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Retrofit ‘daemons’ in the process of low-carbon housing stock renovation

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Abstract

The ‘performance gap’ between design and actual energy use is well recognised. Much of the debate on the performance gap focuses on the use and accuracy of building energy models or on the ‘misbehaviour’ of users and maloperation of measures. This paper focuses instead on the design and construction phases of retrofit projects.

Pioneering case studies in deep low-carbon refurbishment in the UK show a lack of quality assurance and poor integration of the intermediate stages between design and implementation within retrofit process. In retrofitting existing buildings there is an unseen presence of ‘good’ and ‘evil’ daemons that are ‘hidden’ in different retrofit work stages. The intermediate construction stages from design to delivery tend to involve the majority of unforeseen complexities that are difficult to know until work is under way. The consequence of this is not only an uncertainty in actual energy performance that challenges the ambitious carbon emissions reduction targets, but also an unwillingness to invest in low-carbon technologies due to concerns about what will actually be achieved. A more sophisticated understanding of the different types of risks within the retrofit process, from technical or economic risks to commissioning and handover related ones, is required.

Using established professional work plan frameworks, this paper first defines a Plan of Work as a continuous cycle of different retrofit workstages and roles, augmenting and assisting current professional scopes of service, not replacing them. The notion of ‘risks’ is used as a lens for managing and reducing unintended consequences and the performance gap. Drawing upon the evidence from academic and grey literature review, this paper then defines the types of risk(s) encountered within the different retrofit workstages by exploring evidence-based problems, concerns and ‘daemons’ that emerge as major contributors preventing the full potential of low-carbon refurbishments from being achieved.

Keywords: performance gap, renovation, low-carbon retrofit, deep refurbishment, domestic buildings, energy performance, low-carbon technologies, work stages, retrofit risk management.

Introduction

One of the key messages from COP 15 was that '*the failure to encourage energy-efficiency and low-carbon when building new or retrofitting will lock countries into the disadvantages of poor performing buildings for decades*' (UNEP, 2009, p.4). From Rio via Kyoto to the latest Paris Agreement on Climate Change in 2015, at the top of the list are actions to support the role buildings need to play at global scale. Worldwide, green building councils have committed to mobilise a global market transformation to advance by 2030 and achieve by 2050 two fundamental goals: net zero carbon building; and energy efficiency and deep refurbishment of existing stock (UKGreenBuildingCouncil, 2017). In the UK, housing is responsible for a quarter of the total greenhouse gas emissions, while the policy context of the Climate Change Act 2008 requires a 34% cut in 1990 greenhouse gas[1] emissions by 2020, and at least an 80% cut in emissions by 2050 (DECC, 2012).

However, evidence of technical and economic potential does not guarantee delivery of the scale and quality required to achieve the outcomes and policy targets (EST et al., 2012, DECC, 2012, EST, 2010, EST, 2007). The mismatch between building's design and actual energy use, typically known as the 'performance gap', is well recognised in a considerable number of studies (e.g. Bordass et al., 2001, Preiser, 2001, Preiser and Vischer, 2005, Wingfield et al., 2008, Gupta and Dantsiou, 2013, ZeroCarbonHub, 2014a, ZeroCarbonHub, 2014b, Fedoruk et al., 2015, Gupta et al., 2015, InstituteforSustainability, 2012b). The delivery of national energy reduction plans is undermined by the performance gap, with evidence showing that the mismatch can be greater than 100%, as a house's energy performance is determined by several technical and non-technical interacting factors (Fylan et al., 2016, Topouzi, 2015). Building regulation standards may become more stringent worldwide, in order to meet short- and long-term targets. However, this fact does not reduce underperformance risks as buildings may still not perform as intended. Evidence from large-scale, deep, whole-house retrofit projects in the UK (e.g. Retrofit Reality project 2008-2009, Retrofit for the Future 2009-2013, Ready for Retrofit 2012-2014), shows that the success of a whole building refurbishment approach is strongly dependent not only on the choice of high energy efficiency standards, innovative design and low-carbon technological solutions, but also on their implementation, installation, operation and the diagnosis of underperformance causes pre- and post-intervention. Understanding and prioritising the causes contributing to the performance gap is crucial to bring design intent closer to matching the policy imperative.

