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Article

The Comfort Tool: Assessment and Promotion of Energy Efficiency and Universal Design in Home Renovations

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Abstract
This article introduces a method for advancing environmental and social sustainability objectives in relation to home renovations laid out in European and Belgian policies. The comfort tool is an instrument that simultaneously addresses the energy efficiency and universal design aspects of a sustainable home renovation while being usable and meaningful to laymen homeowners and improving their communication with building professionals. It is based on recent research exploring a synergetic merging of energy efficiency and universal design in housing through the concept of indoor environmental comfort. It employs comfort as a way of intervening in the decision-making process for energy efficiency and universal design measures in home renovations. The comfort tool takes a user-centered approach and rests on an interdisciplinary set of theoretical constructs bringing together knowledge from psychology, nursing, design, and building sciences. Besides describing the method itself, the article lays out the theoretical underpinnings and motivations behind its development and discusses relevant future considerations for sustainable home renovations research and practice.

Keywords
comfort; comfort tool; energy efficiency; home renovation; universal design

Issue
This article is part of the issue “Zero Energy Renovation: How to Get Users Involved?” edited by Tineke van der Schoor (Hanze University of Applied Sciences) and Fred Sanders (CPONH NGO).

1. Introduction

In response to societal and policy goals on environmental and social sustainability, this research begins from the idea of merging energy efficiency (EE) and universal design (UD), two fields that are typically considered separately in home renovations. The assumption is that merging them could lead to an increased adoption of both in-home renovations by providing a more appealing package of renovation benefits to homeowners.

However, there is a misalignment of objectives between policy and societal objectives for greater application of EE and UD in home renovations and the individual objectives of homeowners when planning home renovations. Renovators are more concerned with the direct perceived impact of renovation measures on themselves and their families, rather than the effect of measures on society. Non-energy benefits appear to be important motivations for homeowners considering renovation measures, with comfort appearing as a key factor in a wide variety of quantitative and qualitative EE studies (Aune et al., 2011; Bartiaux et al., 2014; Grandclément et al., 2015; Mills & Rosenfeld, 1996; Straub et al., 2014; Velux, 2015) while improving the general sense of comfort for the greatest number of occupants is an underlying goal of UD in housing (Steinfeld & Maisel, 2012).

1.1. Tools and Methods for Promoting Energy Efficiency and Universal Design

A significant number of labels and assessment systems have been researched that address EE and UD in housing, although they do so separately. These tools are often created by and for building professionals such as architects, engineers, and builders, resulting in tools that are relatively objective but uninspiring, opaque, and either too blunt or too detailed and impractical for small projects like home renovations where the key decision-makers, the homeowners, are not able or willing to use professional tools.

Checklist-style methods such as the Zilveren Sleutel (Inter, n.d.) by Inter in Belgium, Lifetime Homes in UK (The Foundation for Lifetime Homes and Neighbourhoods, 2016b), and Liveable Homes in Australia (Livable Housing Australia, 2020), are prescriptive in nature and focused on accessibility and disability, rather than the broader design topics covered by UD. The isUD (self-)certification initiative recently launched in the United States takes a more advisory approach by highlighting innovative solutions for UD as a way of increasing adoption of UD (University at Buffalo Center for Inclusive Design and Environmental Access, 2021). isUD is modeled on the more famous ecological assessment tools, LEED and BREEAM, but with the focus, as the name implies, on UD alone.

On the energy side, in Belgium, the RenovatieStarter (Renofase, n.d.) and MijnBENovatie (Vlaams Energieagentschap, 2017) tools are designed to be simple to use and understand by renovators but, as a result of EE government initiatives, are limited to explaining EE measures for their economic or environmental benefits. The EPB-software energy demand calculation software (Vlaams Energieagentschap, 2021), the obligatory standard in Belgium and similar to the RdSAP in UK, gives a detailed and relatively accurate understanding of the home's energy demand. It is, however, also only focused on EE and far too complex and detailed for most users, including many architects.

Indoor environmental quality (IEQ) is a key concept in EE research. Its four main parameters (light, air quality, noise, and thermal comfort) define the comfort goals against which the EE of a building is measured. Frontczak and Wargocki (2011) reviewed the literature on the importance of IEQ parameters on perceived comfort and developed a "template" questionnaire survey for comfort (Frontczak et al., 2012). Kim and de Dear (2012) show that the relationship is not linear. A wide variety of assessment models have been developed (Heinzerling et al., 2013) which most recently aim for "holistic" assessments of IEQ (Leccese et al., 2021; Rohde et al., 2020). However, despite the name, the holistic IEQ assessment methods are, by their nature, confined to the four main parameters of IEQ—light, air quality, acoustics, and thermal comfort—thus not addressing other (universal) design-related aspects that can contribute to perceived comfort in buildings.

The ambitiously named Perfection research project (Huovila et al., 2010) and the design quality indicator (Gann et al., 2003) have made significant strides towards developing a comprehensive set of building quality key performance indicators that take into account environmental performance as well as other spatial, design, and health concerns. However, both are designed for professional use and get weighed down by the complexity of several dozens of indicators. Particularly in the case of Perfection, the indicators require a multitude of experts to understand and assess appropriately. The design quality indicator stands out from the rest for trying to assess subjective design indicators while acknowledging that the measurements in fact have only meaning in relation to the "intents" of the project. The authors point out its value as a tool for thinking about design and as "a starting point for discussion" that facilitates the writing of the design brief and improves communication during the design process.

