Criteria weighting for green technology selection as part of retrofit decision making process for existing non-domestic buildings

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Abstract: The implementation of green technologies, as part of retrofit, can significantly improve building performance. However, green technology selection is a complex decision making process due to multiple evaluation criteria and often conflicting interests of different stakeholders involved. This paper proposes default criteria weights based for previously-developed criteria tree consisting of in total 39 criteria organised around environmental, economic, social and technical performance of green technologies. Web-based surveys of experts including architects, engineers, planners in the UK and China were conducted to capture expert opinions on sustainability and technical criteria. Analytical Hierarchy Process (AHP) method was used to calculate default criteria weights. Comparisons between expert groups in different countries were also performed. Results show that UK experts more concern about *Economic* performance of green technology, specifically with UK architects and engineers assigning high weights on *Cost*. For the *Environmental* category, *Reduction of energy consumption* and *Reduction of water consumption* are ranked as the most important topics under *In-use environmental performance* by all experts. UK experts have shown a growing concern on *Reduction of water consumption*. Under *The improvement of indoor environmental quality*, *Thermal comfort* is ranked as the most important criterion by UK experts and *Visual comfort* is weighted as the first priority by Chinese experts. Compared with UK experts, Chinese experts have placed a significant importance on *Technical* criteria, represented by engineer group emphasising on *Durability* for this category.

Keywords: Non-domestic building retrofit; Decision making process; Criteria weighting; Analytical Hierarchy Process (AHP) method

1. Introduction

With increased awareness of environmental pollution, natural resource depletion and social issues, sustainable development has become a growing concern throughout the world [1]. At the same time, buildings have been identified as one of the heaviest consumers of natural resources, accounting for 40% of global energy use, 30% of energy-related GHG emissions, approximately 12% of water use and nearly 40% of waste [2]. For buildings to be more environmental friendly, there is a need to reduce energy and water consumption during operation and take advantage of recycling opportunities at the end of the building life cycle [3].

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Apart from environment, buildings can affect occupant productivity and business profitability [4] as well as human wellbeing and community engagement [5].

Building performance can incorporate performance in Energy Efficiency, Water Efficiency, Indoor Enviromental Quality and health and wellbeing[6]. Whilst improvement in environmental performance of new buildings is primarily driven through legislative efforts, existing buildings often require retrofits to improve their environmental or sustainable performance. Environmental, economic, social and technical implications of building retrofits have been investigated through several studies [7-9]. Green technologies such as efficient lighting, PV panels and monitoring systems have proved to improve the building performance to a certain level. [10,11]

The findings indicate that existing building retrofits can offer significant opportunities for improving overall sustainability performance [12-15]. Despite the fact that improved performance through building retrofits was demonstrated for non-domestic buildings [16,17], research on domestic building stock is still dominant.

There is a wide range of green technologies readily available for retrofit projects. However, the decision as to which green technology should be selected is a complex decision making process subjective to several technological alternatives, multiple decision criteria and different stakeholder perspectives [18-20]. Whilst ultimate goals of sustainable development can be considered universal, the sustainable construction has different approaches and different priorities in different countries[18] and the refurbishment part of construction industry is not the exception. In addition to economic and social differences number of other variables and their importance vary from country to country. Agenda 21 on sustainable construction [22] fully recognised that activities within the construction sector driven by sustainable development agenda will be effected by local constructs such as professional practice, nature of building stock, level of industrial development.

Moreover, the stakeholders from different backgrounds may have contrasting opinions which can influence the final decision [20,23]. Multi-Criteria Decision Making (MCDM) methods have been successfully used in selecting green technologies for buildings [20,24]. The MCDM decision-making process consists of four steps: criteria development, criteria weighting, alternatives scoring and results synthesis. Criteria weighting is one of the crucial steps allowing a trade-off between multiple decision criteria and a balance between different stakeholder perspectives [23,25]. As criteria weights can directly influence the ranking order of alternatives and the final results [18], defining them whilst taking into account different stakeholder perspectives is essential.

This paper aims at providing default criteria weights for previously developed decision criteria for green technology selection in non-domestic building retrofits [26]. The default criteria weights would correspond to general preferences of relevant built environment professionals involved in retrofit projects operating in two distinctly different national contexts: UK and China. The research mainly adopts a survey approach to collect expert opinions from UK and China. The Analytical Hierarchy Process (AHP) method is used to calculate criteria weights for expert groups at each national level as well as for different professional backgrounds (architects, engineers, etc.) and comparison between groups is performed. The paper is organised as: Section 2 presents a review of weighting methods and existing research. Section 3 describes the research methodology. Section 4 presents criteria weights results for all experts surveyed as well as for different professional background (architect group and engineer group) and national groups (UK and China) and summarises the results and states the research limitations. Section 5 concludes with main findings.

2. Approaches to criteria weighting

Weighting methods are classified into equal weighting and rank-order weighting [27]. In equal weighting, criteria weights are equally assigned and weighted with the average value of one, which does not require stakeholder preferences. In rank-order weighting, criteria weights are distributed and influenced by stakeholder perspectives. Rank-order weighting methods include objective weighting method, subjective weighting method and combination weighting method [18]. Objective weighting method is characterised by mathematical models, complex calculation process and intensive data requirement [28] and is not often used [29]. Subjective weighting method relies on informing criteria weights directly from stakeholders by interviewing or questionnaire. Combination weighting method is used to balance merits and limitations of objective and subjective weighting methods, but the process is complex and not widely-used [18].

Current research has seen a wide use of subjective weighting methods. Typical subjective weighting methods include Simple Multi-Attribute Rating Technique (SMART), Swing method and Pair-wise comparison methods. In SMART, decision makers assign 10 points to the least important criteria and then add points up to 100 when the importance increases [30]. Swing method is to ask decision makers to assign 100 points to the criteria with the highest expectation for significant improvements. Fewer points are then given to the next alternative. Pair-wise comparison method is comparing the importance between two criteria [31]. The analytic hierarchy process (AHP) is one of pair-wise comparison methods which uses a 9 point scale to compare criteria relative importance. Since individual judgements can never agree perfectly, the degree of consistency achieved in the pairwise comparison is measured by the consistency ratio [32]. Saaty [33] advocates the use of consensus by voting to reach at a common pairwise comparison matrix or by aggregating individual judgments using the geometric mean of individual pairwise comparison matrix. The former approach is applicable when the members can meet as a group. The latter one can be used when group meeting is not applicable [34].

Chen *et al*. [35] used industry wide survey to determine the relative importance of 33 proposed sustainable performance criteria for construction method selection in concrete buildings. The survey has been designed to collect perceptions of experienced practitioners on the importance of the proposed criteria. A scale of 1-5 (where 1 is ‘least important’ and 5 ‘extremely important’) was used for criteria weighting. The 5 point scale was used by Menassa and Baer [36] who developed a model to synthesise stakeholder opinions and determine the technical importance of retrofit measures against stakeholder requirements. They proposed 30 potential stakeholder requirements as decision criteria and the importance of them is suggested to be measured on a scale of 1 to 5 (from “not important” to “extremely important”).

Pan *et al*. [19] proposed the decision criteria for building system selection in housing and quantified their relative importance. Decision criteria are initially compiled through literature review and confirmed with relevant stakeholders through semi-structured interviews. Criteria weighting was then determined during the one-day workshop. Several weighting techniques including direct rating, the point allocation, and AHP were provided to the workshop attendees for flexible use.

Zainab *et al*. [23] investigated decision criteria and their weights for the selection of sustainable technologies for retail buildings retrofits from the perspective of different stakeholders involved. A two-stage approach was adopted: the initial stage was to identify decision criteria with stakeholders using semi-structured interviews; the second stage was to invite stakeholders to complete AHP questionnaires during a one-day workshop, where the method and the importance of consistent judgement was explained to participants.

Banville *et al.*[37] described a stakeholder as everyone with a vested interest in a problem that can either affect, be affected by or is both being affected by and affecting the problem. In the context of green technology selection, stakeholders can have different backgrounds: architecture, design, engineering, planning, management, economy. Rey [38] proposed a multi-criteria assessment methodology for existing building retrofits, which simultaneously takes environmental, social, and economic criteria into account to support the decision making process. The author emphasised that varying stakeholder opinions have a great importance in the selection of the most suitable retrofit strategy, and collaboration between stakeholders is required. Several studies indicate that conflicting stakeholder perspectives are the main barrier in the decision making of sustainable retrofits [39,40].

Apart from professional backgrounds, criteria weighting can also be influenced by local or national contexts. Relevant research can be found for criteria development for different countries but they have not focused enough on rank-order weighting. For instance, Huang *et al.* [41] has found that in China, at the national level, green technology selection mainly emphasised microeconomic efficiency and contribution to industrial development under *Economy* criteria; GHG emission reduction, contribution to the industrial development and land resources under *Environment and Energy* criteria; employment generation and technology safety under *Society* criteria. The equal weighting method was used in this research when integrating technology performance scores. The importance of regional or national context was also identified within wider debate about green building performance assessment process [42]. Whilst sustainability criteria are universally relevant, a variation in relative importance of the criteria is context dependent. And that relevant importance is reflected through weighting systems.

3. Research design

Previous Chapter demonstrated that criteria weighting is an important step in decision making process; from those dealing with construction methods choice, building systems or sustainable technology selection. Whilst decision criteria are usually compiled through literature review and in addition may be verified with stakeholders in interviews or workshops [19,36], criteria weighting can be conducted by interviews, workshops or questionnaires.

Direct weighting or pairwise comparison weighting with AHP method, although commonly applied [19,23] is still limited in the field of green technology selection for non-domestic building retrofits. As this research aims to collect general preferences from industry professionals towards multiple criteria regarding green technology selection in building retrofits at two different national locations, a web-based survey was deployed. The survey is built upon an already-proposed criteria tree [26]. This criteria tree consists of economic, environmental, social and technical criteria (see Figure 1) which are organised from general criteria to specific sub-criteria and some of which are quantitative whilst other are qualitative. The industry wide survey and subsequent statistical analysis of the survey data lead to a development of default weights for these criteria.