In this paper we focus on the detailed causes of the design-performance gap based on UK experience. We introduce the concept of 'daemon' to highlight detailed practices of implementation in the renovation process. These daemons combine in complex ways to shape the final outcome in terms of energy performance. The paper is organised as follows: a brief review of the literature on the design-performance gap is followed by an exposition of positive and negative daemons implied by the real-life performance of retrofit projects. A retrofit-specific Plan of Work is then proposed, adapting the procedure of the Royal Institution of British Architects (RIBA), intended for new construction projects. A conclusions section draws out the implications, for the retrofit agenda, of using the concept of daemon to identify the social dimensions of good and poor energy performance, and of treating retrofit as a different kind of project from new construction.

Design-performance gap

Previous studies have categorised performance gap discrepancies into three main areas: those related to thermal performance of the building fabric, those related to energy performance of the services and those related to occupancy (De Wilde, 2014, Johnston et al., 2016). De Wilde (2014) proposes three retrofit work stages (design, construction and operational) within which performance gaps arise because of different types of mismatch:

- between energy models predictions and real measurements from buildings
- between machine learning and measurements from real buildings,
- between predictions and display certificates in legislation.

This study (mainly from a technical viewpoint) identifies issues related to how people use design tools, computer models, certificates and monitoring techniques. The Zero Carbon Hub's (2014a) review of research on the design-performance gap categorised the underlying causes as primarily non-technical and social:

- a lack of technical knowledge
- poor communication among project teams
- unclear boundaries or roles and responsibilities.

[1] CO_2 is the most important greenhouse gas from housing and the one most closely related to energy use in homes.

In both cases, there is a strong indication that causes of the design-performance gap are bound up in conventional practices of different social groups (including professions), and that the means to reduce the design-performance gap relate to changes in the management of project teams and in education and training.

Retrofit daemons

In modern English usage a 'daemon' is a benign spiritual being, made famous most recently in Philip Pullman's fantasy trilogy His Dark Materials (Pullman 1995; 1997; 2000). However, our use of 'daemon' here is closer to older usage of the term in Greek mythology and philosophy, where a daemon can be either 'good' (*agathodaímōn* -"noble spirit") or 'evil' (*kakodaímōn "malevolent spirit"*) signifying an occult power that drives humans forward or acts against them. We de-emphasise the occult here, instead using 'daemon' to signify the underlying routines, assumptions, practices and methods which are used by a wide range of stakeholders on retrofit projects, and which are reproduced and reinforced through formal training or informal learning through experience. We assert that a daemon can be 'good' or 'evil', not based on the initial intentions, but on the end result. Daemons are used here to highlight several hidden issues in the retrofit process where 'good' intentions can easily lead to unintended risks and disappointing results because of the presence of many 'evil' daemons, which are routinely ignored or under-estimated in their effect. In many cases, daemons represent the practices, the "ways of doing", of whole sectors of stakeholders in the renovation process – from policy and industry through to citizens and consumers. We introduce the concept of 'daemon' to highlight decision points in the renovation process, which combine to influence the final outcome in terms of energy performance.

Complex projects like retrofits are full of decisions, and it seems unavoidable that many of them are made using heuristics and 'rules of thumb' based on previous learning and experience: to deliberate every decision from first principles would be too exhausting, impractical and time-consuming. However, we argue that many conventional responses at key decision points are ill-informed or misaligned with the goals of low-energy renovation. For example, installing Mechanical Ventilation with Heat Recovery (MVHR) systems in households occupied by people smoking indoors is a common misalignment of high design targets with actual in-use performance of the system and controls that do not meet standards as occupants air the house by opening windows ignoring the need for the MVHR to be 'ON' 24/7. Similarly, the capacity to reap the benefits, drive bills down and maximise benefits from solar panel electricity generation is compromised in households that spend long hours away from home (Topouzi, 2013, Topouzi, 2015, InstituteforSustainability, 2012b). The end result in energy terms in these cases is the observed gap between design intent and as-built performance. We use the concept of 'daemon' to investigate this detailed decision-making and its ultimate consequences on the performance of retrofit projects. At different stages of the project, faced by a need for a decision, a daemon may appear; it could be a habit, a practice or simply a response shaped by previous experience. We therefore emphasise here making clear what the daemons are and at what stages they occur in a project.