The RENO-EVALUE project (P. A. Jensen & Maslesa, 2015), in Denmark, aims to place the energy savings and quality of life in the same equation when calculating the economic value of a project. It is a type of multi-criteria decision-making support tool for sustainable renovation projects which can also be used for assessment after construction. The main purpose is to provide a process tool that can identify each stakeholder's priorities and help establish common criteria for success, weighted subjectively by the stakeholders in the early phases of large-scale renovation projects, like social housing buildings (S. R. Jensen et al., 2017). RENO-EVALUE is intended for use on large-scale projects in the professional sector by housing associations, project managers, designers, etc. It is not suitable for small projects without professional clients, like single-family houses.

There has been some more recent work to provide tools and concepts that could help to more holistically understand and motivate homeowners in their home renovations. Kerr et al. (2018) consider renovators as a heterogeneous group and disaggregate them in four renovation narratives that take into account the general home renovation experience as indistinct from an energy renovation.

Wilson et al. (2015) first suggested a situated approach and then developed a contextually rich model (Wilson et al., 2018) for understanding the motivations and process of how homeowners renovate. The model they develop takes into account background conditions of domestic life which spur renovation and identify three particularly influential ones: balancing competing commitments for how space at home is used, signaling identity through homemaking activities, and managing physical vulnerabilities of household members. These, in effect, represent comfort indicators *Usability of spaces* in the first; *Image & identity* and *Elegance* in the second; *Accessibility*, *Safety*, and *Security* in the last. Their model, tested on a UK sample, shows that renovation intentions begin based on these non-energy factors, but the influences on renovation decisions shift during the process. Thus, the authors recommend that "efficiency measures should be bundled into broader types of home improvements, and incentives should target the underlying reasons why homeowners decide to renovate in the first place" (Wilson et al., 2018, p. 1333). The work of Wilson et al. (2015) demonstrates quantitatively many of the same issues and drivers of our own research, such as the focus on non-energy influences on renovation decisions and the idea of bundling EE measures. In contrast, their model is aimed for use by researchers and policymakers to understand renovators rather than for directly influencing the renovators in the decision-making process.

While this is not an exhaustive list of EE or UD tools, to our knowledge it is representative of the current relevant research. It reveals that, even in the rare cases when a more holistic perspective is taken, the intended target is not the homeowner or their aspirations for their home. Hence, at present, there is no tool that: (a) takes both EE and UD aspects into account, (b) points out parameters for improvement from the point of view of the house owner, (c) is sufficiently easy to be used and understood by laymen, and (d) improves communication between house owners and professionals. This article proposes the comfort tool (CT) method as an answer to this knowledge gap.

1.2. Goals and Positioning of the Comfort Tool

The CT is a novel user-centered method for promoting both EE and UD measures in private home renovations. It is an instrument for eliciting the subjective level of indoor environmental comfort (IEC) from the perspective of the inhabitants. Its direct objectives are trifold.

The main purpose of the CT is to raise awareness of EE and UD measures in relation to their impact on comfort at home. It focuses on the perceived benefits of renovation measures, what the people actually experience, rather than on the measures themselves. In other words, it deals with the (non-energy) benefits of EE and the (non-disability) benefits of UD. It broadens the scope of needs or desires of a renovation, and, by extension, it aims to broaden the scope of associated measures to be considered when thinking of renovating. For example, the need of replacing an old window can open up questions about natural light (the size and dimensions), temperature (double or triple glazing), maintenance (the frame material and direction of opening), or accessibility (location and type of handles).

The target group of the CT is home owner-occupiers who have the rights and incentives to renovate but are generally not designers or experts in home renovations. For this reason, the second objective of the CT is to be very simple to use, easy to understand, and yet meaningful in both input and output. In other words, it should measure and output something that is both understandable and relevant to the average homeowner.

Finally, the CT aims to improve communication between residents and experts or building professionals advising in the decision-making process. Homeowners are usually not building experts and often do not have the right vocabulary to explain what they need or why they need it. The tool strives to be a catalyst for deeper, broader, and easier to articulate conversations that start from needs and desires rather than solutions.

For these reasons, the CT does not attempt to be (yet another) source of prescriptive yet general renovation advice. Instead, it is only intended to serve as a platform that energizes and arms would-be-renovators with the right kind of questions, priming them for a discussion with an expert. This approach recognizes the old mantra that "there is no good architecture without a good client." It also recognizes the immense diversity of home renovation situations, diversity of personal preferences, and the ability of designers and other professionals to provide creative and personalized solutions.

