumps).

These need not be detailed here but clearly each measure has several attributes – technical, economic, practical and operational. The balancing of attributes that must be done by decision makers is an example of a complex Multiple Attribute Decision Making (MADM) process (Yoon and Hwang, 1995; Hajkowicz and Collins, 2007). In this context the alternatives are the EPIMs, which have multiple attributes that can be assessed both qualitatively and quantitatively. From this mix, MADM involves the evaluation of information and the prioritisation of solutions, which in turn requires some form of weighting of the various attributes. Since no previous research into the relative importance of the attributes was identified in the literature, the aim of this study is to contribute to the decision making process.

The objective of the work described in this paper was to elicit the views of professionals in identifying the attributes needed by an EPIM being considered for an existing office building of traditional construction and to establish a preliminary view of the relative importance of those attributes.

Methodology

Attributes of EPIMs

Faced with refurbishment of a traditionally constructed building, professionals have to select and evaluate different EPIMs, each of which has various attributes. To apply MADM to decide which EPIM to adopt, professionals need a sense of the relative importance of all the attributes concerned. The first stage of this research was therefore to draw up an agreed list of EPIMs and for this it would be possible to use individual interviews, group interviews, focus groups or a Delphi survey. The use of individual interviews was considered and discarded because the time to complete a sufficient number was not available. Group interviews and focus groups were rejected because of the risk that small group situations can be dominated by members with strong personalities and the results skewed as a consequence. Therefore a Delphi survey was used to develop the agreed list of EPIMs from an initial list, which had been informed by a literature review (Strachan, 2013).

Delphi, used in a wide range of sectors (Hon, Chan and Chan, 2011; Mamaqi, Miguel and Olave, 2011; Bond and Bond, 1982; Schmidt et al, 2001; Lunsford and Fussell, 1993; Höjer, 1998), seeks to obtain a statistically valid consensus between a group of experts in a defined field. Its strength is that it creates an environment where each expert can think independently, without the pressure of a group scenario such as in a focus group, where forceful personalities can unduly influence the group's thinking (Janis, 1972; McCauley, 1989; Turner and Pratkanis, 1998). Whilst Delphi can be carried out either 'in camera' with a panel guided by a facilitator or 'at arms-length' through questionnaires, the former approach potentially faces the same issues as a focus group. Therefore the arms-length approach was adopted here. Delphi may be criticized for its focus on achieving consensus and the suppression of discordant views, but since the present paper consciously seeks consensus, this may be acceptable.

Recruitment of experts

According to Oh (1974) an individual who is highly skilled, with specific specialist expertise about a subject, is an appropriate Delphi expert. Additionally, they must have a reasonable approach and be open to revising their views when presented with new information (Pill, 1971). Turoff (1970) recommends between ten and fifty experts to form the panel. In this case thirteen experts were recruited from among the membership of a private sector industry-led environmental forum, and from public-sector agencies. Their professional qualifications included architecture, engineering and facilities management, and each had specialist post qualification experience of at least ten years within at least one of five relevant sectors:

(i) Client. Experts who work within an organisation with a significant building portfolio, and who are involved in the management of and works to that portfolio.

(ii) Guidance. Experts who work within an organisation that sets standards or guidelines for construction or who are involved in knowledge exchange within the field of energy and buildings.

(iii) Heritage. Experts who work within an organisation tasked with safeguarding the historic built environment.

(iv) Industry. Experts who work within the construction industry.

(v) Non-heritage. Experts who have a technical background with an understanding of the historic built environment but are involved in a broader range of building types.

Table 1 shows the assignment of each participant to these expert groups and it should be noted that every individual appears in at least two categories. They were asked to describe their knowledge and experience but not to score it: confirmation of ‘expert’ status was at the discretion of the research team.

Table 1 Experts' knowledge resource categorization

Identification of attributes

In stage 1, the experts developed an agreed set of attributes for the use of built environment professionals in assessing the suitability of an EPIM for an existing building. This involved three rounds of online questionnaires, administered by Surveymonkey®. In round one, each participant received a short explanation of the objective of the study and a questionnaire consisting of an initial list of 15 attributes, informed by a literature review (Strachan, 2013), with seven questions, some in yes/no format and some requiring a comment (table 2). Care was taken to avoid leading words and the questionnaire was pre-tested by people outside the research team before it was issued.