Two examples from research on retrofit projects will help to clarify what we mean by daemon. Firstly, Fawcett and Killip (2014) describe the situation where successful pioneers of private retrofit projects have responded to contradictory advice from two or more professionals hired to work on a retrofit project. Their response was to educate themselves sufficiently that they felt confident to judge the advice being offered, which in some cases meant ignoring both sources of 'expert' advice and choosing a different path. It is worth emphasising that this 'daemon' is procedural and psychological rather than technical: it is about making decisions in the face of contradictory advice. In the case of the pioneers studied by Fawcett and Killip, this impasse is overcome by an extraordinary effort of self-education – to become more knowledgeable than the so-called 'experts'. The second illustrative case of a daemon is bound up with job roles and project management. Killip et al (2014) describe a series of 36 retrofit projects, which were managed in such a way that designers and on-site workers collaborated to find workable solutions to unforeseen problems, involving them in practices which are not normal to UK construction sites: specialist workers helped out on tasks beyond their specialism; and the whole team periodically stopped work to discuss an ongoing problem and find a workable solution. Here the daemon is an innovative approach to project management, which led not only to positive energy outcomes but also to the project being completed on time and on budget despite being late and overspent not long after it started.

Both of these examples describe good daemons from innovative projects; however evil daemons are also common. In the two examples of good daemons, what is remarkable is how uncommon these practices are, suggesting that most of the time these challenges, without a daemon as a response, end up leading to negative outcomes. In the UK, this evil daemon is deeply ingrained in the culture of the entire construction industry (Egan, 2000, Egan, 1998). In most cases, the reality of retrofit hides unforeseeable evil daemons (e.g. structural damage, hazardous building components or different location of utilities) which appear as work progresses. This inevitably involves a certain amount of on-the-job problem-solving and dictates decision making that not only needs to solve that specific problem, but to also take the 'whole-project'[2] perspective. The role of a key person in decision making (e.g. client, project manager) has to face evil daemons from a contradictory 'expert' advice that may lead simply to do nothing; or from workers (e.g. heat pump installer, specialist builder) that stick rigidly to their specialist roles as a way of limiting their responsibility on-site to individual tasks, rather than taking responsibility for the outcomes of the project as a whole.

Our analysis uses evidence from large scale retrofit projects[3], pioneering housing retrofit networks in the UK and from 'grey' literature (e.g. NEF, 2014, EST, 2007, ZeroCarbonHub, 2014b, ZeroCarbonHub, 2014a, Dollard and Edwards, 2016, Dollard and Edwards, 2015). This leads to a classification of some (not all) daemons at different stages[4] of a retrofit project (Table 1).

Table 1: Some important daemons within retrofit process work stages

Work stages	Examples of daemons
A. Preparation Stage 0 - Appraisal, Stage 1 – Design brief	▪ **Diagnosis** of existing situation and problems (existing building condition and occupants'/users' past experience, format -Energy Performance Certificate assessment and Post Occupancy Evaluation (POE)/ Building Performance Evaluation- and granularity) ▪ **Communication** of diagnostic insights (design team, client, occupants, constructor) ▪ Assigning **responsibilities and roles** ('key person', coordinator, liaison, communicator) ▪ Making **design choices** (design team and clients -'tick box' culture of targets and standards, non-achievable options, non-realistic for the specific property and users)
B. Design Stage 2 - Concept, Stage 3 – Developed Stage 4 - Technical	▪ **Design** (standardised 'one solution fits all', complicated modelling solutions, lacking technical detail, default user, disregard occupants' lifestyle) ▪ **Communication** between actors (client, design and construction teams agree on target/standards and design options, low-carbon measures and technologies and project timeline) ▪ **Responsibilities and roles** (design participation,'key person' as coordinator, liaison, communicator, overlook process gaps, team's knowledge and skills, frequent review of design-build, commission and maintenance ability) ▪ **Reality check** (on-site checklist of technical and non-technical issues of the design solution with construction team and client, solution flexibility and adaptability of technical details) ▪ **Commissioning** (coordination of site activities, credentials to adequate knowledge on the combined low-carbon systems and controls proposed)
C. Construction Stage 5 – Pre-Construction, Stage 6 – Construction, Stage 7 – Handover & reality checks	▪ **Installation technical** (lack of quality assurance, combined systems and controls communication, building system performs as a whole) ▪ **Installation operational** (operational complexity, personal capacity) ▪ **Reality checks** (frequent review of 2D designs or other design aspirations into 3D reality) ▪ **Communication** between teams (ensure contractor/sub-contractor understanding of design and standards, combined skills and complement one another knowledge deficiencies) ▪ **Responsibilities and roles** ('key person' ensures on-site problem solving, co-ordinate different professions, technical skills and expertise) ▪ **Commissioning** (choice of contractors/ sub-contractors look first their expertise on the specific design and targets requirements and then the tender offer) ▪ **Skills and knowledge** (deficiency of multi-skills/knowledge of the installation) ▪ **Economic** project management (project timeline deviations whole-house approach or room-by-room, installation failures and product delivery delays)
D. In-use Stage 8 – Post-construction, Stage 9 – Repair	▪ **Reality check** of how a project is performing in use (monitoring and as-build spot checks of combined systems and measures performance and user operational feedback) ▪ **Handover processes** (to users: operation and fine tuning of combined systems, personalised information and time of training, ensure a demonstrator's knowledge of combined and individual systems; to clients: ensure that) ▪ **Communication** (feedback to design and construction teams, list of key people and contacts for technical and operational aftercare support, encourage feedback) ▪ **Operation** (operational complexity, personal capacity and life changes over building lifetime)