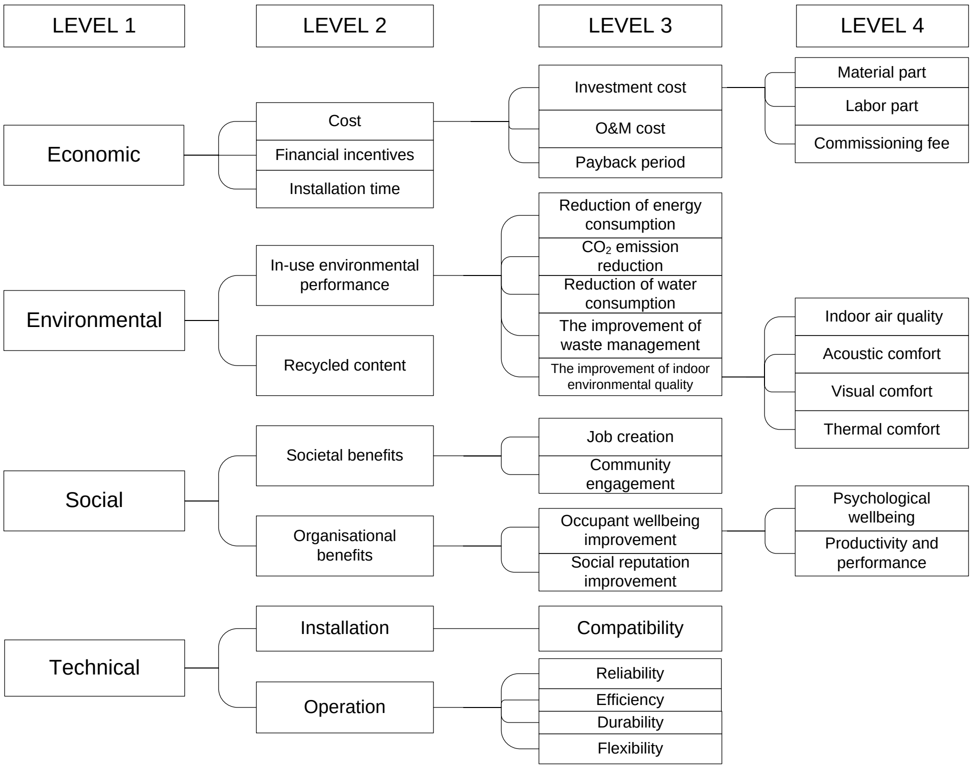


Figure 1 Integrated AHP hierarchy with multiple criteria [26]

The survey design in general includes four steps: survey sampling, question design, pilot survey and final survey. The nature of research implied the need for purposive sampling where participants are chosen base on their professional experience in non-domestic building retrofit projects. In order to ensure inclusion of relevant participants as well as a diversity within targeted population a multi-stage sampling method is adopted. Figure 2 illustrates the multi-stage sampling strategy: step 1) to identify professional groups in the field of built environment; step 2) to determine expert groups who have working experience in the building retrofit; step 3) to select individual experts to be the final sample.

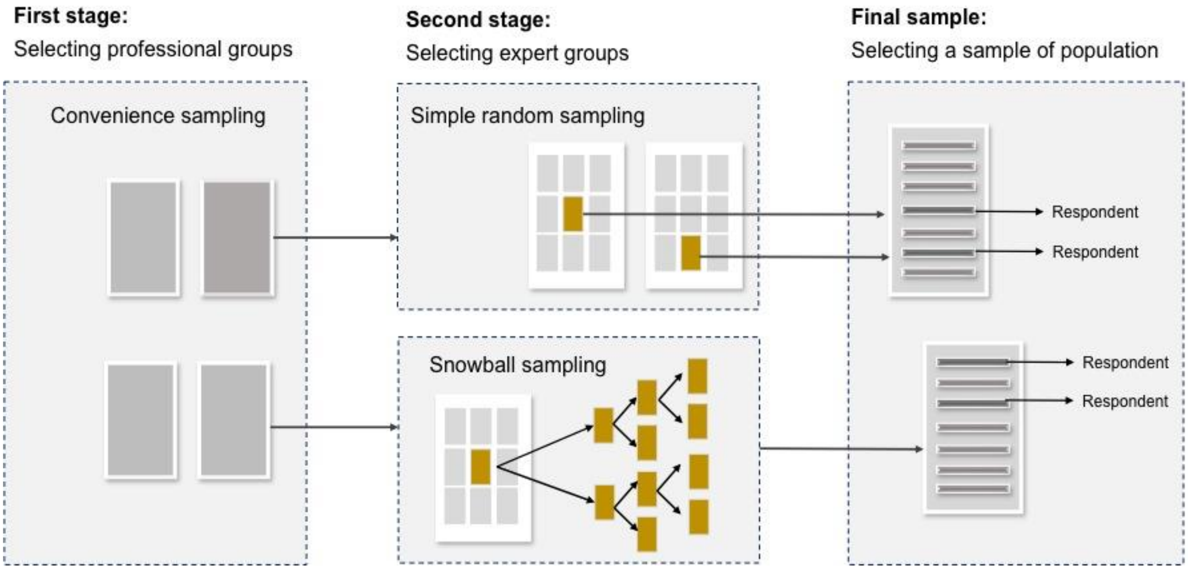


Figure 2 Multi-stage sampling strategy (adapted from [43])

Targeted professional groups at Stage 1 are listed in Table 1. In the second stage, two sampling methods are applied: Simple random sampling method and Snowball sampling method [44,45] in order to maximise the reach. The response rate is not easy to calculate because the size of expert groups cannot be calculated.

Table 1 Targeted professional groups

Country	Professional groups
UK	MSc Environmental design and Engineering alumni community
	Industry corporation intranet
	LinkedIn Connections
	Total
China	Institutes of Architectural Design personal connection
	Industry corporation intranet
	Higher Education personal connection
	Total

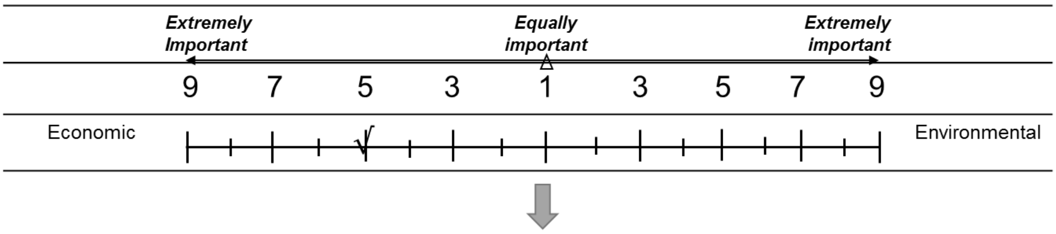
The survey questions have been divided into three groups:

1. Respondents' relevant professional experience;
2. Further criteria development;
3. Criteria weighting for existing criteria.

Open-format question is used to collect the suggestion for further criteria tree development as below: "Is there any criterion you want to add? If so, please also indicate its parent criterion on the existing tree. [For example: Environmental (Ecosystem impacts)]" However as the analysis of received responses go beyond the aim of this paper they are not featuring in the analysis of the results. The full set of responses to this group of questions can be found in [46].

The third group of questions which aims to inform criteria weighting is based on a 1-9 scale developed by Saaty [32]. The clarity of scale design is important for survey respondents who are not familiar with the AHP method to comprehend the principle. The purpose of the scale is to show the relative importance of the criteria immediately, which enables the respondents to provide their opinions directly instead of spending time on figuring out the meanings of scale values. Figure 3 illustrates the design of criteria weighting question.

The way the scale is used is demonstrated below for the example of comparing the relative importance of Economic and Environmental criteria.



A vs B	A is more important than B					B is more important than A			
	Extremely more important	Very strongly more important	Strongly more important	Moderately more important	Equally important	Moderately more important	Strongly more important	Very strongly more important	Extremely more important
	A>>>>B	A>>>B	A>>B	A>B	A=B	A<B	A<<B	A<<<B	A<<<<B
[A] Economic/ [B]Environmental	○	○	⊙	○	○	○	○	○	○

Figure 3 An example of criteria weighting question

The survey is initially designed in a paper version and tested within a group of 10 researchers working at UCL's Institute of Environmental Design and Engineering. Three feedback questions were individually asked when they returned the survey:

1. How long did it take you to complete the survey?
2. Did you find any questions ambiguous or difficult to answer?
3. Is there any difficulty to understand the method doing criteria weighting?

All the participants in the the pilot study thought that questions are well developed and generally easy to understand, but a total of 43 pairwise comparisons might take a long time to answer and thus affect the number of returns. They suggested that clear and concise explanation of technical criteria in the criteria tree is provided.

Based on the feedback, the survey has been improved by providing definitions for technical criteria of compatibility and flexibility. The full survey can be found in [46]. The paper version survey is then designed into formal web-based survey using survey design tools. Google form is used for English version, and the survey design tool called "Sojump" is used for the Chinese version. Survey links are generated and sent to professional groups listed in Table 1.

The data collection took approximately two months for each country. For the UK, the survey circulation and data collection were conducted from November-2015 to January-2016. For China, this was from January-2016 to February-2016. All the data collected was organised in the format of Excel sheet for further statistical analysis.

Descriptive analysis methods are used to analyse sample characteristics. Criteria weights are calculated in three steps:

1) composition of matrices of pairwise comparison (MPC);
2) consistency checking for MPC;
3) criteria weights derivation using AHP method [47].

This 3-step process is applied to each criteria weighting question and all expert groups. The geometric mean of individuals' judgements is used for criteria weights calculation for different expert groups. Aczel and Saaty [48] have shown that the geometric mean is uniquely appropriate for combining individual judgements because of its preservation of the property of the judgement matrix.

4. Results

4.1 Respondents' professional experience

After circulating the survey link to targeted professional groups, a total of 54 valid responses were received, 25 from the UK and 29 from China. As sample size is relevant only when research goal is to provide estimates or statistically significant discriminatory variable, the obitaned sample size can be described as being within the acceptable range[49].

The responses in relation to their professional background indicate that the engineering background was dominant for both UK (48.6%) and China (41.4%) professionals followed by architecture abckground (42.9% in the UK and 31% in China) . UK respondents who selected "others" background (8.6%) are mainly from ecology and environmental consultancy. In addition to architectural background, 13.8% of Chinese respondents have planning background and 6.9% design background. Chinese respondents who selected "Others" background (6.9%) are from safety assessment.

Figure 4 shows respondents' s expertise distribution. The dominant groups are those with the expertise in structure engineering and façade engineering for both Chinese and UK expert groups.

Based on the collected survey responses, 86% of survey respondents have more than 3 years of working experience in built environment and the majority had been involved in several retrofit projects [46].