Table 2 Delphi survey questions applied to the initial list of attributes

The experts' replies expanded the list of 15 initial attributes to 23 in round two, whereupon the adjusted list of attributes was administered again, using the same seven questions. In the third round, in response to the experts' suggestions the attributes were grouped based on the life cycle stage(s) – installation, operation and end of life - to which the attributes relate. Additionally, two attributes were merged, leading to the final list of 22 shown in table 3 with the working definitions given in table 4. Table 4 also identifies the attributes which were in the initial list. The definitions were finalized with the approval of the experts. Careful note of feedback was taken to ensure that all views were incorporated in the final list. Experts were given two weeks to reply to each round of questionnaires, in line with recommended practice (Hsu and Sandford, 2007).

Table 3 EPIM Assessment Attributes categorized according to their relevant life stage

Table 4 Agreed definitions of EPIM assessment attributes

Weighting of attributes

Having established an agreed set of attributes through a Delphi process their relative importance in the decision-making process must be established. MADM is a well-established method with many examples of applications to diverse fields (Pohekar and Ramachandran, 2004; Romero and Rehman (1987; Hajkowicz and Collins, 2007; Eckenrode, 1965). Of the many techniques for 'solving' a MADM problem, Hajkowicz and Collins (2007) conclude that no single technique is universally applicable. Among the available weighting methods are fixed point scoring, rating, ordinal ranking, graphical weighting and paired comparisons (Bartlett et al, 1960; Eckenrode, 1965; Hobbs, 1980; Hajkowicz et al, 2000). Since methods requiring participants to distribute points over several items are too demanding in their requirement to keep numerous items in consideration at the same time (Hajkowicz et al, 2000), the paired comparison method has the advantage of breaking the decision problem down into pairs: participants compare their relative importance in a systematic questionnaire. This simplification forces the participants to consider each attribute and its meaning within the set, preventing any attribute from being overlooked. The method is well-established in the

Analytic Heirarchy Process (Saaty, 1987) where decision makers are asked to express preference for one alternative over another in each pair. Using a nine-point Likert scale to achieve an appropriate level of discrimination for the assessment, the comparison may be unipolar, e.g. 1 to 9 (Saaty, 1990), or bipolar with a central point of equal importance, e.g. -4 to +4 (Hamilton et al, 2007). In order to compare all 22 attributes against every other attribute 231 pairs of comparisons were presented to each respondent (Table 5) – a lengthy questionnaire. The comparisons were presented in random order to minimize the negative impact of respondent fatigue. It demands a substantial time commitment from the participants to complete a paired comparison survey and in this case two experts withdrew between stages 1 and 2. The resulting panel of eleven exceeds the minimum of 10 required for statistical significance (Turoff, 1970) and the weightings presented below are therefore considered to be valid, but the small panel size does mean that this can be considered as only a preliminary study. Table 5 also shows how the ordinal scale was derived from the questionnaire response.

Table 5 Sample question taken from the paired comparison questionnaire showing the scores assigned under bipolar and unipolar assessment methods. The respondents were asked to consider attributes A and B and tick the appropriate box.

In view of its size, the questionnaire was administered on paper and posted to the experts. Experts were asked to reply in 28 days but this period grew because of the number of questions asked. Nevertheless the whole process was completed within the recommended 45 days (Hsu and Sandford, 2007).

The results of the paired comparison questionnaire were analysed in three ways:

(i) negative to positive bipolar ranked assessment

(ii) bipolar sum of differences, and

(iii) unipolar ranked assessment.

In the negative to positive bipolar ranked assessment, the 9 point scale essentially represents two opposing poles with a central point denoting equal importance. The scores obtained by an attribute in each comparison with the other 21 attributes are summed and the total score can therefore range from +84, denoting an overwhelmingly important attribute, to -84, denoting the reverse. In practice, most but not all of this range was used. In the bipolar sum of differences analysis, the attribute of lesser importance in each pair is scored zero instead of the negative value. This avoids over-emphasising the negative view of the less important attribute, and truncates the total score range to 0 to +84. The option of equal importance remains, with both attributes scoring zero. This analysis is considered to be the most appropriate for this investigation because it avoids over inflation of the negative view of the attribute considered to be less important (Hajkowitz et al, 2000). Finally, the unipolar ranked assessment ascribes one pole in each pair as being more important, and can be viewed as a less natural fit with the paired comparison approach, despite having been used in this way previously (Hamilton et al, 2007). In this case the total score can range from +21 to +189.

