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Development and pilot evaluation of an online retrofit decision-making tool for homeowners.

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Development and Pilot Evaluation of an Online Retrofit Decision-Making Tool for Homeowners

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Abstract: Many retrofit projects went wrong in the UK principally because of the application of inappropriate retrofit solutions, which resulted in damp issues, with some leaving houses in worse conditions than pre-retrofit. Various online tools were developed to inform homeowners about the benefits of retrofitting. Prior to this study, little was known about users' evaluation of these tools and the effects of calculator use. Furthermore, no retrofit tool aims to raise the awareness of homeowners about moisture risks in a retrofit project. The originality of this study is to develop and evaluate an online moisture-safe retrofit decision-making tool for homeowners. The adopted methodology consisted of two phases. Phase one aimed to develop the tool. In phase two, semi-structured interviews were conducted to evaluate the tool. The results indicate that the tool has been well received by homeowners. The tool significantly increased participants' awareness of moisture risks related to a retrofit project. Most participants considered the tool an eye-opener, while few of them found it scary. However, the tool did not result in an increased willingness to invest in energy efficiency measures. The discouragement was related to high investment costs and long payback periods of some retrofit measures. Based on our findings, we formulate a set of design recommendations to improve the proposed tool and help retrofit calculators, in general, overcome challenges.

Keywords: decision-making; online tool; retrofit; pilot evaluation; homeowners; moisture-safe

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1. Introduction

In 2020, the UK residential sector emitted 67.7 $MtCO_2$, accounting for 20.8% of all carbon dioxide emissions [1]. UK homes' greenhouse gas emissions need to fall by at least 24% by 2030 from 1990 levels to meet the UK's ambitious goal, which is reaching zero emissions from existing buildings in 2050 [2]. The current rate of retrofitting progress is around 9000 measures installed per week across the whole UK housing stock and needs to rise by around seven times to meet its climate targets. The UK has the ambition to retrofit almost all homes to a minimum of Energy Performance Certificate (EPC) band C standard by 2035 [3].

Researchers have found that insufficient support measures hinder homeowners from investing in energy renovations and recommended states to identify a set of support measures that is appropriate to homeowners by involving them in the preparation and implementation of their strategies [4]. It has been found that information on the capital cost of energy efficiency measures and the amount of energy savings is one of the strongest incentives to encourage homeowners to invest in energy renovation [5].

There have been several projects that aimed to develop simple energy tools to assist homeowners in their renovation projects by providing them with information on energy improvement solutions suitable for their homes. Seddiki et al. [6] provided a comprehensive literature review on existing energy retrofit web decision tools available for homeowners. For instance, Request2Action, which is a European Union Intelligent Energy programme funded project, developed a web-based tool named Home Energy Check (HEC) that aims to familiarise the user with the different available energy improvement solutions and to highlight the implementation of EPCs recommendations and energy savings achieved [7].

Elsewhere, the city of Ghent in Belgium developed a user-friendly web application, "Check Je Huis", that guides homeowners/tenants in their renovation projects. The application helps users to identify the energy efficiency of their home and the possibilities of improving them [8].

Several retrofit tools are available in the UK to help homeowners understand how their houses and flats use energy and how their home's energy is used. The identified tools in the UK are "Home Energy Saving" tool developed by Halifax (part of Lloyds Banking Group) [9], "Energy Efficiency calculator" developed by the UK government [10], "Home Energy Check tool" developed by home energy Scotland [11], "AECB Home Energy Check" developed by AECB—the sustainable building association [12], "Quick Scan tool" developed by the city of Aberdeen (Scotland) [13], and "Reducing home heat loss" developed by energy saving trust [14]. Another tool available for England that is worth mentioning even though it is not destinated for homeowners and targets professionals is the TABULA tool which was developed as part of the European project EPISCOPE [15].

Most available tools for homeowners evaluate retrofit options by taking into consideration energetic, financial, and environmental criteria, while other key characteristics that need to be considered when selecting an appropriate package of improvements are neglected, such as the disruptions caused by the renovation work or more importantly the risks related to moisture after a retrofitting work [6].

In fact, the perceived hassle of installation has been found to be one of the factors influencing house owners' preferences on energy retrofits [16]. As indicated in Glew et al. [17], disruption is an important indicator because it can be a serious barrier to the implementation of retrofit measures, especially if the property cannot be used while the retrofit work is carried out.