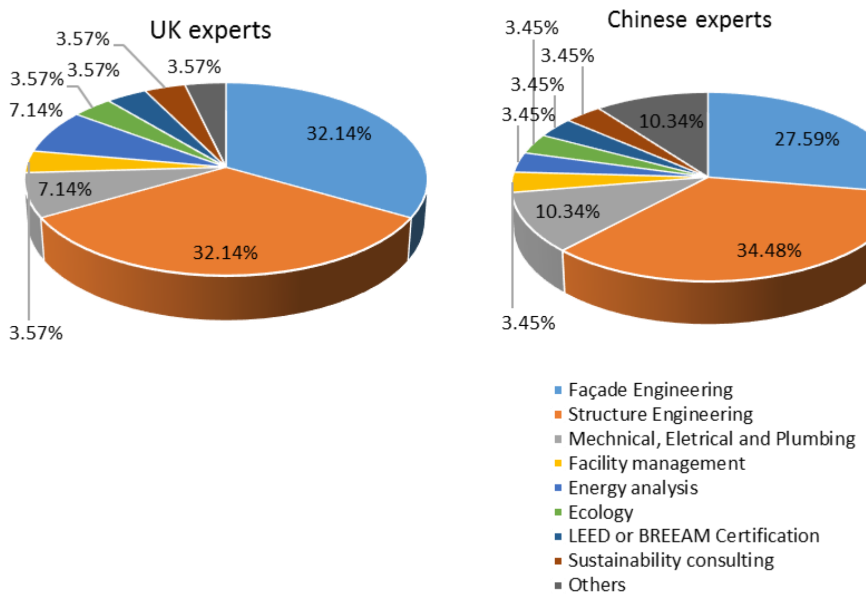


Figure 4 The expertise distribution of the survey respondents

Table 2 presents the difference between the most frequent client requirements in the UK and China. The most frequent client requirements in the UK are “to reduce the operational cost”, “to improve energy performance” and “to increase asset value”. In China, the most frequent client requirements are “to improve building safety and security”, “to reduce operational cost” and “to improve occupant well-being”.

Table 2 Comparison of the the most frequent client requirements in the UK and China

Client requirements	UK	China
To reduce operational cost	62.90%	48.48%
To increase asset value	42.90%	12.12%
To improve energy performance	60.00%	30.30%
To improve water efficiency	20.00%	9.09%
To improve occupant wellbeing	31.40%	42.42%
To improve building durability	20.00%	18.18%
To conserve fabric (heritage building)	28.60%	21.21%
To improve building safety & security	8.60%	48.48%
To improve corporate sustainability	17.10%	18.18%
Others	14.30%	6.06%

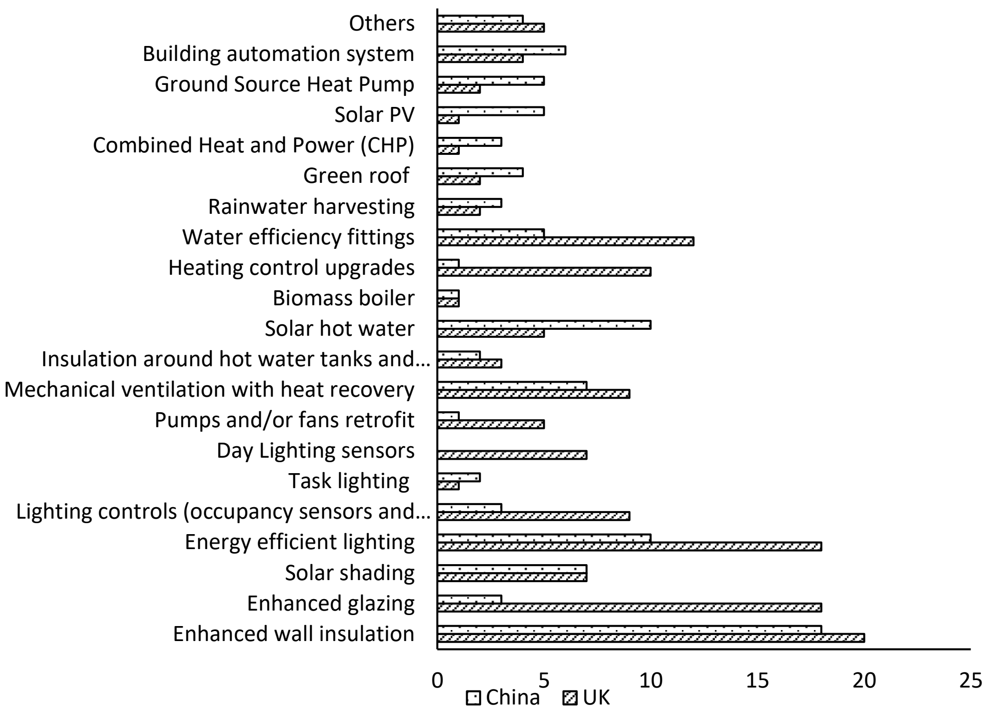


Figure 5 Comparison of the most commonly-used green technologies from the UK and China

The results presented in Figure 5 show that in the UK, the most commonly used green technologies in retrofit projects are Energy efficient lighting, Enhanced wall insulation, and Enhanced glazing. In China, the most commonly used green technologies are Enhanced wall insulation, Energy efficient lighting and Solar hot water. The results also indicate that control technologies such as Heating control upgrades, Daylighting sensors, Pumps and/or fans retrofit and Water efficiency fittings are not frequently used in the retrofit projects in both UK or China. However, the Building automation system has been given considerable attention during retrofit projects in China.

4.2 Criteria weighting group of questions

The respondents were first asked to rank the importance of all Level 1 criteria: environmental, economic, social and technical (see Figure 1). They were then asked to rank criteria at the next level within each individual group. For example, at Level 2 *Economic* criterion, experts were asked to rank the criteria of *Cost*, *Financial incentives* and *Installation time*. The same process was repeated for all levels of the existing criteria tree. All responses received were tested for consistency. For example, if *Economic* is weighed more important than *Environmental*, and *Environmental* is weighed more important than *Social*, then if *Economic* is preferable over *Social* the judgment is considered to be consistent. Instead, if *Social* is weighed more important than *Economic*, the judgement is inconsistent. Results of all the Matrices of Pairwise Comparison (MPC) that passed consistency checking are listed in Appendix A. The number of MPC for each level that passed consistency checking is listed in Table A.1. The consistency ratio is listed in Table A.2. Group weighting values for decision criteria at Level 1 and 2 are presented in Table 3. The default weights for all levels of criteria are shown in Appendix B.

Table 3 Group weighting values given by the UK and Chinese groups for Level 1 and 2 of criteria tree

Criteria	Sub-criteria	UK			China		
		All	Architects	Engineers	All	Architects	Engineers
Level 1	Economic	0.296	0.173	0.326	0.190	0.250*	0.189
	Environmental	0.279	0.303	0.289	0.290	0.250*	0.282
	Social	0.185	0.303	0.152	0.181	0.250*	0.248
	Technical	0.240	0.220	0.234	0.338	0.250*	0.282
Level 2 (Economic)	Cost	0.465	0.405	0.504	0.467	0.515*	0.333
	Financial incentives	0.304	0.405	0.234	0.226	0.097*	0.333
	Installation time	0.231	0.189	0.262	0.306	0.388*	0.333
Level 2 (Environmental)	In-use environmental performance	0.665	0.646	0.670	0.577	0.539	0.590
	Recycled content	0.335	0.354	0.330	0.423	0.461	0.410
Level 2 (Social)	Societal benefits	0.521	0.545	0.534	0.543	0.567	0.528
	Organisational benefits	0.479	0.455	0.466	0.457	0.433	0.472
Level 2 (Technical)	Installation	0.475	0.452	0.506	0.525	0.580	0.516
	Operation	0.525	0.548	0.494	0.475	0.420	0.484

* Singular response that has passed the consistency checking.

When criteria weighting is conducted in semi-interviews or workshop, consistent judgements from participants can be easier to manage [19,23]. When the criteria weighting is conducted through Expert Choice, a software professionally designed for AHP method, a reminder of inconsistency can be triggered. The number of MPC that can pass consistency checking may be adjusted when using a different CR threshold value. In this study, we adopted a standard CR threshold value of 0.10 which has been widely used as a measure of the consistency checking of AHP applications in literature.

4.3 Criteria weights comparison

4.3.1 Criteria weighting within the individual country

As demonstrated in the Introduction, criteria weighting can be influenced by stakeholder perspectives. In this section a comparison of criteria weights by levels between expert groups within each country was performed. The default weights for Level 1 criteria in relation to a stakeholder background is presented in Figure 6 for the UK and Chinese experts respectively.

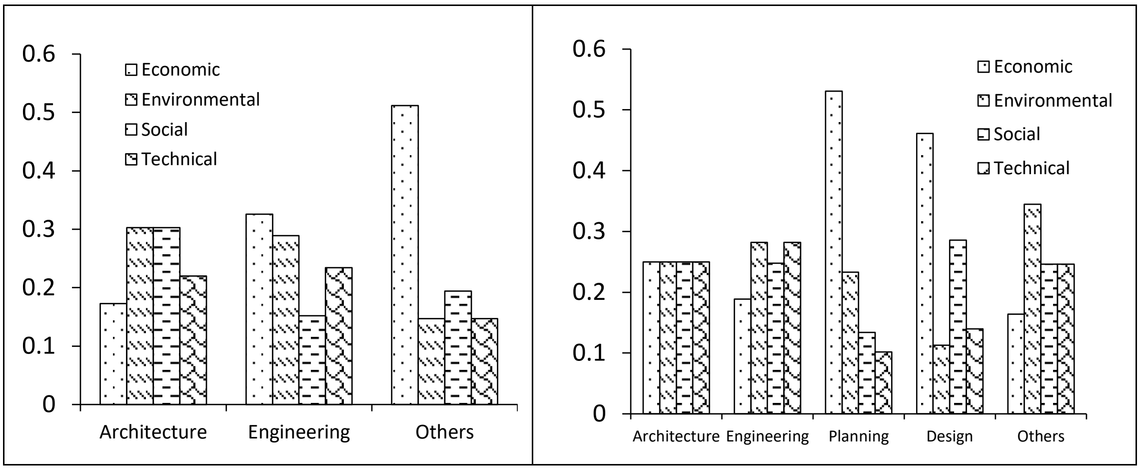


Figure 6 Comparison of Level 1 criteria by expert groups with different background in the UK (graph on the left hand side) and in China (graph on the right hand side)

In the UK, for Level 1 criteria, the architect group have assigned the highest weighting factors to *Environmental* and *Social* criteria whilst they regard *Economic* criterion as the least important criterion. The engineer group has assigned weighting factors from highest to lowest, to *Economic*, *Environmental*, *Technical* and *Social* criteria. The expert group from other backgrounds regard the *Economic* criterion as the most important criterion as well followed by *Social* criterion whilst the other two criteria were rated to be of equal importance but less important than Economic and Social criterion.

The results presented in Figure 6 indicate that Chinese architects consider all Level 1 criteria (Economic, Environmental, Social and Technical) equally important. Chinese engineers give slight advantage to Environmental and Technical criteria whilst those with planning and design background clearly put economic criterion above all others. Designers also highly value Social criterion.