Results

The 22 agreed attributes listed in tables 3 and 4 are largely self-explanatory but some comments may be helpful. It can be seen from tables 3 and 4 that the attributes of each EPIM are framed in neutral terms, such as ‘impact on …’ or ‘level of …’, to avoid prejudicing the experts’ comparisons. However, since the objective of an EPIM is to save energy and reduce carbon emissions number 9 was framed explicitly as ‘potential energy / carbon savings’. The word ‘significant’ is included in number 4 (loss of fabric) because it discourages the user from being too cautious and rejecting a beneficial EPIM because of a loss of fabric that would not be considered important in heritage conservation terms. Some separate attributes were merged when it became obvious that, for example, payback period and financial savings are essentially equivalent, leading to attribute 10 ‘financial payback’, but are, however, unconnected with maintenance costs, thus retaining attribute 11 ‘change to maintenance costs’.

In each of the three analyses, the total score gained by each attribute was averaged over all the 11 experts, and the mean values normalised to enable them to be presented as weightings in percentages. Table 6 shows the resulting scores for each attribute, and it is clear, firstly, that the five top scoring attributes in each case are the same and appear in the same order. Secondly, eight of the attributes all score lowly but in a different order and, thirdly, the unipolar analysis gives a narrower distribution of values than the two bipolar methods.

Table 6 Comparison of weightings (%) of the three analyses

Figure 1 shows that the bipolar sum of differences method clearly groups the attributes into three broad weightings – a group of low importance assigned 2-3%, a group of medium importance assigned 4-5% and a group of high importance assigned 7-9%. Likewise the bipolar negative scoring method formed three groups with the same membership but with slightly different weightings ascribed to each attribute – 1-3%, 3-6% and 7-9% respectively. The unipolar ranked assessment produced a uniform distribution of scores from 3.6% to 5.7% with no clear grouping.

Figure 1 Attribute weightings obtained from the bipolar sum of differences analysis

Discussion

Attributes

Figure 1 shows that three attributes - capital cost, potential energy / carbon savings and financial payback - are assigned the highest importance within the set. Since the objective of any energy improvement measure is to save energy and reduce carbon emissions within a business context, it is not surprising that these are the top three attributes. It confirms the experts' pragmatic view that the typical user of the decision support tool is concerned with the financial impact of their decision on their organization. However, the fact that there are a further 19 attributes, together accounting for over 70% of the weighting scores, shows that they believe that decision making should be informed by much more than these three fundamental factors.

The prominence given to attribute 19 'impact on building's vapour permeability' is at first sight unexpected because this is a very technical attribute of an EPIM. It can be explained because it is key to the traditional form of construction that the survey has targeted. Traditional buildings are known to be more complex in the way in which the building fabric handles moisture, as compared to modern impermeable forms of construction (CIBSE, 2002; English Heritage, 2011; Historic Scotland, n.d.; STBA, 2012; Suhr and Hunt, 2013). Therefore, any EPIM that directly impacts the building fabric and how it interacts with the environment could have a detrimental effect upon the original building, as well as reducing the EPIM's performance, if it is not compatible with or not appropriately applied to the traditional construction form. One expert stated "...traditional buildings enable moisture to move through their fabric, get that wrong and you get an impervious building that gets damp and rotten quickly”. Therefore attribute 19 essentially represents the EPIM’s suitability for the construction form undergoing improvement. It is possible that opinions on attribute 19 might also be affected by the expert’s discipline but close scrutiny of figure 2 and table 1 reveals that there is no correlation between weightings and profession. It would be interesting to see how highly this attribute would have been weighted if the assessment attributes were designed to address an existing building of modern construction.

The contrast between the importance placed on the fabric and the services is quite marked. Attribute 17 ‘impact on existing building services’ is weighted lowly (position 19 in the rank order) whereas attributes 19 and 4 clearly relate to the effect of an EPIM on the building fabric, and are ranked in the top 6. This could again be due to the focus of this survey on traditional construction, and the more complex behaviour of the fabric than in modern construction.

Of the attributes with low weightings, numbers 3 and 12 concern the ease of installation and maintenance of the EPIM, respectively. An explanation for their low importance is that these works would most likely be carried out by external contractors and therefore the risks are passed on to them. Cost of disposal of the EPIM at the end of its life (attribute 20) is considered relevant but of low importance, perhaps because this is a cost to be borne in the future. Disruption to the occupants during installation (attribute 6) can be managed by working out of hours, and training the occupants in the use of the new systems (attribute 15) is possibly less important when handing over a refurbished traditional building than when first occupying a new low-energy building.

