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The relationship between quality defects and the thermal performance of buildings

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ABSTRACT

The construction sector accounts for a significant portion of the total final energy use and carbon emissions worldwide. Despite efforts to reduce energy consumption through energy efficiency improvements in buildings, the measures proposed by the construction sector are falling short. Among several causes which lead buildings to perform differently to what was defined in the design stage, commonly referred to as the 'energy performance gap', the occurrence of quality defects has been acknowledged. This paper aims to identify through an in-depth literature review, quality defects which undermine the thermal performance of buildings by comparing the studies' findings with regard to defect characteristics and attributes; major causes and influencing factors; and their impact on the energy performance of construction projects. This review also aims to highlight areas where more research is needed if the expected thermal performance of buildings is to be achieved. Understanding the generation process and effects of defects on the energy efficiency of buildings can support the implementation of appropriate quality management systems in construction projects and thus contribute to the achievement of the intended energy performance targets.

1. Introduction

Construction is the largest energy consuming sector in the world. Buildings account for over 40% of the total final energy consumption and an equally significant source of carbon emissions [1,2]. Policy-makers and scholars have realised that only with significant reductions in the energy demand of buildings, provided by increased energy efficiency, it will be possible to reduce carbon emissions [3,4].

The construction sector has made improvements towards increasing the energy efficiency of buildings by upgrading the thermal performance of the existing stock and building new low energy buildings [5,6]. However, despite the efforts, recent studies indicate that the intended energy savings are falling short [5,7,8].

According to research by the Carbon Trust [9] on 28 case studies in the United Kingdom, measured building energy consumption was up to five times higher than estimated at the design stage. Another study by Zero Carbon Hub [10] of 16 housing developments in the UK indicated that all the dwellings assessed presented a measured heat loss higher than predicted. This mismatch between the energy performance as predicted at design stage and as measured once the building is in operation is known as the energy performance gap [11–14].

The causes of the energy performance gap have been defined in the literature according to its root causes, such as design and construction processes, and operational issues [9,11]. At the design stage, the issues are closely related to the miscommunication among clients, design teams and builders when defining the building energy performance aspirations and the required strategies for implementation stage. Another important contributor are the discrepancies between simulated and actual building occupants' behaviour due to the impossibility to fully predict the buildings' future use and occupants' behaviour [10–12,14]. At the construction stage, site management and workmanship have been acknowledged as possible causes of the gap. The buildings elements are often not in accordance with the design specification due to lack of information, skills or motivation. In addition, the occurrence of changing of orders by clients or material specifications by value engineering have the potential of compromising the performance attributes of the buildings components [2,7,8,11,15,16]. Finally, during the operational stage, the occupant behaviour is often cited as the major contributor to the energy performance gap. Moreover, the building energy management system can be particularly complex and unfriendly to use, thus affecting the operational energy use of the building [3,8,9,11]. Among this wide number of contributing factors to the energy performance gap [14] and related to the three stages of the building lifecycle, poor quality management and the occurrence of defects have been identified as important contributors [2,8,11,15,16].

Whilst poor quality management and defects in construction

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projects are well-known problems [17,18] and have been widely discussed in the literature, existing studies have mainly focused on the impact on projects' key performance indicators (e.g. time, cost, client satisfaction, etc.) [19]. To the authors' knowledge, there are few studies which identify and assess the impact of poor quality management and defects on the energy performance of buildings, in particular regarded to the thermal performance.

Within the context of energy and buildings, this paper provides a literature review of quality defects in the construction sector with the aim to identify those areas of knowledge that suggest the existence of a relationship between quality defects and poorer building thermal performance. The review combines the findings of previous studies to establish the defect characteristics and attributes; major causes and influencing factors; their impact on construction project performance, and finally, the effect on the thermal performance of buildings. The paper also highlights the areas where more research is needed if the intended thermal performance of buildings is to be achieved. It is hoped that this review will help researchers, construction associations and practitioners working on improving building energy performance or quality in construction by providing a detailed review of the most reported defects and their impact on construction projects.

2. Definition of quality defect in construction

In both academia and industry, different terms such as 'defect' (e.g. [20–22]), 'snag' (e.g. [22,23]), 'fault' (e.g. [24]) and 'failure' (e.g. [25]) are used to describe imperfections on an element or an item that constitutes a building system. Although with a slight different meaning, the terms 'quality deviation' [25,26] and 'non-conformance' [27] are also used.