The default weights for Level 2 criteria in relation to a stakeholder background is presented in Figures 7 and 8 for the UK and Chinese experts respectively.

In the UK, for Level 2 criteria, all groups agree that under the *Economic* category, *Cost* is the most important criterion. *Financial incentive* has been weighed higher than *Installation time* by the architect group. Under the *Environmental* category, all background groups regard *In-use environmental performance* as more important than *Recycled content*. Under the *Social* category, the criterion of *Societal benefit*s has been weighed higher than *Organizational benefits* by the architect group and the engineer group. The expert group from other backgrounds think oppositely. Under the *Technical* category, the architect group and the expert group from other backgrounds think *Operation* is more important. The results presented in Figure 8 indicate that Chinese experts have very similar opinions about relative importance of different Level 2 criteria to their UK colleagues.

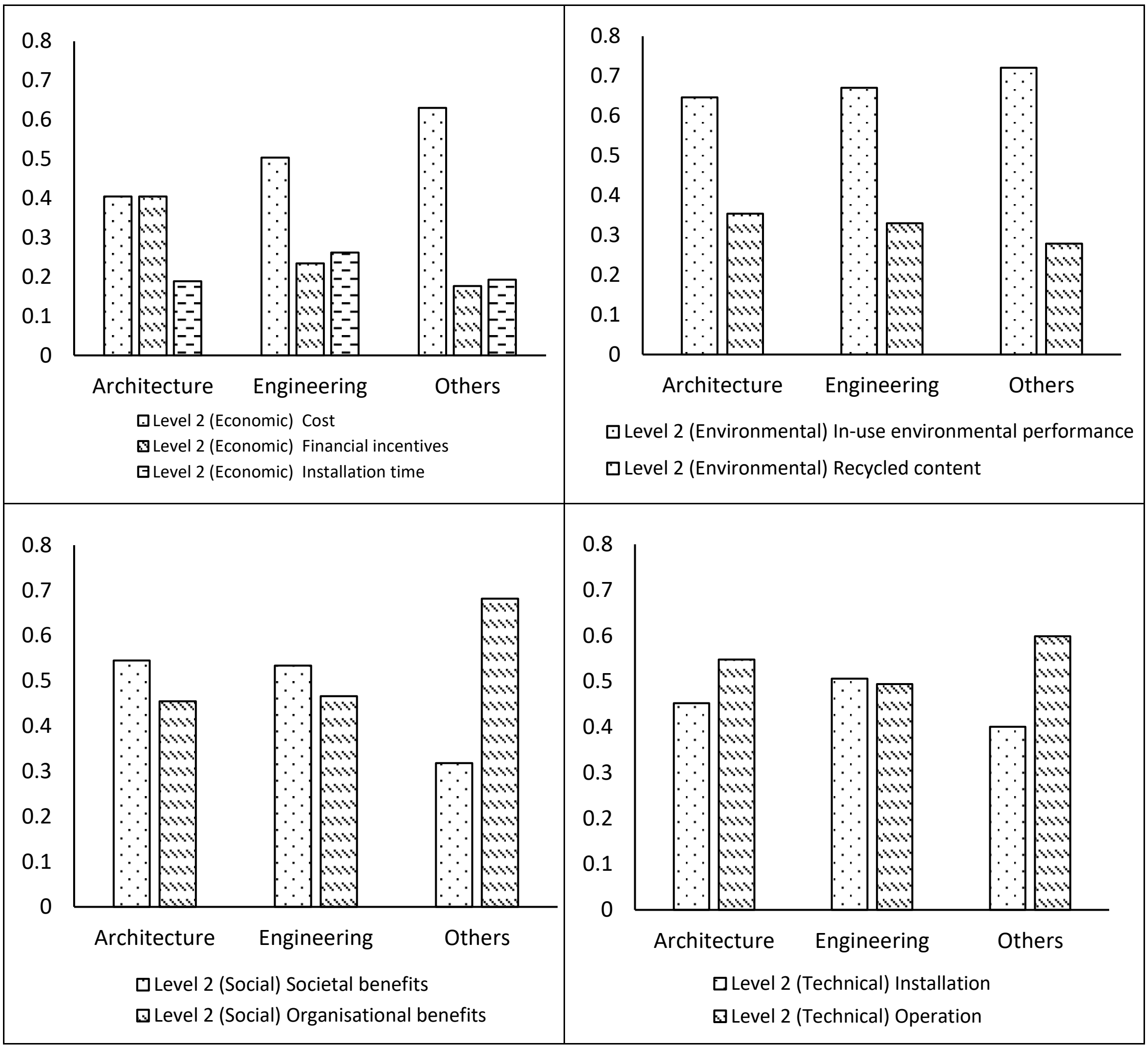
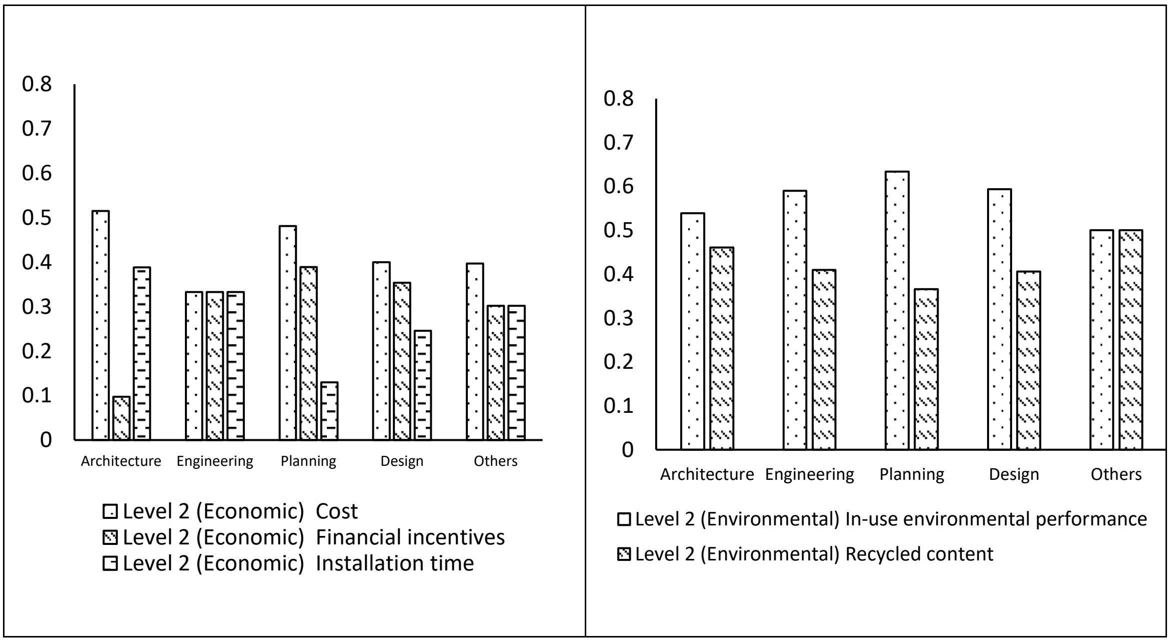


Figure 7 Comparison of Level 2 criteria by expert groups from different backgrounds in the UK



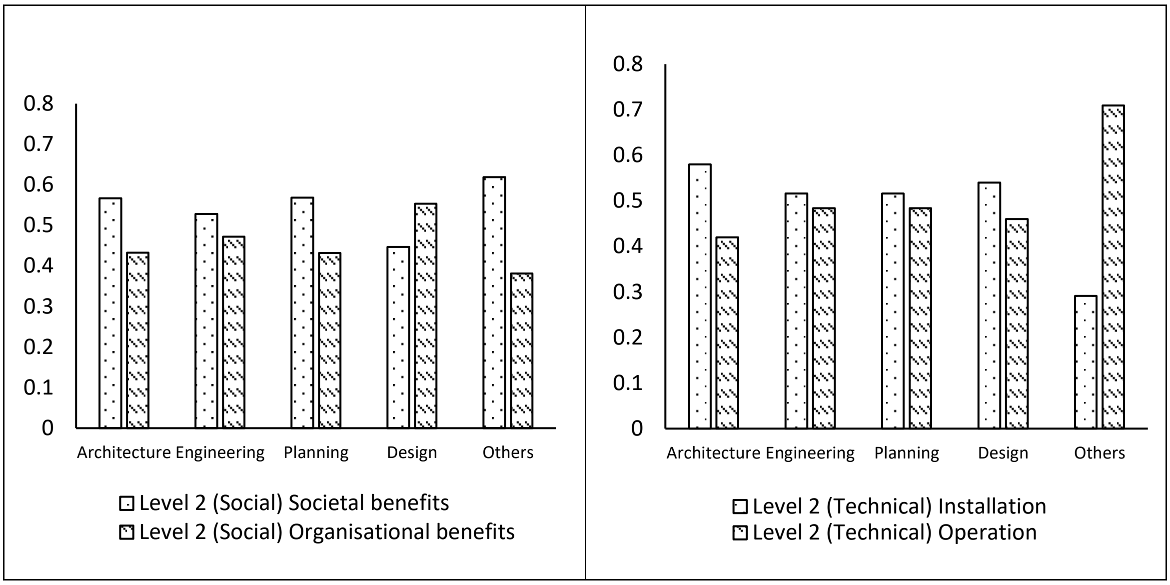


Figure 8 Comparison of Level 2 criteria by expert groups from different backgrounds in China

The default weights for Level 3 criteria in relation to a stakeholder background is presented in Figures 9 and 10 for the UK and Chinese experts respectively.

In the UK, for Level 3 criteria, under *Cost*, the architect group have assigned the same weights to the criteria of *O&M cost* and *Payback period*. The engineer group have assigned equal weights to all criteria under *Cost*. The expert group from other backgrounds think *O&M cost* should be the most important criterion under *Cost*. Under *In-use environmental performance*, the architect group think *Reduction of energy consumption* is the most important criterion, and the engineer group alternatively thinks *Reduction of water consumption* should be the most important criterion. Under *Societal benefits*, *Job creation* is much more important than *Community engagement*, shared by all expert groups. Under *Organisational benefits*, *Occupant wellbeing improvement* is more important than *Social reputation improvement* for all expert groups. Under *Operation*, the architect group consider *Durability* as the most important criterion. Other expert groups consider *Reliability* as the most important criterion.