Experts

To assess the different perspectives of the experts, Figure 2 presents the mean weightings for each attribute for the different groups of experts, as defined in Table 1. The broadly similar profiles of each group suggests general agreement, which is to be expected considering their shared interest in the energy performance of buildings. However, two attributes have significantly divergent scores - number 4, loss of significant original building fabric, and number 19, impact on the building's vapour permeability / breathability. In both these cases the weightings range from about 2% to about 10% and these differences justify a closer examination of the reliability of the experts' responses to the paired comparison survey.

Figure 2 Comparison of attribute weightings assigned by the different expert groups

The intra-class correlation coefficient was calculated for a two-way random model using SPSS Statistic version 17.0 from which Cronbach's alpha was extracted as a measure of internal consistency. With all eleven experts included alpha is 0.662 and according to Antony et al (2007) a value of >0.6 is acceptable but 0.7 is desirable: this value suggests that the results are internally consistent. Closer scrutiny of the responses identified two experts with the most widely divergent views. Expert eight is a senior technical officer within the heritage sector of the construction industry whose views would reflect an intimate knowledge of traditional buildings. By contrast, expert eleven is an industry professional from outside the heritage sector, who is involved in research around the interaction between occupants and building energy performance, and this suggests less experience of traditional buildings. If experts eight and eleven are excluded Cronbach's alpha increases to 0.705. These differences and the observation that their opinions on eight out of 22 attributes agree very closely suggests that these two experts represent merely the extreme ends of the group, one favouring heritage-related attributes and one not.

Considering the expert group as a whole, whilst everyone weighted capital cost, financial payback, potential energy savings and impact on the vapour permeability of the building fabric highly, those with a heritage focus also weighted loss of significant fabric (attribute 4) and impact on appearance (attribute 7) highly. In Delphi round 1 the panel insisted that these two attributes should be included separately, with one expert stating "Some improvement measures may have a low visual impact but require substantial removal of a building's original fabric. Where this is significant, it should be factored into the decision making". In fact, attribute 7 being weighted two places below attribute 4 suggests that the experts view the physical impact of an EPIM as slightly more important than the visual impact. Reliability of the EPIM was weighted the same but less highly by all experts. Finally, experts with a client focus weighted internal comfort, existing services and impact on internal air movement more highly than other expert groups.

Policy significance

Despite the small sample size, there is a clear policy significance arising from this preliminary study. A panel of industry experts has identified 22 attributes to be considered in making the choice of an EPIM. This means that policies incentivising or focusing on a single (or a restricted range of) attribute(s) – such as boiler replacement or subsidies for particular technologies through incentives for renewable heat - are less likely to deliver the desired improvements in energy performance without unintended consequences. A wide range of unintended consequences of the energy-led refurbishment of UK housing have been identified (Shrubsole et al, 2014) and some of these – effects on occupant health and well-being, on the building fabric and on the environment – are equally applicable to the non-domestic stock. Decision-takers and policy-makers need to be aware that the top three attributes – capital cost, potential energy / carbon savings and financial payback – account for only about 30% of the overall value of the decision and that the remaining 70% is spread over 19 other attributes. This reinforces the views of Roberts (2008) and Fyhn and Solli (2012) that EPIMs and the energy-led refurbishment of buildings must be considered holistically.

Conclusions

Decision-makers, who are faced with the challenge of energy-led refurbishment of traditionally constructed non-domestic buildings in order to meet targets set by regulations or corporate policies, have to employ multiple attribute decision making in order to prioritise different energy performance improvement measures. As a contribution to the decisioin-making process, this work elicited the views of expert professionals to identify and prioritise 22 attributes of energy performance improvement measures that need to be considered in the process. These 22 attributes cover the installation, operation and disposal stages of the life cycle. A pairwise comparison questionnaire using a panel of 11 experts revealed weightings of the relative importance of each attribute, and this can be used by decision-makers to score the refurbishment options in terms of appropriateness to their own building. The top three attributes – capital cost, potential energy / carbon savings and financial payback – contribute only 30% of the decision's weight, with the remaining 70% spread among 19 other attributes.