In recent research, comfort is identified as an important driver in pushing people forward between each of the four phases of the decision-making process (Klöckner & Nayum, 2016). The phases start from "not in decision mode," which means that the person is considering the idea of a renovation but is not yet making any decisions. A series of barriers and drivers affect the move to "deciding what to do," then on to "deciding how to do it," and finally to "deciding how to implement." The CT is intended to be used largely in the early phases encouraging a shift from "not in decision mode" to "deciding what to do." Here it can help to incentivize residents to consider EE and lifelong living measures by framing them as aspirational comfort measures and by improving communication with the architects or other relevant advising professionals. This approach is supported by Kerr et al. (2018) who argue for developing "holistic narratives" for renovations as people typically don't distinguish energy renovations from a general home renovation. It should be emphasized that the target group is people who are already thinking about renovating but are not sure what to do yet. It is not meant for people who are not considering any renovation works at all.

The article first describes the theoretical foundations and previous research on which the CT method is built upon. The development process and methods are then outlined, followed by a detailed explanation of the different elements that make up the CT method as derived from the theory. Finally, we discuss the CT's limitations and current and future considerations relevant to the practice and research of EE and UD in home renovations.

2. Three Theoretical Pillars of the Comfort Tool

2.1. Comfort as a Product

The first theoretical pillar for the CT is the view of comfort as a product with an associated set of indicators. Comfort is a complex, socially constructed, evolving, and variously understood and debated concept. When used as an umbrella encompassing EE and UD, it is necessary to differentiate between product and process.

Kapedani et al. (2016) have argued that UD and EE are concepts of a different type, UD being a process and EE a product, and that in order to treat them concurrently we need to compare both at the same level. UD and associated terms such as "inclusive design" and "design for all" are most often understood as a process or paradigm for designing buildings (as well as products and services) that are usable by all people to the greatest extent possible (Iwarsson & Ståhl, 2003; Ostroff, 2011). However, we focus on the output or product outcome of the UD process. This interpretation of UD is arguably more in line with the earlier descriptions by Mace (1998). For clarity, in this article, we use the term "lifelong living" which can be considered as a physical manifestation, product, or design output of a UD process. Similar concepts are called "lifetime homes" in the UK (The Foundation for Lifetime Homes and Neighbourhoods, 2016a), "livable housing" in Australia, etc.

A framework that describes IEC as the aggregate impact of the physical features of a home on the inhabitant's individual sense of perceived comfort (Kapedani, Herssens, & Verbeeck, 2017) is used as the basis for the CT. It takes a socio-technical approach and uses as a starting point Shove's (2003) analysis of comfort as a socially constructed concept (see also Shove et al., 2008), and the historical evolution of the notion of comfort at home outlined by Rybczynski (1986). It goes far beyond the technical definitions of thermal comfort. IEC encompasses aspects discussed in IEQ literature (temperature, light, noise, and air quality) as well as design and spatial aspects associated with lifelong living (such as maintenance, accessibility, and safety; Figure 1). The comfort assessed by the CT is thus a product—a socially constructed and individually perceived product, made up of 16 indicators which are further explained in Section 3.1.

2.2. Comfort as a Relative Concept

Comfort as concept that does not have a meaningful absolute value is the second theoretical pillar. Although there are a myriad of definitions and understandings of the concept of comfort, including in the fields of architecture and EE, the CT adopts a particular understanding of comfort as mainly used in nursing literature. Kolcaba and Kolcaba (1991), Kolcaba (1994), and Kolcaba et al. (2006) have progressively explored its meaning, applicability, and measuring tools in the healthcare context. A key feature of comfort in nursing is its lack of an absolute value. In other words, not only is comfort differently perceived by different people, but it is also differently understood by the same person in a different situation. It acknowledges that a nurse cannot measure the absolute level of comfort felt by the patient but only the improvement of perceived comfort felt by the patient as a result of an intervention by the nurse (such as providing medicine, a blanket, or just holding the patient's hand).

This understanding of comfort implies two things: (a) comfort is relative in the sense that it depends on the person perceiving it, so the same home could result in a different sense of comfort for different people; and (b) when measuring comfort there are three elements: an intervention, perceived comfort before the intervention, and perceived comfort after the intervention. In the context of comfort at home, the intervention is the act of renovation—physically changing the home. Therefore, measuring the relative improvement of a renovated home is in fact a measurement of the ΔComfort—of the change in comfort as a result of a renovation from the point of view of the inhabitant who compares perceived comfort before the renovation to perceived comfort after the renovation.

2.3. A Person–Environment Fit

The third theoretical pillar for the CT is the person–environment fit (P–E Fit) theory. The P–E Fit theory originated in the 1970s, with Lawton and Nahemow (1973).