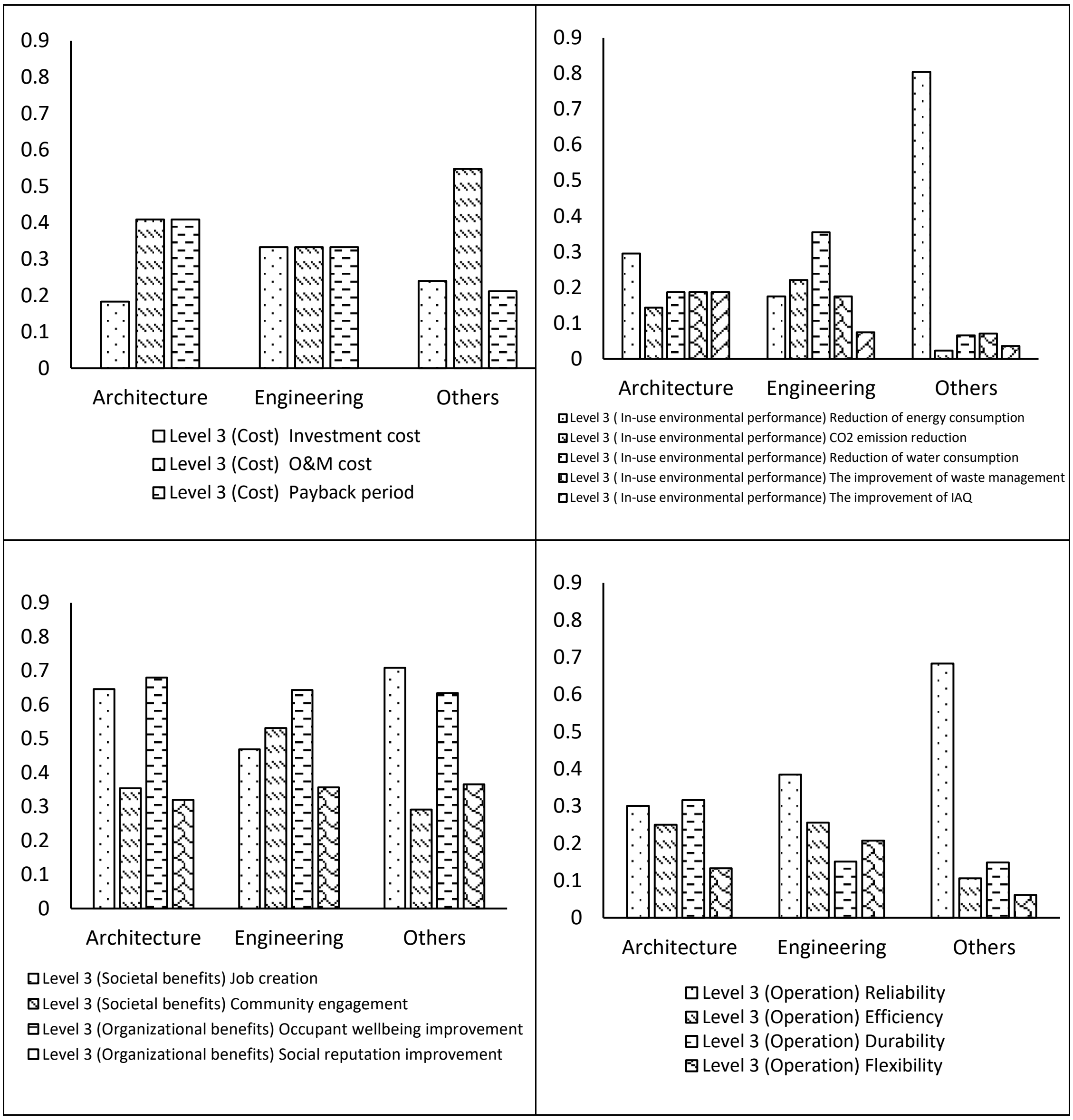


Figure 9 Comparison of Level 3 criteria by expert groups from different backgrounds in the UK

In China, for Level 3 criteria, under *Cost*, the architect group regards *Investment cost* and *O&M cost* as equally important. The engineer group considers *O&M cost* more important than *Investment cost* and *Payback period*. Other groups including the planning group, design group and experts from other backgrounds agree that *Investment cost* should be the most important criterion. Under *In-use environmental performance*, expert groups from the backgrounds of architecture and planning claim that the importance of *Reduction of energy consumption* override other sub-criteria. The engineer group have assigned similar weights to the criteria of *Reduction of energy consumption*, *CO_2 emission reduction* and *Reduction of water consumption*. The expert group from other backgrounds considered *Improvement of IAQ* as most important. For *Societal benefits*, all expert groups except the group from other backgrounds think *Job creation* is much more important than *Community engagement*. For *Organisational benefits*, all expert groups regard *Occupant wellbeing improvement* as more important than *Social reputation improvement*. Under *Operation*, different expert groups hold different opinions on the relative importance of the four sub-criteria. The architect group considers all sub-criteria equally important. The engineer group regards *Durability* as most important criterion. The planning group and the expert group from other backgrounds consider *Reliability* as most important criterion. The design group regards *Flexibility* as most important criterion.

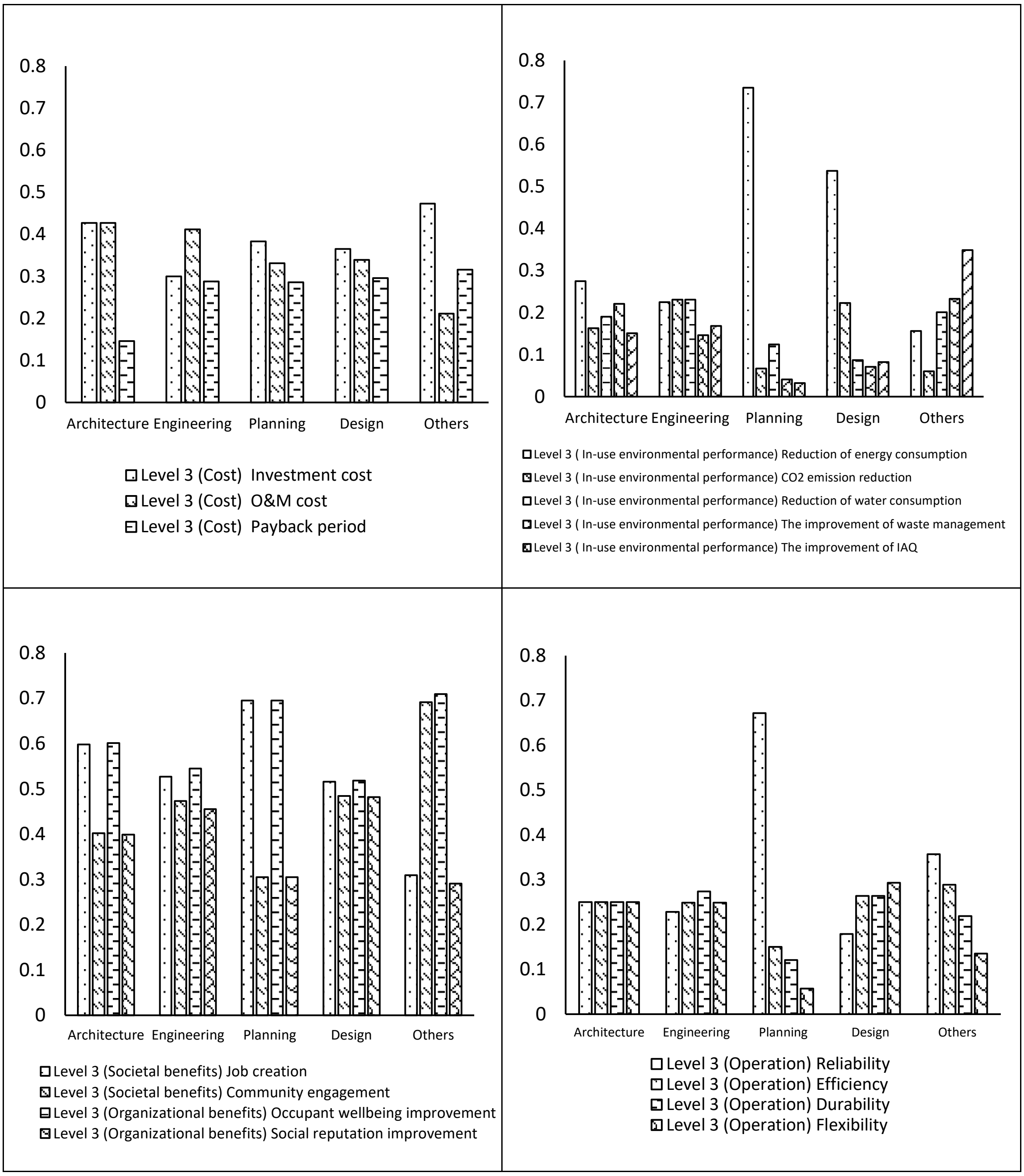


Figure 10 Comparison of Level 3 criteria by expert groups from different backgrounds in China

The default weights for Level 4 criteria in relation to a stakeholder background is presented in Figures 11 and 12 for the UK and Chinese experts respectively.

In the UK, for Level 4 criteria, the architect group and the expert group from other backgrounds regard *Material part* as most important criterion. The engineer group regards *Labour part* as most important criterion. For the sub-criteria of *the Improvement of IEQ*, all the expert groups agree that the most important criterion should be *Thermal comfort*. The importance of *Indoor air quality* has been also emphasised by all expert groups. Under *Occupant wellbeing improvement*, all expert groups except for experts from other backgrounds consider *Psychological wellbeing* as more important than *Productivity and performance*.