Whilst the expert survey is statistically valid, a larger group would have been preferable and the conclusions must be regarded as preliminary. However, the fact that so many attributes are considered to be important confirms that energy-led refurbishment must be dealt with holistically and, further, suggests that policies targeting key attributes may give rise to unintended consequences. Further work should investigate how the relative weightings vary between expert groups with different.

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List of tables

Table 1 Experts' knowledge resource categorization

Number	Position	Organisation	Category				
			Client	Guidance	Heritage	Industry	Non-heritage
1	Environment Officer	City Council		X			X
2	Energy Manager	Government Executive Agency	X	X	X		
3	Senior Building Surveyor	Engineering Consultancy				X	X
4	Senior Project Manager	Conservation Charity			X	X	
5	Project Manager	Project Management Consultancy				X	X
6	Sustainability Consultant	Project Management Consultancy				X	X
7	Associate Director	Engineering Consultancy			X	X	
8	Senior Technical Officer	Government Executive Agency		X	X		
9	Energy and Sustainability Manager	Financial Services Company	X				X
10	Sustainable Development Manager	Government Body	X				X
11	Principal Sustainability Consultant	Architecture Consultancy		X		X	X
12	Property and Services Coordinator	Government Body	X				X
13	Architect	Architecture Consultancy				X	X

Table 2 Delphi survey questions applied to the initial list of attributes

Number	Question	Response format
1	In your opinion, does the list contain sufficient attributes to assess the suitability of an Energy Performance Improvement Measure?	Yes/No
2	Are there any attributes that should be added to the above list?	Yes/No
3	If yes, then please describe what additional attributes should be added.	Comment box
4	If yes, then please explain why these additional attributes should be added.	Comment box
5	Are there any assessment attributes that should be omitted from the above list?	Yes/No
6	If yes, then please describe what attributes should be omitted.	Comment box
7	If yes, then please explain why these attributes should be omitted.	Comment box

Table 3 EPIM attributes categorized according to their relevant life stage

Energy Performance Improvement Measure (EPIM) Attributes					
Attribute result realised in the short term (beginning of EPIM's useful life)		Attribute result realised in the long term (i.e. during / end of EPIM's useful life)			
EPIM Installation		EPIM Operation		EPIM Disposal	
1	Capital cost	9	Potential energy/carbon savings	20	Disposal cost of EPIM at end of useful life
2	Availability of grants, tax allowances and other financial incentives	10	Financial payback		
3	Ease of installation of EPIM	11	Change to maintenance costs		
4	Loss of significant, original building fabric	12	Ease of maintenance of EPIM		
5	Requirement of planning and/or building control approvals	13	Reliability of EPIM's performance		
6	Level of disruption to building occupants during works	14	Degradation of EPIM's performance		
7	Impact on building's appearance	15	Training building occupants in the use of new system(s)		
8	Impact on building's internal space/layout	16	Level of improvement in building occupants' comfort		
		17	Impact on existing building services		
		18	Impact on building's internal air movement/ ventilation		
		19	Impact on building's vapour permeability/ breathability		
21	Embodied energy/carbon of EPIM				
22	Environmental impact of EPIM				