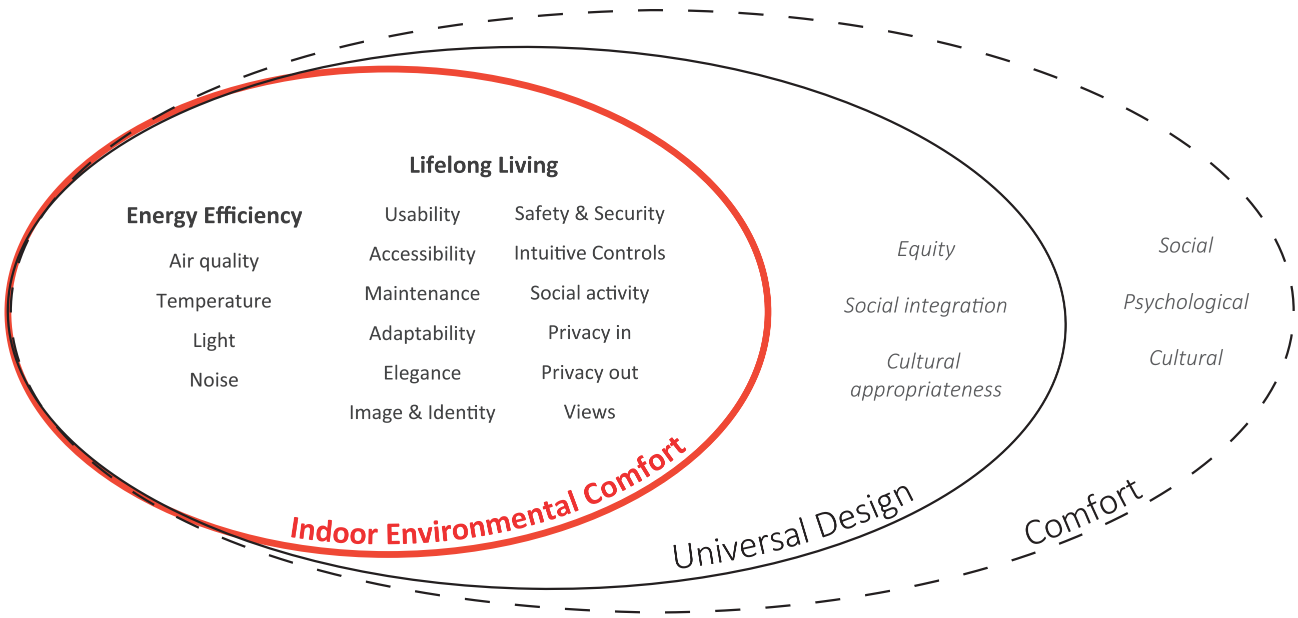

Figure 1. IEC framework and indicators.

It has been adopted in a variety of disciplines and has undergone several adaptations since then (Su et al., 2015). For the purposes of the CT, the various versions and adaptations of P–E Fit are less relevant than the fundamental conceptual model.

The basis of all versions of P–E Fit theory rests on two interacting elements, one human and the other contextual, each with their own characteristics, and the level of congruence between the two determines their fit to each other. In the context of the home, the two interacting parties are the resident and the indoor environment. This implies that if either of the two variables change, then the resulting fit should also change. In other words, the same person would experience a different fit in different environments, and, conversely, different people would experience a different fit in the same environment.

The CT queries both the *resident's preferences* and the *subjective performance* of the indoor environment in the home according to that resident. The fit between the resident's needs and desires and the performance of the indoor environment is what can be termed the comfort fit (CF).

The CT is not alone in using the P–E Fit as a basis. Steinfeld's ideogram "The Enabler" (Steinfeld et al., 1979) was the first to conceptualize disability as something relating to both the person and the building. It charts 188 environmental features which must be assessed against 15 (dis)abilities of a person, producing a "fit." The idea has become a key reference in occupational therapy research and was the basis for Iwarsson's (1999) "Housing Enabler" accessibility assessment method. Both tools need trained assessors to be carried out and are focused on accessibility and as such they present limitations in relation to the CT's intent of including also EE-related indicators. Unlike the "Housing Enabler" which results in a standardized assessment (regardless of the assessor or inhabitant), the original "Enabler" is dependent on the person using the building, i.e., the assessment is personalized. The CT follows this initial approach.

The study of P–E Fit is somewhat similar to studies of residential satisfaction, and some consider the P–E Fit as a key component of residential satisfaction (Kahana et al., 2003). Research on residential satisfaction, like P–E Fit, separates the residential environment from the resident and thus presents the same issues with the dynamic relationship between the two. However, asking separately the same user for the importance *and* the perceived performance of an indicator still offers some important advantages over simply asking about their satisfaction with an indicator. Firstly, studying the two parts of a concept offers more information than studying only the result—higher data resolution. Secondly, not asking directly about satisfaction avoids the social desirability problem with the concept of satisfaction which can lead to overstating (Amérigo & Aragonés, 1997). In addition, it provides conceptual clarity. Satisfaction has general connotations that apply to a more global, aggregate, rather than a specific indicator of indoor environment. Amérigo and Aragonés (1997) argue that indirect methods of asking about satisfaction are superior, despite their validity disadvantage.

Bringing together the view of comfort in the indoor environment as a product that can only be measured in a subjective and relative sense with the CF, it follows that the impact of a renovation is shown by the ΔCF, i.e., by the difference in fit between before and after renovation.

3. Comfort Tool Development and Methodology

Conceptually, the CT has two self-contained but connected parts: the CF assessment and the link with professionals. The comfort assessment method represents the main theoretical contribution of this article. It can be done digitally or by pen and article, with or without a building professional present. However, the resulting comfort profile is better suited to a digital tool to provide immediate feedback to users. Therefore, the CT is envisioned as a website or a digital application. Sections 3 and 4 concern the development of such a tool based on the theoretical principles described above.