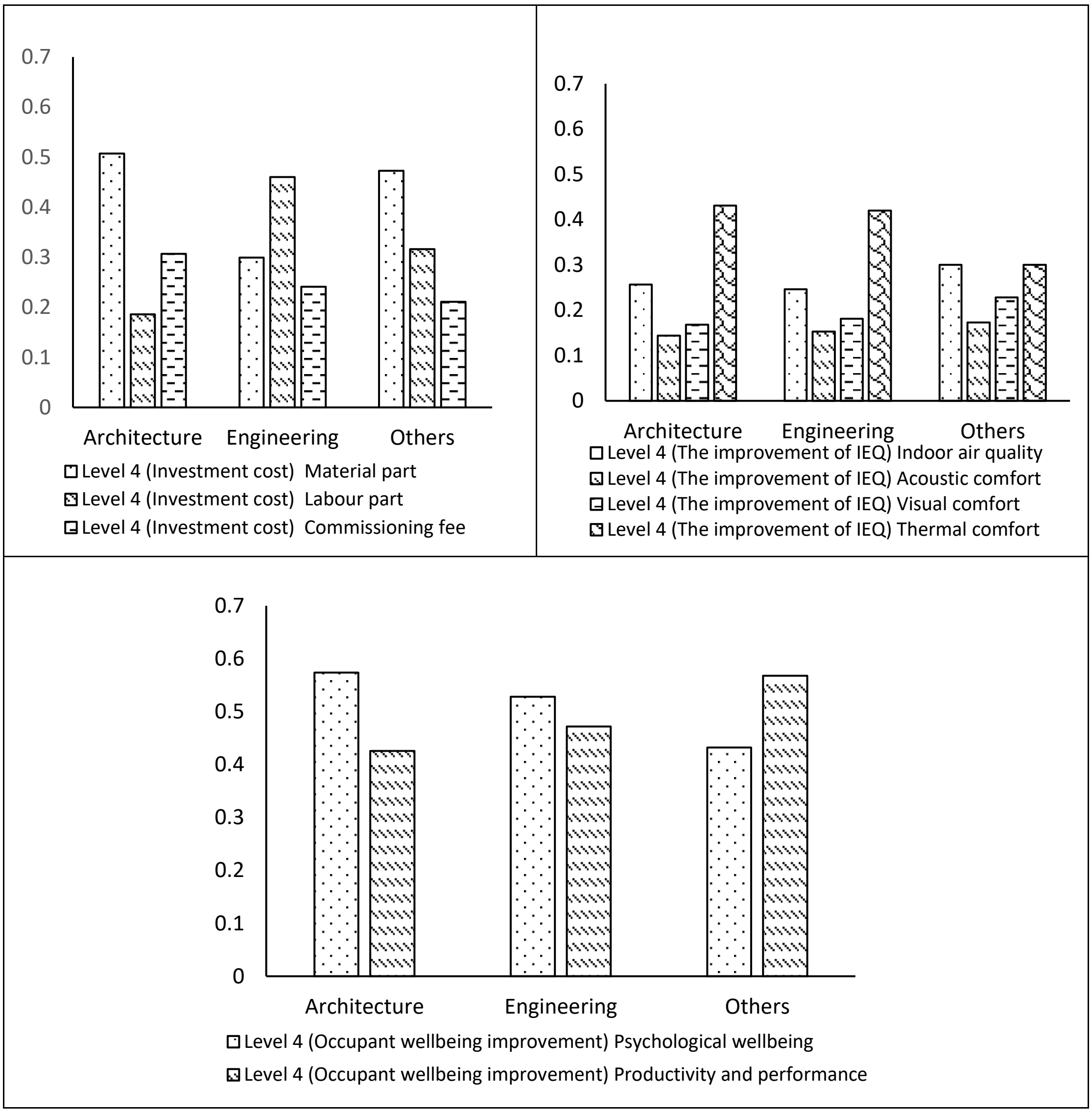


Figure 11 Comparison of Level 4 criteria by expert groups from different backgrounds in the UK

In China, for Level 4 criteria, the architect group and planning group regard *Material part* as the most important criterion. Other expert groups take *Labour part* as the most important criterion. Under *The improvement of IEQ*, the architect group considers *Visual comfort as* most important criterion. The engineer group consider all the sub-topics with the same importance. Experts from backgrounds of planning, design and others all agree *Indoor air quality* is most important. Under *Occupant wellbeing improvement*, the majority of experts regard *Psychological wellbeing improvement* as more important than *Productivity and performance*. The expert group from other backgrounds considers them of the same importance.

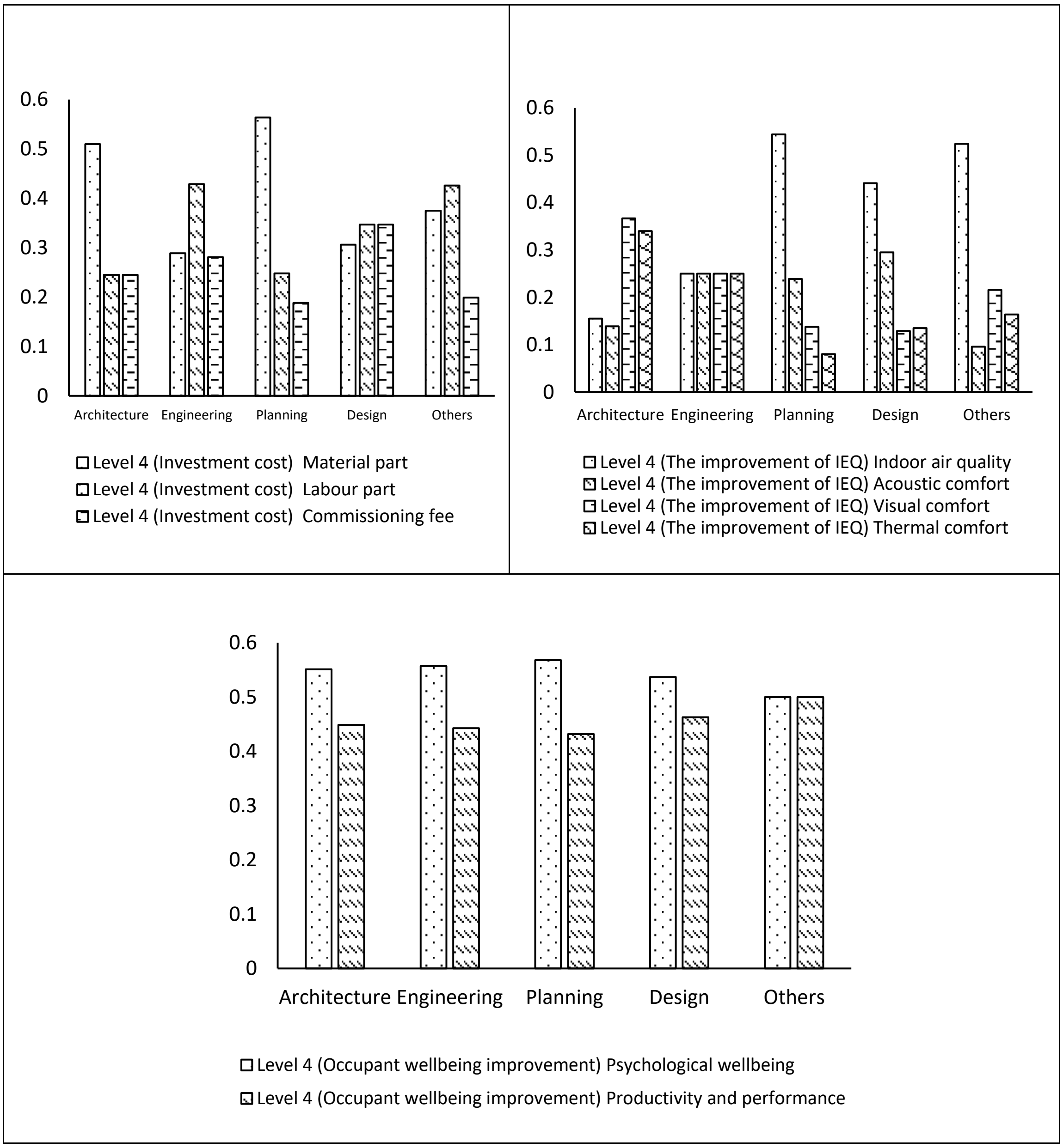


Figure 12 Comparison of Level 4 criteria by expert groups from different backgrounds in China

4.3.2 Criteria weighting comparison between two countries

Criteria weighting differences are analysed between the UK and China for three different groups: all experts who responded to a survey; the architects only group and the engineers only group. The difference of criteria weights between expert groups is calculated using formula (1).

$$Weights\ difference = \frac{Absolute\ value\ (w_i - w_j)}{1.000/n} \times 100\% \qquad (1)$$

Where w_i is the criteria weight given by expert group i, w_j is the criteria weight given by expert group j, n is the dimension of pair-wise comparison matrix, $1.000/n$ is the average criteria weights for MPC with n dimensions. The exact differences are listed in Table 1 in Appendix C and are here summaried as: “Large difference” (>50%), “Medium difference” (20%~50%) and “Small difference” (<20%) [50] and presented in Figures 13 to 15..

The difference of criteria weighting by all expert groups in the UK and China (see Figure 13) can be summarised as:

1) On Level 1, UK experts appear to be more concerned with the overall *Economic* performance of green technologies, while Chinese experts put more emphasis on their overall *Technica*l performance.

2) On Level 2, experts have different opinions about *Financial incentives* and *Installation time* which belong to *Economic* criteria. UK experts consider the availability of *Financial incentives* that can support technology adoption as much more important. Chinese experts, contrastively, regard *Installation time* as much more important.

3) On Level 3, differences are found in criteria relating to *Investment Cost*, *In-use environmental performance* and *Operation*. Chinese experts regard investment cost as most important criterion, while UK experts consider the other two sub-criteria, Operation and maintenance and Payback period, under *Cost*. Experts from UK and China have distinct opinions on the relative importance of five topics of *In-use environmental performance*. UK experts consider *The reduction of water consumption* as most important but *The improvement of Indoor Environmental Quality (IEQ)* is the least important, while Chinese experts consider them of similar importance. Under *Operation*. UK experts consider technology Reliability as highly important but Chinese experts give preference to *Durability*.

4) On Level 4, UK experts regard *Thermal comfort* as their first concern and Chinese experts regard *Visual comfort as the first priority.*

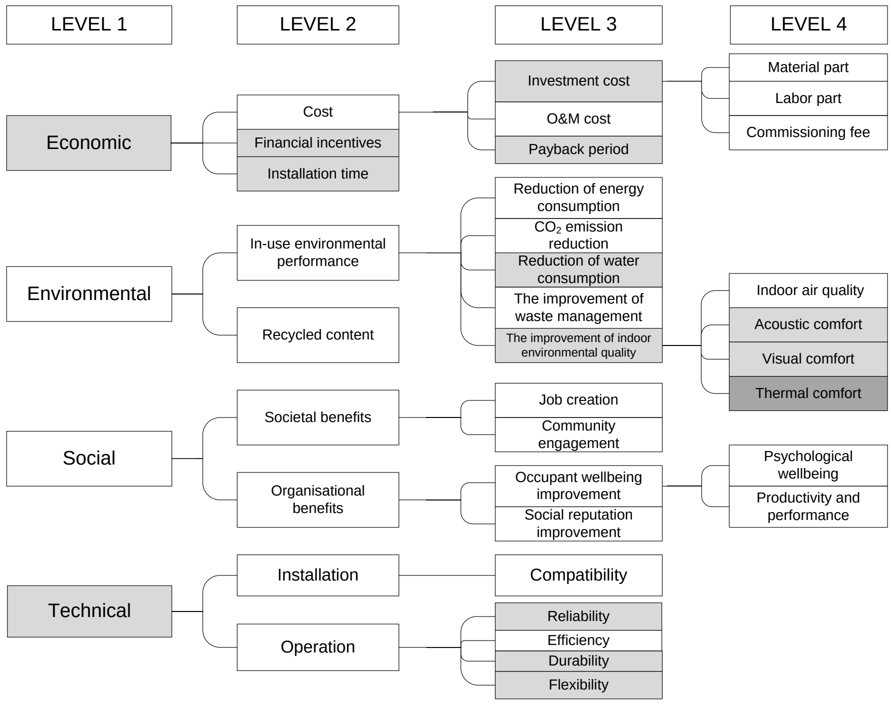


Figure 13 Difference of Criteria weighting for the all expert groups ("Large difference" (>50%) (dark grey); "Medium difference" (20%~ 50%) (light grey); "Small difference" (<20%) (No shading)

The difference of criteria weighting by the architect groups in the UK and China (see Figure 14) can be summarised as:

1) On Level 1, results show that architect groups from two countries have different opinions about *Economic*, *Environmental* and *Social* criteria. Chinese architect group consider these three criteria equally important, whilst UK architect group regard *Environmental* and *Social* criteria more important than *Economic* criteria.
2) On Level 2, criteria weights difference exists for all the criteria except for sub-criteria under the *Social* aspect. Criteria with large weighting difference are *Financial incentives* and *Installation time*. *Financial incentives* are weighed much higher by UK architects than Chinese architects.
3) On Level 3, large differences have been identified in the criteria of the *Investment cost* and the *Payback period*. The UK architects are more concern about *Payback period* while Chinese architects are more concern about *Investment cost*.
4) On Level 4, the differences have been identified for *Indoor air quality*, V*isual comfort* and *Thermal comfort* under *The improvement of IEQ*. Chinese architects regard *Visual comfort* as the most important criterion.