Table 4 Agreed definitions of EPIM attributes

No.	Attribute	Definition
1*	Capital cost	Initial cost incurred to purchase the EPIM, including all associated transport, labour and materials.
2	Availability of grants, tax allowances and other financial incentives	The availability of financial incentives for the implementation of particular EPIM's.
3*	Ease of installation of EPIM	Also known as 'buildability'. The level of difficulty associated with the installation of an EPIM, including ease of transport to and movement on site.
4	Loss of significant original building fabric	Some EPIM's installation will have a low visual impact but may result in loss of significant, original building fabric.
5*	Requirement of planning and/or building control approvals	The likelihood of requiring some form of formal approval for the installation of an EPIM, including Listed Building Consent where applicable.
6*	Level of disruption to building occupants during works	The level of disruption caused by the installation of an EPIM on the building occupants' working environment, and consequently their productivity.
7*	Impact on building's appearance	The impact the installation of an EPIM will have upon a building's appearance, both externally and internally.
8	Impact on building's internal space/layout	The installation of some EPIM's could impact upon the gross internal floor area or the internal layout of the building.
9*	Potential energy/carbon savings	A quantitative measure of the energy savings and associated carbon emission savings of installing an EPIM.
10*	Financial payback	A measure of the time required to recover the initial cost invested.
11*	Change to maintenance costs	A potential increase or decrease in the building user's maintenance budget due to the installation of an EPIM.
12	Ease of maintenance of EPIM	The level of difficulty associated with the maintenance of an EPIM and any associated equipment or materials. Including the availability of spare parts over the lifetime of the EPIM.
13*	Reliability of EPIM's performance	The reliability of an EPIM's performance. Risk of failure in meeting predicted energy savings, as well as any other performance attributes.
14	Degradation of EPIM's performance	The potential year on year reduction in the EPIM's ability to deliver energy savings.
15*	Training building occupants in the use of new system(s) post refurbishment	The level of training and regular re-training required of building occupants to ensure the EPIM is operated at its maximum efficiency.
16*	Level of improvement in building occupants' comfort	The level of improvement in indoor environmental quality due to EPIM installation, consequently improving the building occupants' comfort levels and potentially, worker productivity.
17	Impact on existing building services	The impact the EPIM's installation will have upon the existing building services (BS), including building fabric improvements, as these will change the internal environment and how it interacts with the BS. Some BS-related EPIM's can have a negative impact on the existing plant and its maintenance, and this must be considered.

18	Impact on building's internal air movement/ventilation	The impact of the EPIM's installation on how the existing building deals with air movement. A negative impact could lead to serious air quality and condensation issues. Also, whether changes to the building's ventilation strategy need to be considered as a result of this EPIM.
19	Impact on building's vapour permeability/'breathability	A qualitative measure of the impact an EPIM's installation has on the building fabric and how it interacts with moisture. Whether or not that EPIM is compatible with the existing construction form.
20	Disposal cost of EPIM at end of useful life	The financial cost of removing and disposing of the EPIM and any associated parts at the end of their useful life.
21	Embodied energy/carbon of EPIM	The total energy/carbon inputs required to manufacture an EPIM and its associated materials, from extraction of raw materials to reuse/recycle/disposal. This also covers the issue of EPIM availability, in terms of the energy/carbon cost of sourcing and transport.
22	Environmental impact of EPIM	The level of pollutants/environmental cost accumulated in the manufacture of an EPIM and its associated materials, from extraction of raw materials to reuse/recycle/disposal.

*denotes one of the initial attributes but note that attributes 9 and 21 were formed from the merger of three and two attributes respectively in the initial list of 15.

Table 5 Sample question taken from the paired comparison questionnaire showing the scores assigned under bipolar and unipolar assessment methods. The respondents were asked to consider attributes A and B and tick the appropriate box.

		Very strongly more important	Strongly more important	Moderately more important	Slightly more important	Equally important	Slightly less important	Moderately less important	Strongly less important	Very strongly less important	
	Attribute A	☐	☐	☐	☐	☐	☐	☐	☐	☐	Attribute B
Bipolar scoring		+4	+3	+2	+1	0	-1	-2	-3	-4	
Unipolar scoring		9	8	7	6	5	4	3	2	1	

Table 5 Comparison of weightings (%) of the three analyses

Number	**Attribute**	**Bipolar negative**	**Bipolar sum of differences**	**Unipolar**
1	Capital cost	9.03	9.30	5.66
2	Availability of grant, etc	3.61	3.64	4.31
3	Ease of installation	2.50	2.42	4.04
4	Loss of significant building fabric	5.21	5.35	4.71
5	Requires planning approvals	1.83	2.56	3.87
6	Level of disruption to occupants	2.27	2.82	3.98
7	Impact on appearance	4.80	4.93	4.61
8	Impact on internal layout /space	4.93	5.22	4.64
9	Potential energy savings	8.79	8.77	5.60
10	Financial payback	8.31	8.22	5.48
11	Change in maintenance costs	2.86	2.87	4.13
12	Ease of maintenance of EPIM	2.53	2.27	4.05
13	Reliability of EPIM	5.67	4.85	4.82
14	Degradation of EPIM	4.48	3.77	4.53
15	Training of occupants in new systems	0.95	2.82	3.66
16	Level of improvement in comfort	4.55	4.48	4.55
17	Impact on existing building services	2.89	2.48	4.14
18	Impact on internal air movement	6.09	5.45	4.93
19	Impact on vapour permeability	7.49	7.19	5.27
20	Disposal cost of EPIM	2.00	2.08	3.92
21	Embodied energy of EPIM	4.32	4.22	4.49
22	Environmental impact of EPIM	4.90	4.30	4.63
	Total	100.00	100.00	100.00