3.1. Indoor Environmental Comfort Indicators

The IEC indicators used in the CT are a list of 16 distinct but overlapping and interacting aspects. The 16 indicators were developed through an iterative process of qualitative and quantitative studies. Initially, 21 comfort indicators were distilled from three qualitative studies which asked various groups to describe comfort at home in their own words (Kapedani, Herssens, & Verbeeck, 2017). Then, the results from a survey on comfort indicators (Kapedani, Herssens, Nuyts, & Verbeeck, 2017), the outcome from case studies on passive houses with lifelong living measures (Kapedani et al., 2019), and insights from literature research (see also Section 1.1) were used to fine-tune the list of indicators. Through this process, the list of IEC criteria was gradually distilled from an initially proposed 21 to the current 16. For example, the indicator "artificial light" was eliminated because it was important to only one in 10 people according to the results of the survey (Kapedani, Herssens, Nuyts, & Verbeeck, 2017). Based on feedback from expert participants in the Mutatie+ Living Lab project (Mutatie+, 2018), which was used for testing the IEC framework, the indicators of "safety" and "security" were merged under "safety" since people often used them interchangeably (especially in Dutch) and found the distinction confusing. A similar argument is made by experts, neighbours of the Pilot 2 house project, and colleagues regarding the indicators "adaptability" and "flexibility," and so these are also merged in a common indicator.

Some of the indicators are well understood and directly measurable (at least in theory) such as thermal comfort, noise, and air quality, while others are much more difficult to measure or even define (such as adaptability, elegance, and privacy). Ultimately, the tool relies on a subjective understanding of these indicators, and as consequence on a subjective understanding of comfort. This is purposely done. It is by directing, rather than prescribing these understandings of comfort that the CT works towards its aforementioned goals and reaches a personalized result that is meaningful to each particular user. Providing some kind of standardized and precisely measurable definitions for the IEC indicators could lead to conceptual pitfalls regarding their subjective perception. Gann et al. (2003) reported this difficulty with indicators describing architectural design quality. Discussions around the Fanger (1970) equation and the adaptive comfort model (de Dear & Brager, 1998; Nicol & Humphreys, 2002), which takes into account that people do adapt to their environment, reveal that it is an issue even in engineering-minded IEQ research. More importantly, such standardized definitions would be counterproductive in the drive for an individually relevant and aspirational definition of comfort.

3.2. Feedback and Revisions

The CT has been in development since Spring 2017 when previous theoretical work was used to offer a practical solution for measuring the impact of EE and lifelong living renovation in a pilot project of the Mutatie+ Living Lab, in Belgium, in which three social houses were renovated.

The tool has been continuously fine-tuned based on feedback from several sources until 2019. The partners of Mutatie+, which include experts in lifelong living, EE, and construction techniques, have been involved in a general feedback meeting and a live test of the tool on their Pilot 2 project. The CT was also used with neighbors living around the Pilot 2 house.

Colleagues, most of whom trained as architects, were asked for feedback on three separate occasions. They were first asked in a focus group setting to comment on the list of indicators and the structure of the tool. A few weeks later they were asked to test a limited paper-based version of it with the Mutatie+ Pilot 2 project as a case study. Five months after that, they were asked a final time to comment in a focus group setting after using a functional online version of the tool using their own homes as case studies.

The feedback has been recorded and, after careful consideration to maintain the tool's theoretical integrity and focus on its objectives, the feedback has been incorporated into the tool proposed here.

4. Comfort Tool Design

4.1. The Four Steps in the Comfort Tool Process

Based on the theoretical foundations described above, the CT is designed in four distinct consecutive steps (Figure 2). We first outline the four steps that are part of a full process in the CT. Each step is further detailed in the following sections. First, residents' needs and desires, i.e., their preferences, are queried using the list of comfort indicators. Then the perceived performance of the house on each of the indicators of IEC is gathered. From these two parts of information, a CF for each indicator is calculated in the third step. As part of this step, the improvement potential (IP)—the amount of unrealized CF—is introduced. The last step provides basic information on each comfort indicator and links to experts.

After the renovation, residents can re-evaluate their home in step two and a new CF will be calculated in step three. They can then compare their CF scores before and after the renovation to see an explicit analysis of the impact of the renovation measures implemented. The comparison reveals the ΔCF which is in line with the idea of comfort as a relative concept.

4.2. Preferences and House Evaluation

Residents' preferences and their evaluation of the home's performance are gathered with short questionnaires. First, users are asked to indicate how important each indicator is to them in making a comfortable home. A Likert scale of 1 to 5 is used where 1 means "not important" and 5 means "very important." When evaluating the home, users are asked to rate how well the home currently performs on each indicator. These are the same comfort indicators used for the user's preferences and a similar Likert five-point scale is used. In this

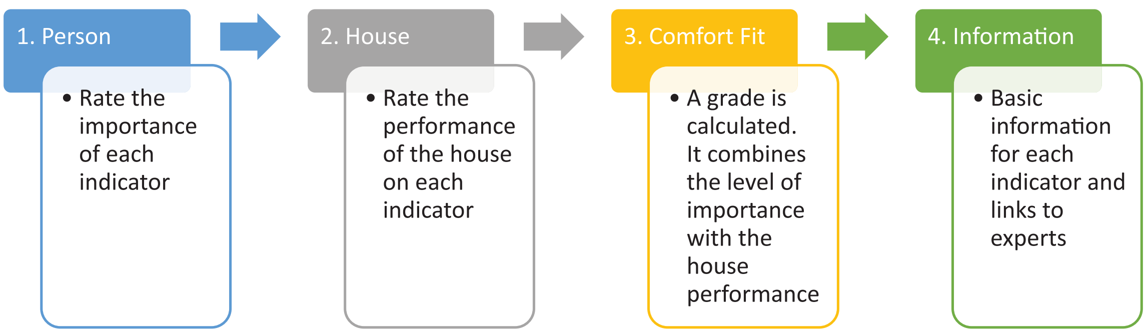

Figure 2. The four steps in the CT process.

case, a 1 means the home performs "badly," while a 5 means it performs "excellently."