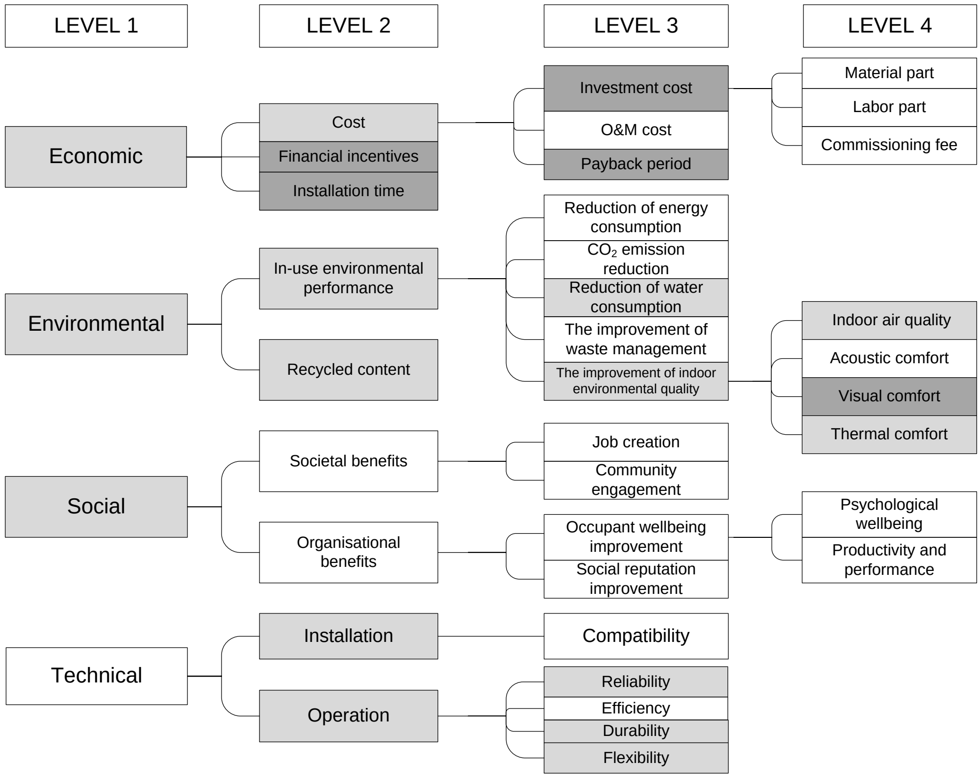


Figure 14 Difference of Criteria weighting for the architect groups ("Large difference" (>50%) (dark grey); "Medium difference" (20%~ 50%) (light grey); "Small difference" (<20%) (No shading))

The difference of criteria weighting by the engineer groups in the UK and China (see Figure 15) can be summarised as:

1) On Level 1, results show that engineer groups have different opinions towards *Economic* and *Social* criteria. UK engineer group are more concern about *Economic* criteria, whilst Chinese engineer group with *Social* criteria.
2) On Level 2, criteria weights differences are mainly identified for *Cost*, as well as *Financial incentives* and *Installation time*. The largest differences are related to Cost which is of higher concern to UK engineers than Chinese engineers.
3) On Level 3, results show that UK engineers assign more weights on *The reduction of water consumption* than Chinese engineers as well as technology *Reliability* during *Operation*.
4) On Level 4, UK engineer group regards *Thermal comfort as* their first priority.

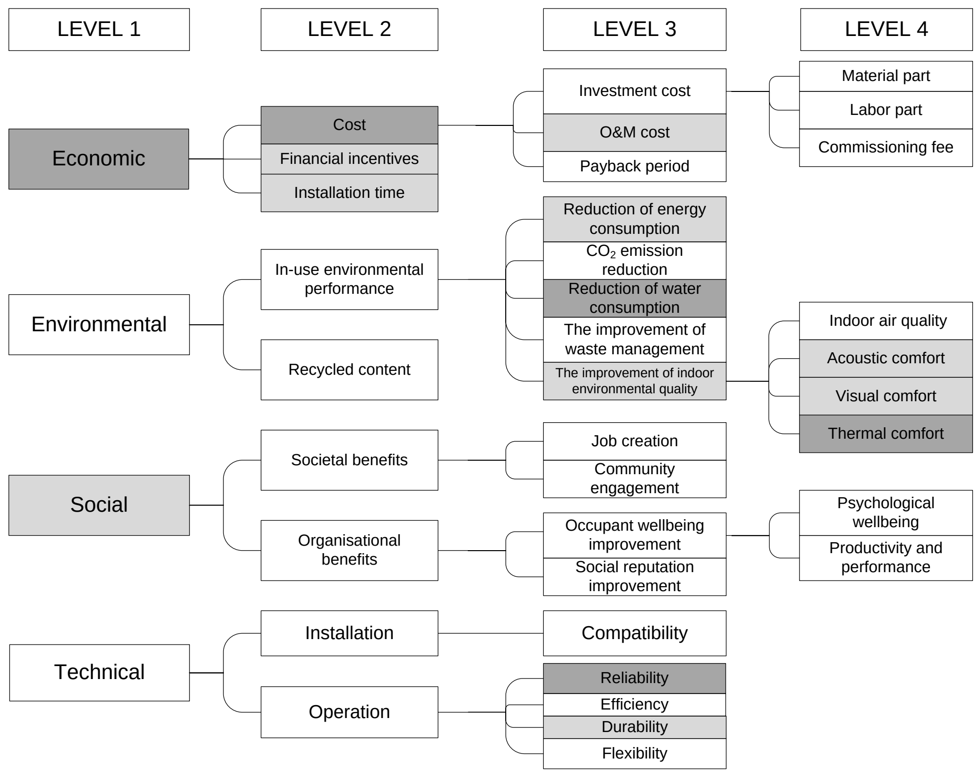


Figure 15 Difference of Criteria weighting for the engineer groups ("Large difference" (>50%) (dark grey); "Medium difference" (20%~ 50%) (light grey); "Small difference" (<20%) (No shading))

The visual summary of overall differences at national level (Figure 13) as well as summaries of differences for architect group only (Figure 14) and engineering group only(Figure 15) clearly indicates that different professional backgrounds, amount other identified 'local' factors, will influence which criteria can be seen as 'universal' and which are context dependent.

5. Discussion

Todd *et al*. [51] argues that whenever criteria are used some form of weighting is automatically applied (equal weights also assume weighing). Although this argument is used within the context of green building assessment, it applies for multiple criteria decision making process. No refurbishment criteria, and especially those involved with sustainability, can be regarded as equally relevant for every building on any location. Weighting process is however, fraught with difficulties. Given the lack of scientific objectivity, (personal) judgment will influence weighting process [51]. The existing practices used in weighting processes indicates that consensus based approach among groups of experts or stakeholders is the most common. However, seeking a consensus among specific group of experts or stakeholders involved in a specific retrofit project is not always feasible within given time and financial constraints. By proposing default criteria weights for previously developed criteria tree, opportunities for adopting the method of integrative assessment for green technology selection are maximised. The authors are fully aware that the proposed retrofit criteria and default weighting factors present just one way of approaching the problem. However, used together, criteria and weighting factors, offer the opportunity to all parties involved to investigate different retrofit options for non-domestic buildings.

Criteria weights comparison between expert groups in UK and China can further indicate criteria preferences of expert groups when involved in selecting the optimal technology for non-domestic building retrofits. For four general aspects of *Economic*, *Environmental*, *Social* and *Technical* performance of possible green technologies UK experts place more emphasis on *Economic* criteria, more specifically sub-criteria of *Cost* and *Financial incentives* for green technology. UK architects have especially placed higher weights on *Financial incentives*. Chinese experts, in contrast, are more concerned about Technical criteria. This difference between UK and China is supported by the results of most-frequent client requirements. In the UK, they are "to reduce operational cost" and "to increase asset value". Comparatively, in China, the most frequent client requirement is found to be "to improve building safety and security. For *In-use environmental performance*, *Reduction of energy consumption* and *Reduction of water consumption* are ranked as two most important topics in both countries. UK experts, especially engineer group, tend to put more emphasis on water efficiency over energy efficiency. Under *Indoor environmental quality*, *Thermal comfort* is regarded by UK experts as their first priority, whilst Chinese experts regard *Visual comfort* as their first priority, especially by architect group. It has been found there is no obvious difference from all expert groups on *Social* criteria weighting, but Chinese engineer group have paid a particular emphasis on *Social* criteria. Chinese experts give more emphasise on *Technical* criteria, eg. *Durability* compared to their UK colleagues.

The weighting factors were developed based on collected responses from relevant professionals with experience in retrofit projects at two locations: UK and China. The comparison of criteria weights between both national groups as well as based on professional background is performed and presented. Whilst the findings do not claim to be statistically representative, they do give an insight into relative importance of proposed economic, environmental, social and technical criteria depending on professional background as well as national context. UK and China are at different stages of economical development, their non-domestic building stock have different characteristics and have different professional as well as regulative practices. Whether or not similar difference in relative importance of proposed refurbishment criteria would be found in countries with similar non-domestic building stock, professional, legislative and economical characteristics is not certain and needs further research. This study of criteria weighting is developed to provide opportunities for integrative assessment method involving multiple criteria when selecting green technologies as part of non-domestic building retrofit process. In the absence of project specific criteria weights, previously proposed criteria tree and now proposed default criteria weights can enable an informed decision making process and further the understanding how different professional backgrounds in specific national context (UK and China) can influence this decision making process.