[2] The 'whole-project' perspective needs a good understanding and knowledge of the ways systems and measures are interrelated affecting each other performance.

[3] The retrofit projects' review includes: the Retrofit Reality project (2008-2009, Gentoo Group), the Retrofit for the Future (2009-2013, Innovate UK), the Ready for Retrofit (2012-2014 Energy Saving Trust) and Superhomes UK (http://www.superhomes.org.uk/). These are projects in mass refurbishment programmes involving typical and deep low-carbon retrofits intervention in both social housing and private owed housing sector.

[4] The analysis borrows the four different construction work stages as these are described in established professional work plan frameworks (e.g. RIBA and Soft Landings) and discussed in following section.

	▪ **Technical support and maintenance risks** (calibration of different measures and technologies lifetime, maintenance interval and complexity) ▪ **Economic assessment** (pre- and rebound effects, installation failures, maintenance difficulty)

A proposed plan of work for retrofit

For over a half century in the UK, the Royal Institute of British Architects (RIBA) Plan of Work has been the model building design and construction process providing a framework for organising and managing building projects for both new and existing buildings (RIBA, 2013). It is a process map and a management tool that organises important processes in a building project of briefing, designing, constructing, maintaining and operating. The RIBA Plan of Work 2013 recognises that 'buildings are refurbished and reused or demolished and recycled in a continuous cycle' -from Preparation to In-use - promoting the importance of recording and disseminating information about completed projects. However, the tasks and objectives described in each of these stages are most relevant to new build and are not detailed or aligned with key issues in a retrofit process. For instance, the initial stages (e.g. Appraisal/ Strategic in RIBA's Plan of Work, Preparation in Figure 1 below) miss important diagnostic actions for evaluating client/occupant past experience and assessing existing building energy performance and indoor environmental quality. Similarly, although project roles are described, they do not include the skills/knowledge needed in individuals (or teams). Neither does the Plan of work suggest the tools and methods that can be used to manage and reduce unforeseen risks in retrofitting existing buildings. In 2012, the Government Soft Landing policy was driven by the UK Government Construction Board as an opportunity to incorporate principles of the Soft Landings framework (SLF) (2009) for both new construction and refurbishment. Since then various amendments to SLF (2014) address the problem of performance gap highlighting the importance of in-use performance, of setting realistic energy targets and understanding roles and responsibilities of different actors in different stages (BSRIA, 2014). An integration of the RIBA work stages and SLF project key activities are summarised in the latest version Soft Landings and Government Soft Landings (BSRIA, 2015). A major strength of this integration for a retrofit project is that it underlines important procedures to progress a project in a rationalised and structured order from commencement to completion and beyond. However, even though it highlights the value of feedback and post-occupancy evaluation (POE) techniques, it does not explicitly review some of the major issues involved in different types of risks in retrofit (e.g. the evaluation of past experience/existing building condition and how this can influence the success of the retrofit is described generically). This is mainly because both frameworks (e.g. RIBA and Soft Landings) have been designed with new build construction in mind, and without explicitly capturing important stages of a retrofit project that close the loop from in-use to design and round to in-use again.

The Plan of Work proposed in this paper integrates into the existing BSRIA (2015) framework additional stages, developed explicitly for retrofits in a continuous cycle with feedback loops between stages (Figure 1 below). It suggests that within different types of retrofit stages and in each of the new feedback loops several different forms of daemons are hidden (as illustrated both in Table 1 and Figure 1). The scope of this is to bring together key issues related to different roles and responsibilities, highlighting the hidden daemons ('good' or 'evil') involved in decisions and choices within these stages.