A five-point scale was selected over more nuanced scales of seven or nine categories because it would be easier for people to differentiate between each of the five categories of importance (not at all important, not so important, somewhat important, important, very important). Therefore, the results would be coarser but more accurate.

The scores of importance and performance are used to calculate the CF between the home and the resident for each indicator.

4.3. Comfort Fit and Improvement Potential: Calculation and Presentation

The "comfort profile" is what can be called the result or output of the CT. Its calculation and presentation are important innovations of the instrument. The comfort profile shows the IP and the CF on each comfort indicator for the particular user in his or her particular dwelling.

The CF should not be misunderstood as simply the rating of the house's perceived performance by the resident entered in step two. This would ignore the other half of the P–E Fit theory, namely the personal preferences. The CF is a value that combines the performance of the indicator with how important that indicator is to the user. The simple performance rating does not tell us much about the potential impact of any improvements to the indicator, which is the central purpose of the CT.

The comfort profile needs to show how much more can comfort be improved towards an ideal fit—the IP. IP is a positive framing of the perceived shortcomings and expectations of the house in order to stimulate the tool users towards aspirational action.

When the house performance (HP) on a certain indicator is scored as "excellent" (five points), that implies that this indicator cannot, or at least does not need any improvement from the perspective of the homeowner. If it is however rated as performing "very badly" (one point), it implies that the indicator can be improved by up to four points (5 − 1 = 4).

This still only considers the "environment" part of the P–E Fit and does not take into account the person's preferences. The importance (I) of each indicator to the person is therefore introduced as a weighing factor ranging from one to five which moderates the value of any improvements to the house. Thus,

$$CF = HP \times I \tag{1}$$

The lowest score in the scale is set as one, rather than zero, to show that even an improvement that is peripheral to the needs of the residents still has some (although minor) value for them. If a value of zero was allowed, according to the CF formula (equation 1), the value of a significant improvement of an indicator rated as "not at all important" would be zero, which would not accurately reflect reality. The maximal possible fit would be:

$$HP_{max} \times I_{max} = 5 \times 5 = 25 \tag{2}$$

It can be shown that this maximal fit consists of three components (see Supplementary File):

$$\text{Maximal Fit} = CF + [\text{IP if the importance of the indicator does not change for the person}] + [\text{IP if the importance of the indicator increases for the person}]$$
$$\Leftrightarrow \text{MaxFit} = CF + IP_{house} + IP_{person\ change} \tag{3}$$

The goal of the tool is to show how the building can be improved for the person, and not to change the person's ideas about what is/is not important. Hence, the CT will focus on the IP of the house, which is the gap between the ideal performance and the current performance of the house, multiplied by the importance:

$$IP = (HP_{max} - HP_1) \times I_1 \tag{4}$$

The indicators are presented in the comfort profile, a horizontal bar chart (Figure 3), the left-hand side of which is the MinFit = 1, and the right-hand side is the maximum MaxFit = 25. Each indicator is calculated and displayed separately. They are ordered with the indicators that have the highest IP of the house at the top in order to bring them to the viewer's attention. As explained in Section 2.2, absolute values of comfort have little meaning. Therefore, a conscious decision was made to remove numbers from the visualization to avoid creating senseless interpretations. the comfort profile's interpretation is based on an intuitive understanding of magnitude: "a lot," "a little," "more," or "less."

The elements described above are represented in different colors for clarity. Yellow represents the IP of the house. The more yellow there is in an indicator's bar, the more potential for renovation measures to improve the perceived performance of that indicator. The other part of the bar, colored blue or green, is the sum of the CF and the IP if the importance of the indicator increases for the person. These two could be represented separately, but especially the concept of "IP if the importance of the indicator increases for the person" is hard to explain intuitively to laymen. To avoid complexity without increased insight of the target audience, they are grouped and presented as "a part of comfort that can be hardly improved in the present situation." This we can call CF extended (ComfortFit^{ext}), although in the online tool, which is aimed at a non-academic audience, it is simply called CF.

The yellow bar, the IP of the house, can be small due to the small importance of the indicator (see Supplementary File). Thus, the other part, the ComfortFit^{ext}, can be large even if the rated performance of the indicator is low. The ComfortFit^{ext} is colored green except when the rated performance of the indicator is very low (rated 1 out of 5), in which case it is colored blue. This is done to say that the indicator may need attention even if the IP with the present importance is low.