Our research has contributed, at least to some extent, to the understanding of stakeholder perspectives and country contexts' influence on criteria weighting. As criteria weights can directly influence the ranking order of alternatives and the final results, the selection which takes into account stakeholder perspectives and country development is essential. Based on the proposed multiple criteria tree, criteria weights were collected from industry professionals through the surveys for UK and China. Our results can present an unique insight into how different professional backgrounds affect individual value positions in relation to proposed retrofit criteria. UK and China became examples of certain national contexts (professional and legislative practises, building stock characteristics) for us to extend the arguments relating to how weighting systems in general are designed and created.

However, the major method in this research, AHP method, has its intrinsic limitations. A portion of the survey responses using the AHP method was checked inconsistent, with consistency ratios > 0.1. However, this inconsistency seems not to be unusual in making paired comparisons, just as in thinking, people do not have the intrinsic logical ability to always be consistent. Existing research has shown that the use of AHP requires substantial beforehand training and the usage could be explained in semi-interviews or workshops, where consistent judgements from participants are much easier to manage.

The AHP method can also be implemented through the Expert Choice, a software professionally designed for the method, a reminder of inconsistency will be triggered for users and more consistent results can be received. By identifying the limitations of the research design and the AHP method, future works could be conducted in the way that the survey of criteria weighting is designed with the assistance of the Expert Choice. With more consistent results achieved through the software, a validation of criteria weights could be further carried out. In the validation process, the Pearson correlation test can be conducted between the weights elicited through the Expert Choice software and the weights proposed through the web-based surveys, and the correlation coefficient between these two results can be calculated. Criteria weights with the low correlation coefficient will be identified and validated in the future research.

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Appendix A

Table A.1 Numbers of matrices that have passed consistency checking

Level	Dimensions	UK			China		
		All Expert group	Architect group	Engineer group	All expert group	Architect group	Engineer group
Level 1	4×4	14	4	9	4	1	2
Level 2 (Economic)	3×3	9	4	5	7	1	2
Level 3 (Cost)	3×3	4	2	2	9	3	4
Level 3 (In-use Environmental Performance)	5×5	2	1	1	9	3	4
Level 3 (Operation)	4×4	11	4	7	6	2	3
Level 4 (Investment cost)	3×3	9	4	4	10	3	6
Level 4 (The improvement of IEQ)	4×4	16	4	10	8	3	2

Note: In Table A.1, the dimensions of MPC means that the dimension of the matrix which is formed by pair-wise comparisons of the criteria on each level. For example, on Level 1, there are four criteria, and the dimension of the matrix is 4×4.

Table A.2 Consistency ratios of matrices for Group Weighting Values generation

Level	UK			China		
	All Expert group	Architect group	Engineers group	All Expert group	Architect group	Engineer group
Level 1	0.002	0.004	0.002	0.012	0.000	0.013
Level 2 (Economic)	0.000	0.000	0.000	0.000	0.040	0.000
Level 3 (Cost)	0.000	0.000	0.000	0.002	0.000	0.001
Level 3 (In-use Environmental Performance)	0.042	0.084	0.049	0.004	0.006	0.002
Level 3 (Operation)	0.009	0.004	0.014	0.001	0.000	0.006
Level 4 (Investment cost)	0.000	0.001	0.000	0.000	0.000	0.000
Level 4 (The improvement of IEQ)	0.004	0.009	0.003	0.002	0.014	0.000

Appendix B

Table B.1 The default criteria weights assigned by different expert groups from UK and China

Criteria	Sub-criteria	UK All	China All	UK Architects	China Architects	UK Engineers	China Engineers
Level 1	Economic	0.296	0.190	0.173	0.250*	0.326	0.189
	Environmental	0.279	0.290	0.303	0.250*	0.289	0.282
	Social	0.185	0.181	0.303	0.250*	0.152	0.248
	Technical	0.240	0.338	0.220	0.250*	0.234	0.282
Level 2 (Economic)	Cost	0.465	0.467	0.405	0.515*	0.504	0.333
	Financial incentives	0.304	0.226	0.405	0.097*	0.234	0.333
	Installation time	0.231	0.306	0.189	0.388*	0.262	0.333
Level 2 (Environmental)	In-use environmental performance	0.665	0.577	0.646	0.539	0.670	0.590
	Recycled content	0.335	0.423	0.354	0.461	0.330	0.410
Level 2 (Social)	Societal benefits	0.521	0.543	0.545	0.567	0.534	0.528
	Organisational benefits	0.479	0.457	0.455	0.433	0.466	0.472
Level 2 (Technical)	Installation	0.475	0.525	0.452	0.580	0.506	0.516
	Operation	0.525	0.475	0.548	0.420	0.494	0.484
Level 3 (Cost)	Investment cost	0.251	0.342	0.183	0.427	0.333	0.300
	O&M cost	0.375	0.433	0.409	0.427	0.333	0.412
	Payback period	0.375	0.225	0.409	0.146	0.333	0.288
Level 3 (In-use environmental performance)	Reduction of energy consumption	0.233	0.245	0.295*	0.275	0.175*	0.225
	CO_2 emission reduction	0.186	0.161	0.143*	0.163	0.221*	0.231
	Reduction of water consumption	0.271	0.211	0.187*	0.190	0.355*	0.231

	The improvement of waste management	0.189	0.187	0.187*	0.221	0.175*	0.146
	The improvement of IEQ	0.122	0.196	0.187*	0.151	0.074*	0.168
Level 3 (Societal benefits)	Job creation	0.561	0.536	0.646	0.598	0.469	0.527
	Community engagement	0.439	0.464	0.354	0.402	0.531	0.473
Level 3 (Organizational benefits)	Occupant wellbeing improvement	0.657	0.574	0.680	0.601	0.643	0.545
	Social reputation improvement	0.343	0.426	0.320	0.399	0.357	0.455
Level 3 (Operation)	Reliability	0.359	0.239	0.301	0.250	0.385	0.228
	Efficiency	0.259	0.25	0.250	0.250	0.256	0.249
	Durability	0.202	0.262	0.316	0.250	0.151	0.274
	Flexibility	0.180	0.250	0.133	0.250	0.208	0.249
Level 4 (Investment cost)	Material part	0.400	0.332	0.507	0.510	0.299	0.289
	Labour part	0.310	0.376	0.186	0.245	0.460	0.429
	Commissioning fee	0.290	0.292	0.307	0.245	0.241	0.281
Level 4 (The improvement of IEQ)	Indoor air quality	0.248	0.206	0.257	0.155	0.246	0.250
	Acoustic comfort	0.152	0.211	0.144	0.139	0.153	0.250
	Visual comfort	0.184	0.305	0.168	0.367	0.181	0.250
	Thermal comfort	0.416	0.278	0.431	0.340	0.420	0.250
Level 4 (Occupant wellbeing improvement)	Psychological wellbeing	0.538	0.543	0.574	0.551	0.528	0.557
	Productivity and performance	0.462	0.457	0.426	0.449	0.472	0.443

Appendix C

Table C.1 Categorisation of criteria weights difference by expert groups in the UK and China

Criteria	Sub-criteria	Criteria weights difference (%)			Criteria weights difference (In Levels)		
		All expert	Architect group	Engineer group	All expert	Architect group	Engineer group
Level 1	Economic	42.40	30.80	54.80	Medium	Medium	Large
	Environmental	4.40	21.20	2.80	Small	Medium	Small
	Social	1.60	21.20	38.40	Small	Medium	Medium
	Technical	39.20	12.00	19.20	Medium	Small	Small
Level 2 (Economic)	Cost	0.60	33.00	51.30	Small	Medium	Large
	Financial incentives	23.40	92.40	29.70	Medium	Large	Medium
	Installation time	22.50	59.70	21.30	Medium	Large	Medium
Level 2 (Environmental)	In-use environmental performance	17.60	21.40	16.00	Small	Medium	Small
	Recycled content	17.60	21.40	16.00	Small	Medium	Small
Level 2 (Social)	Societal benefits	4.40	4.40	1.20	Small	Small	Small
	Organisational benefits	4.40	4.40	1.20	Small	Small	Small
Level 2 (Technical)	Installation	10.00	25.60	2.00	Small	Medium	Small
	Operation	10.00	25.60	2.00	Small	Medium	Small
Level 3 (Cost)	Investment cost	27.30	73.20	9.90	Medium	Large	Small
	O&M cost	17.40	5.40	23.70	Small	Small	Medium
	Payback period	45.00	78.90	13.50	Medium	Large	Small
Level 3 (In-use	Reduction of energy	6.00	10.00	25.00	Small	Small	Medium

environmental performance)	consumption						
	CO_2 emission reduction	12.50	10.00	5.00	Small	Small	Small
	Reduction of water consumption	30.00	1.50	62.00	Medium	Small	Large
	The improvement of waste management	1.00	17.00	14.50	Small	Small	Small
	The improvement of IEQ	37.00	18.00	47.00	Medium	Small	Medium
Level 3 (Societal benefits)	Job creation	5.00	9.60	11.60	Small	Small	Small
	Community engagement	5.00	9.60	11.60	Small	Small	Small
Level 3 (Organizational benefits)	Occupant wellbeing improvement	16.60	15.80	19.60	Small	Small	Small
	Social reputation improvement	16.60	15.80	19.60	Small	Small	Small
Level 3 (Operation)	Reliability	48.00	20.40	62.80	Medium	Medium	Large
	Efficiency	3.60	0.00	2.80	Small	Small	Small
	Durability	24.00	26.40	49.20	Medium	Medium	Medium
	Flexibility	28.00	46.80	16.40	Medium	Medium	Small
Level 4 (Investment cost)	Material part	20.40	0.90	3.00	Medium	Small	Small
	Labour part	19.80	17.70	9.30	Small	Small	Small
	Commissioning fee	0.60	18.60	12.00	Small	Small	Small
Level 4 (The improvement of	Indoor air quality	16.80	40.80	1.60	Small	Medium	Small
	Acoustic comfort	23.60	2.00	38.80	Medium	Small	Medium

IEQ)	Visual comfort	48.40	79.60	27.60	Medium	Large	Medium
	Thermal comfort	55.20	36.40	68.00	Large	Medium	Large
Level 4 (Occupant wellbeing improvement)	Psychological wellbeing	1.00	4.60	5.80	Small	Small	Small
	Productivity and performance	1.00	4.60	5.80	Small	Small	Small