Diagnosis: One big difference with retrofit (compared to new-build) is the need for an appraisal stage, diagnosing what is already present in the existing building. This will include assessments (and assumptions) about, for example, built form, age and type of construction. Appraisal will also need to include any symptoms of pathologies (e.g. damp, mould, rotting wood) which might need to be treated as part of the refurbishment works. In the Plan of Work this stage is listed first but in reality, it may need to be revisited at later stages, hence the need for feedback mechanisms. A typical example of this in practice is where pathologies only become apparent when work has started. 'Stage 0 – Appraisal' in Figure 1 suggests new core objectives compared with the 'Strategic Definition' in RIBA Plan of Work 2013. The sustainability checkpoints in RIBA's 'Strategic Definition' outline only very briefly that 'a strategic sustainability review of client needs and potential sites needs to be carried out, including reuse of existing facilities, building components or materials' (RIBA, 2013). However, from this task description, it is clear that daemons in this initial stage can be hidden in the detail that is absent. This is important in retrofit because the starting point of the project is not a blank sheet of paper or an empty site. Instead, the existing building represents an assemblage of materials and systems, a history of past interventions, and in some cases there will be pathologies to remedy. Appraisal of the existing building is an important pre-requisite for the design and construction phases, related to activities such as the specification and installation of sympathetic materials. It is a commonplace occurrence in retrofit projects for problems to emerge after the project has started, which means that there need to be feedback loops from the preparation stage back to in-use, construction and design.

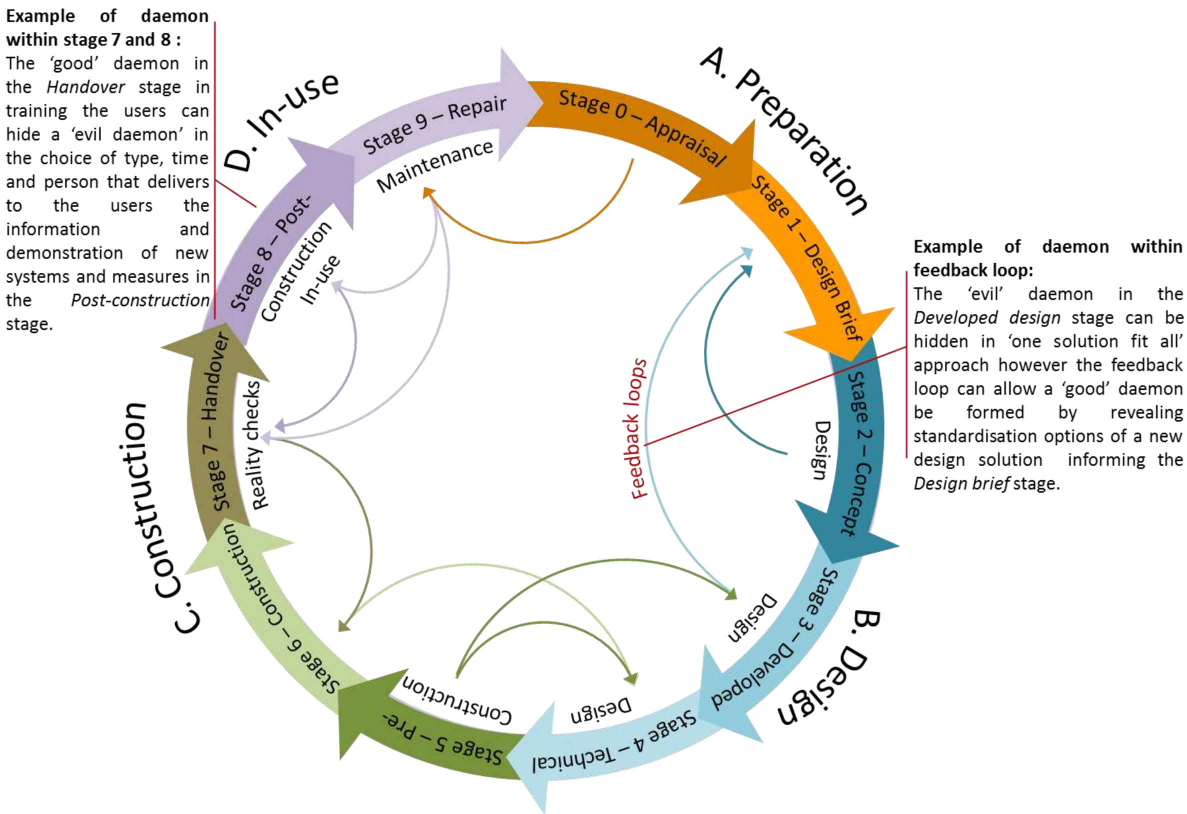

Figure 1 Proposed outline of main work stages in a retrofit process and feedback loops (based on sources (RIBA 2013, BSRIA 2014)