Figure captions

Figure 1 Attribute weightings obtained from the bipolar sum of differences analysis

Figure 2 Comparison of attribute weightings assigned by the different expert groups

Figure 1

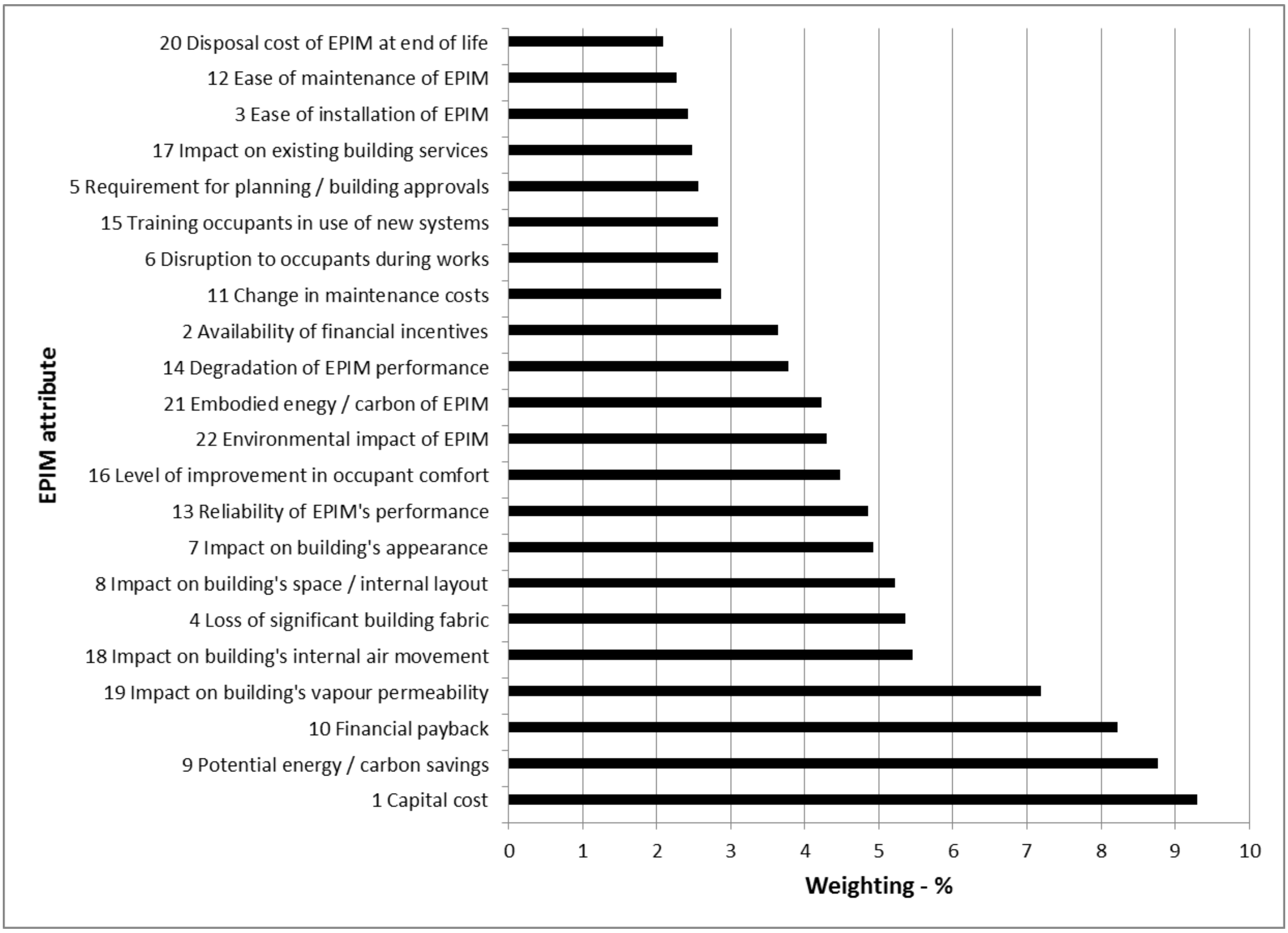
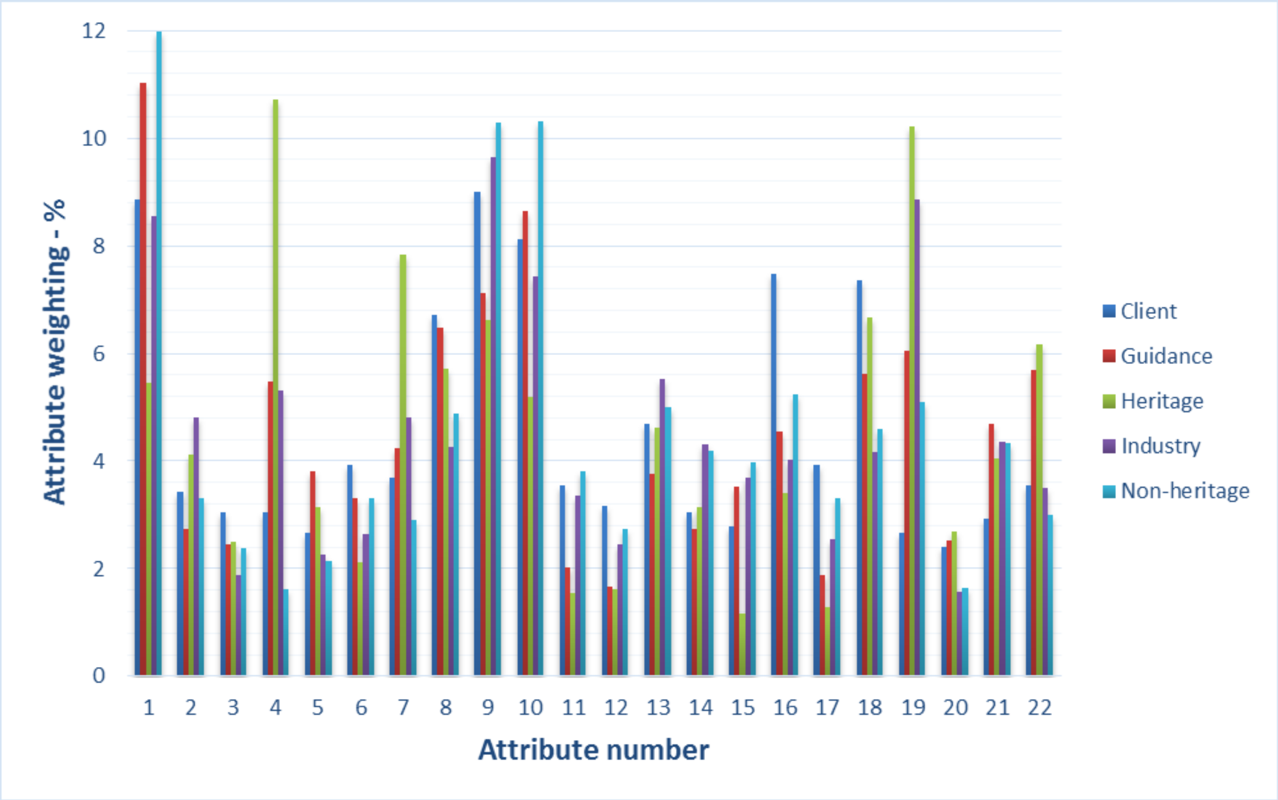

20 Disposal cost of EPIM at end of life
12 Ease of maintenance of EPIM
3 Ease of installation of EPIM
17 Impact on existing building services
5 Requirement for planning / building approvals
15 Training occupants in use of new systems
6 Disruption to occupants during works
11 Change in maintenance costs
2 Availability of financial incentives
14 Degradation of EPIM performance
21 Embodied enegy / carbon of EPIM
22 Environmental impact of EPIM
16 Level of improvement in occupant comfort
13 Reliability of EPIM's performance
7 Impact on building's appearance
8 Impact on building's space / internal layout
4 Loss of significant building fabric
18 Impact on building's internal air movement
19 Impact on building's vapour permeability
10 Financial payback
9 Potential energy / carbon savings
1 Capital cost
EPIM attribute
0
1
2
3
4
5
6
7
8
9
10
Weighting - %

Figure 2



12
10
8
6
4
2
0
Attribute weighting - %
1
2
3
4
5
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7
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12
13
14
15
16
17
18
19
20
21
22
Attribute number
Client
Guidance
Heritage
Industry
Non-heritage