Similarly, different definitions to describe the term defect exist. For example, Georgiou et al. [28] defines defect as a "shortcoming or falling short in the performance of a building element" or "a situation where one or more elements do not perform its/their intended functions". Watt [29] refers to defect as a "failing or shortcoming in the function, performance, statutory or user requirements of a building, and might manifest itself within the structure, fabric, services, or other facilities of the affected building".

Unfortunately, the lack of differentiation of these terms and definitions, and the interchangeable use between studies, have led to inaccurate identification of defects, quantification of the associated costs and definition of the most appropriate mitigation strategies [30]. For the purpose of this study, the term defect is defined based on Watt's definition [29]. However, it is worth mentioning that not all the studies included in this review defined the term defect in such an objective way.

3. Previous studies investigating quality defects in construction

This paper aims to provide a comprehensive state of the art on quality defects in construction. It provides an analysis of the literature in terms of previous research's findings related to the defects' characteristics and attributes; the major causes and influencing factors; and the consequences of defect occurrences on the project and building performance.

Table 1 classifies the reviewed studies by the year when the study was published, the country where the study took place, the building type (domestic or non-domestic), stage of the project when the data was collected (construction, handover, or post-handover), the method used to collect the data (author, third party, contractor, or building occupant), and the sample size (both number of projects involved and buildings/dwellings studied).

The majority of previous studies (79%) focused on residential buildings. In Europe the studies explored domestic building projects located in Portugal [31], Spain [20,21,32–35], Sweden [36,37], and UK [9–11,13,15,18,22,23,29,38–56]. Internationally, the domestic building projects studied were located in Australia [24,28,30,57–61], China [62], Malaysia [63], Singapore [64–67], and United States (US) [68,86].

A smaller number of studies (37%) focused on non-domestic buildings. In Europe, the studies focused on commercial, educational, governmental and industrial buildings in Sweden [36,37]; and commercial, educational, governmental, health, industrial and infrastructure projects in the UK [8,9,15,29,39,53,55,69]. At an international level, there are studies investigating quality in commercial, educational, governmental and industrial facilities in Australia [59–61,70]; commercial and infrastructure projects in Canada [71,72]; governmental buildings in China [62]; infrastructure projects in Iran [73]; educational buildings in Nigeria [74]; commercial, health, industrial, infrastructure and governmental buildings in Singapore [64–67]; and commercial, governmental and industrial facilities in the US [26,68,75].

Noteworthy, 24% of the studies analysed in this paper studied both domestic and non-domestic buildings and in 8% of the studies the building type analysed was not mentioned. The concentration of studies undertaken in residential buildings might be due to the fact that the residential building stock in Europe, for instance, corresponds to 75% of the total building stock [76]. In addition, the reasons and impacts of quality issues in domestic building are more tangible and representative. The non-residential building stock comprises a more complex and heterogeneous sector compared to the residential sector and thus researchers' key findings tend to be less replicable [15,76,77].

Quality defects are identified and collected by different stakeholders and through different methods depending on the stages of the building project. For example, during the construction process, quality defects are usually collected by the main contractor by means of internal quality inspections at different checkpoints in the programme of works, incoming material inspections, and internal and/or external audits. Once the construction is complete, quality issues may be identified as a result of building performance surveys by specialized consultants (e.g. thermographic survey of the building fabric and airtightness test), by both the contractor and the project client at the pre-commissioning stage prior to the practical completion of the works (normally 2 weeks before handing over the building), and by the project client and warranty providers at the final commissioning and handover, when the building is deemed completed and ready for occupation. At post-handover, when the building is occupied and operational, defects are normally gathered through client, owner or building occupants' complaints during the defects liability period, normally 12 months after handover in which the contractor is responsible for any defect occurring in the building.

In 47% of the studies reviewed, data was collected during the construction phase; 22%, at handover, and 41%, at post-handover. Some studies, however, collected data in more than one stage (20%). For instance, Chong and Low [67] analysed data from both construction and post-handover stages to understand the different causal factors of visible and latent defects.

In respect to the data collection methods used, in 61% of the reviewed studies data was collected by the academics/researchers; 22% by a third party (insurance companies, warranty providers or independent inspection companies); 14% by constructions companies (non-conformances records); and 11% by the occupants through warranty claim forms. It is noteworthy that in only 12% of the studies the authors relied on more than one source of data. In 8% of the studies analysed, the data collection method could not be identified. Several authors claim that there are structural differences in regard to the perceived quality between end-users and trained professionals; and between contractors' building surveyors and independent inspectors [22,50,52]. For example, Sommerville et al. [52] studied the quantity of defects recorded in the post-handover stage in 600 residential units in the UK. The study suggested that independent inspectors working on