Looking at previous examples of retrofits, the process is generally arranged linearly in three main stages: design and specification, construction, and handover-delivery. In the Retrofit for the Future (RfF) project (2009-13), key features of the deep whole-house retrofits designs (e.g. airtightness, improved fabric insulation levels, renewable energy) had, in the design stage, to comply with a 'whole house' carbon and energy evaluation protocol developed by Energy Saving Trust, with a 'good' daemon's impact, standardising a baseline approach for collecting, measuring and reporting performance information (EST, 2009). This process of evaluating a building's existing condition was a prerequisite requirement in the RfF project to help the design and specification brief, low-carbon strategies and set of requirements for the procurement to be better defined at early stages. However, in practice the insights from this assessment were often turned into a 'tick box' approach ('evil' daemon) that 'fed' modelling or assessment tools mainly to meet the project's energy targets. In the RfF project, ineffective review of a building's existing pathologies in many cases led to less bespoke or accurate approaches offering one solution and one set of technologies to fit all refurbishment cases. Poor understanding of the causes of pre-refurbishment underperformance (technical and operational) and lack of alignment with the early design decisions had an irreversible impact on how some of the RfF buildings were operated and how low-carbon technologies were used (Topouzi, 2015, Gupta et al., 2015, TSB, 2013).

Communication: Communication problems were found to affect early design stages, for instance communicating the POE insights to different members of the design team and the impact this can have in design choices, technical detailing of measures and finally in construction. However, a lack of communication has negative impacts on outcomes at all stages (from early stages of pre-refurbishment evaluation to handover and in-use), especially in understanding the different roles and responsibilities of a client, design and building teams and the ways these responsibilities need to be structured, evolving across all retrofit stages. Feedback loops from design stages need to inform back to preparation stages, with technical and non-technical issues also identified from reality checks on-site from the design or construction team. This process can increase design flexibility and adaptability of technical detailing. From the design to construction stage, 'evil' daemons (Topouzi, 2013, De Wilde, 2014, Gupta et al., 2015, InstituteforSustainability, 2012b, InstituteforSustainability, 2012a), can be also formed by miscommunication of performance targets between client, design team, building team and users. Lack of design detail, over-specification of low-carbon measures and a 'tick box' culture in setting energy targets, misalignment of modelling and simulation inputs with the actual conditions of installation and use, as well as the over-optimism on measures' acceptance and operation by the intended user are often some of the underlying causes (Topouzi 2013, De Wilde 2014, Topouzi 2015) that start at the design stage and affect all stages in the construction and in-use.

Roles and responsibilities: A 'key person' (coordinator, liaison, communicator) can manage daemons' (negative or positive) impact in several stages by: ensuring POE key insights from actual performance and users' needs are effectively communicated to different teams; identifying process gaps in design choices, in teams' knowledge and skills; creating feedback loops that ensure users understand how to operate their home and controls because design teams understand how information and training need to be tailored to the specific users; and, finally, ensuring technical and operational support, maintenance and monitoring is a continuous loop throughout a building's lifetime. In all this, continuity of the same 'key person' leading the project or of the construction teams involved throughout all stages from early design to delivery and handover, is important to the way responsibilities evolve in the retrofit process.

Conclusions

The concept of daemon presented in this paper brings decision-making to the foreground in debates about the design-performance gap in relation to low-energy retrofits. Specifically, daemons relate to practices of implementation, including some which are based on explicit analysis or reasoning, and others which rely on implicit heuristics or rules of thumb. By investigating the type of daemons, in more or less successful retrofit projects, many hidden and unquestioned common practices are revealed as essentially misaligned with the objectives of low-energy construction. In mainstream industry practice, responsibilities fall well short of in-use energy performance. Exceptions to this general rule – such as energy performance contracting – can be found, but it is very rare to find such disruptive business models on projects with ambitious low-energy design objectives.

The fact that so many daemons relate to management and training is worthy of note. Most policy and industry debates on low-energy futures focus on standards, technologies and financial incentives. These largely techno-economic debates tend not to question habitual ways of working and mainstream management of complex projects with multiple stakeholders. And yet our analysis suggests that 'soft' social issues are responsible for the design-performance gap, along with engineering and economic issues. The suggested work stages and feedback loops needed in a retrofit process allows identifying the links between different types of uncertainties and risks that are hidden; the role of the different people involved and how their expertise, skills, communication and responsibilities can form the ground for forming less 'evil' daemons.

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