Such is the case of "accessibility" in the hypothetical comfort profile in Figure 3. For example, if we suppose that a user has indicated that accessibility is "not important" (I = 1) and the house performs "badly" (HP = 1), on a Likert scale of 1 to 5, then the IP is:

$$IP = (HP_{max} - HP_1) \times I_1 = (5 - 1) \times 1 = 4$$

And ComfortFit^{ext} would be:

$$ComfortFit^{ext} = 25 - 4 = 21$$

Therefore, a low HP coupled with low importance can give a low IP and high ComfortFit^{ext} score.

As mentioned in Section 4.1, residents can reevaluate their homes after the renovation has been completed. A new comfort profile is calculated using the new rating of the home performance and the same importance scores given before the renovation. The comfort profiles before and after the renovation are presented side by side (Figure 4). In this manner, the difference in CF is not displayed as a value but made apparent visually. This encourages a more intuitive rather than precise understanding by the viewer of the impact of renovations on their perceived comfort. Unlike the individually presented comfort profiles, in the comparison, the comfort indicators are ordered alphabetically.

4.4. Linking With Experts

The final step in the process is not about the IEC assessment but is an important step for the initial motivation of developing the CT: to improve awareness and communication in order to increase adoption of EE and lifelong living measures. Thus, the CT can bridge the gap from dreaming to realization by making it easier for people to connect with experts who would provide personalized advice on how to improve each comfort indicator that is shown to have a high potential for improvement in their home.

Each comfort indicator is connected with a dedicated set of information that provides basic descriptions about the indicator and suggestions of external experts and recognized sources of knowledge on the topic. Due to the widely varied nature of home renovations, the information is intended as a springboard to contact experts who can give more personalized and therefore more relevant advice. It is also not intended as a repository of knowledge on any of the topics. Many such repositories, networks, and tools already exist. The CT intends to simply guide users to that knowledge, framed as a direct answer to their needs/desires for improvement rather than as top-down general advice on how to renovate. It is out-

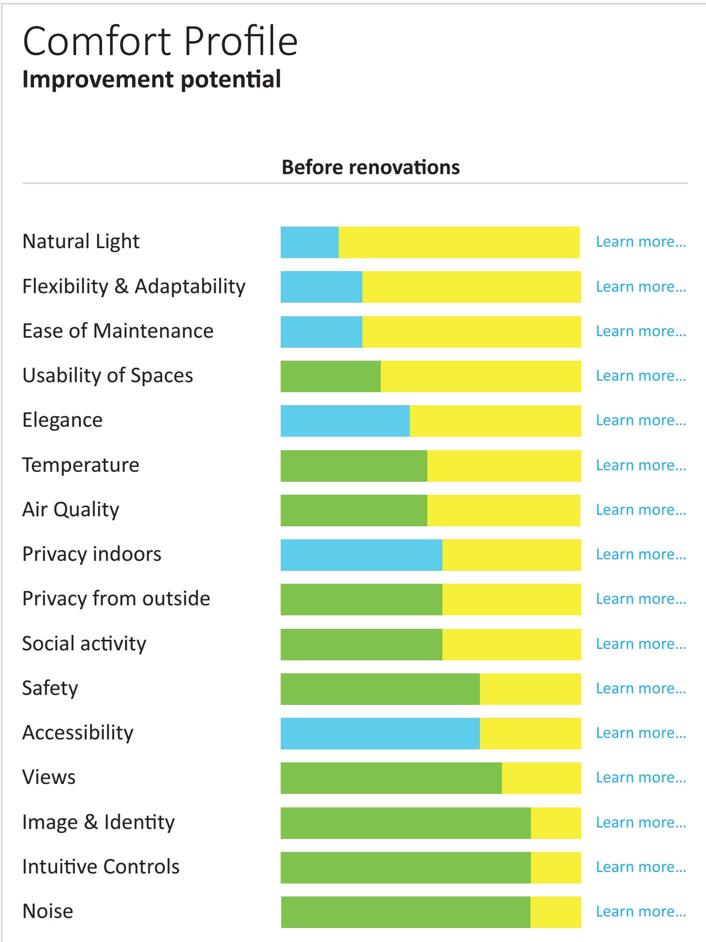

Figure 3. Example of the comfort profile before renovation visualizing ComfortFit^{ext} and the IP.

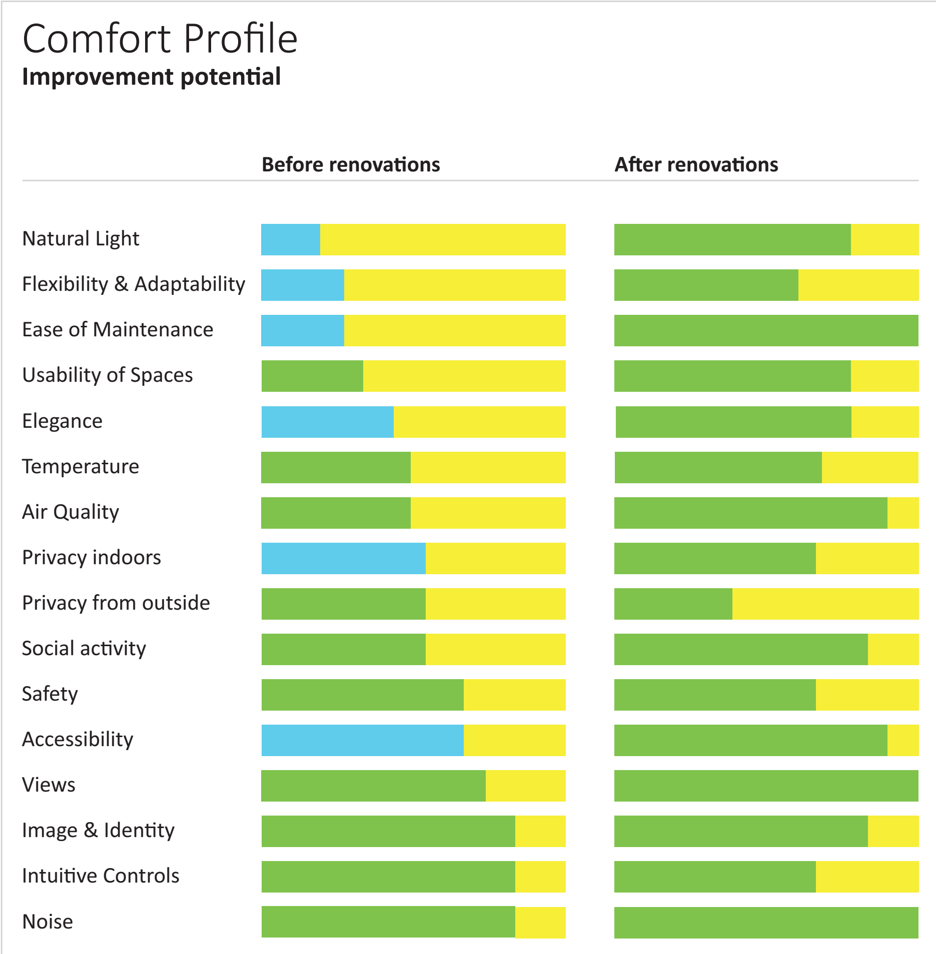

Figure 4. Comparison of comfort profiles before and after renovation.

side the scope of this research to design the way this information is conveyed.

5. Discussion and Conclusions

The CT is first and foremost a tool for thinking, starting, and expanding the discussion between homeowners and building professionals about renovation measures towards the deeper and longer-term needs and desires. The CT relies on a subjectively understood concept of comfort. This makes its results difficult to turn into a standardized assessment or to aggregate and generalize into something like policy guidelines. However, this is not its goal. It is its subjective nature that can make it more relevant to people and link aspirational ideas of renovation with otherwise boring or even depressing discussions about insulation or wheelchair-accessible bathrooms.

The CT also does not directly provide answers or designs for improving comfort indicators. Although it guides users towards information on EE and lifelong living, it cannot guarantee that this will lead to more of those measures. The CT relies on the principled knowledge, wisdom, and experience of designers and other experts to provide sustainable solutions for homeowners. In other words, the instrument does not aim to replace architects, but rather it acknowledges their crucial roles in shaping the kind of solutions that are ultimately adopted and offers assistance in this regard. The CT also acknowledges the crucial role of the homeowners in a home renovation as final decision-makers.

The CT has a structural focus on the individual preferences of inhabitants who are often both decision-makers and not sophisticated in terms of building knowledge. This means that the CT is best suited to single-family home applications. It is not directly applicable to large projects with sophisticated clients and large numbers of varying users such as public buildings, or speculative housing developments where the decision-making client is not a resident and has interests other than the long-term comfort of the residents.

The CT method requires further field testing and refinement. The underlying theoretical principles described in Section 2 and the introduced concepts of CF and IP (Section 4) make for a flexible foundation of the CT method allowing for further revisions, expansions in scope, and a variety of different applications.

One area for further exploration, suggested by some Mutatie+ experts, would be to expand the target group of the CT to include people looking to rent or buy a new home. In this scenario, instead of comparing a home before and after renovation, the tool shows the differences in comfort between the new prospective home (to buy or rent) and the current home, always starting from the needs and desires of the residents. In such a scenario, the CT could be used to visualize the additional value of homes with integrated EE and lifelong living measures, providing another incentive for their adoption.

Another possible use for the CT, in practice, is by building professionals such as architects, builders, and real estate agents to better understand the needs and desires of their clients and to judge how well they have met them. It can be used as a reference for discussions throughout the design, construction, or property searching process. In a similar vein, research questions can be asked about policy assertions that deep energy renovations lead to higher comfort and the CT can be used to assess the actual impact of these deep renovations on the perceived IEC of residents.

In education, the CT can be used as a teaching aid in architectural design studios to expand the scope of design and avoid tendencies to narrowly focus on aesthetics. This approach brings into high relief the wide range of needs and desires a design must consider and the balancing act that a designer needs to perform. In addition, the CT can be used to highlight the relevance of or put into practice knowledge from technical courses on building physics and accessibility by placing them in a context of aspirational comfort—the same characteristics that make the CT meaningful to homeowners.

In sum, the CT is an instrument that takes into account both EE and UD when pointing out aspects of the home in need of improvement from the perspective of the homeowner. It serves as a tool for thinking and a starting point for an informed discussion between homeowners and building professionals. The CT can be used variously in practice, research, and education applications related to architectural design and decision-making in sustainable home renovations.

Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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