Another crucial aspect is the moisture risk in retrofitting projects. Many homeowners are reluctant to undertake renovation works, particularly in traditional houses, because they are afraid that this may cause damp and mould growth issues in the building [18] which would negatively affect the value of the building, the energy performance, and the health of occupants. These worries are sustained by the fact that during the last decade, a large number of retrofit projects went wrong in the UK mainly because of the application of inappropriate retrofit solutions which resulted in damp and mould growth issues leaving homeowners with houses in a worse condition than pre-retrofit [19]. Not only does this undermine the UK target to meet net zero by 2050, but it also costs a fortune to remove the applied measures and redo the work for already vulnerable householders having generally to rectify problems themselves, not to mention the disturbance, stress, and often health issues caused to homeowners. In fact, damp and mould development due to poorly designed and installed retrofit measures are likely to cause respiratory problems, respiratory infections, allergies, or asthma [20]. A report produced by the UK Office of Gas and Electricity Markets (Ofgem's) indicated that 6.9% of the almost 1.5 million measures installed in the UK between January 2013 and March 2015 were inspected, and 9.9% of the examined measures haven't been installed correctly in the first instance and required additional work to be undertaken [21].

After the observation that many retrofit projects failed, the Secretaries of State of the Department for Energy and Climate Change (DECC-now BEIS) and the Department for Communities and Local Government (DCLG-now MHCLG) commissioned an industry-led report "Each Home Counts review" [21]. The aims of the review were to restore the confidence of consumers and of Government in the retrofit industry in order to facilitate new central and local government policies to promote and support a national programme of domestic retrofit. The recommendation made in the report "Each Home Counts review" led the UK government to introduce the PAS2035 standard, which provides a comprehensive methodology on how to perform a retrofit project. The standard introduced a new actor, namely the retrofit coordinator, which is responsible for overseeing the assessment of dwellings, elaborating a risk assessment and management plan, as well as the subsequent specification, monitoring, and evaluation of energy efficiency measures, in accordance with PAS 2035. The retrofit coordinator should have an adequate training to assess moisture risks related to the implementation of retrofit measures which is anticipated to prevent catastrophic situations. However, PAS 2035 is currently compulsory only for public buildings, while for private buildings, landlords and homeowners could install retrofitting measures simply on the basis of an assessment of installers or domestic energy assessors which are not qualified to assess moisture risks and related issues in retrofit measures [22].

Hence, including moisture risks assessment in an energy retrofit online tool for homeowners presents various advantages. On one hand, this could reassure reluctant homeowners that are afraid of moisture issues on the feasibility of managing the risks and would likely encourage them to invest in retrofit measures. On the other hand, for homeowners that are not aware of moisture risks, the online tool would prevent them from implementing risky solutions recommended by a retrofit assessor or an installer and would raise their awareness on moisture risks.

This paper extends the current knowledge by including moisture risks in an online energy retrofit tool for homeowners. In contrast, existing tools evaluate retrofit options by considering only energy, financial, and environmental criteria. Furthermore, little is known about the (positive and negative, intended and unintended) effects retrofit calculators may have on the awareness and the willingness to pursue renovations of their users. The proposed paper extends existing findings by shedding light on the experiences of retrofit calculator users. The paper focuses on the (1) users' acceptance of and satisfaction with the developed retrofit calculator, (2) effects of the tool on moisture awareness and behaviour, and (3) effects of the tool on the willingness to invest in energy efficiency.

2. Materials and Methods

As indicated in Seddiki et al. [6], four major methodologies have been adopted in developing energy retrofit tools for homeowners; empirical data-driven methods, pre-simulated databases, simplified normative calculation methods, and advanced calculation methods. In this paper, the tool development was based on a database of multicriteria assessments carried out for 20 building typologies representative of the UK housing stock. In a pre-simulated database, the energy performance of several combinations of building envelope, HVAC systems, and renewable energy integration is predicted using detailed numerical models of representative buildings. The choice to base the developed moisture-safe tool on a pre-simulated database is motivated by the fact that this approach allows the creation of extremely easy to use tools as they require few inputs and are highly accurate as simulations are performed in advanced simulation engines.

The methodology used to create the tool consists of different steps (Figure 1): First, building typologies representative of the UK housing stock were defined, then the energy model of each building typology was created and validated against statistical data. Then, individual retrofit measures as well as packages of solutions were generated. Afterward, the retrofitting measures were evaluated according to four criteria: energy saving, capital cost, disruption level, and moisture risks. Then, the results of the multicriteria assessment were compiled into a user-friendly online tool. Finally, a pilot evaluation was performed to collect feedback about the tool and requirements for user interface design. A detailed explanation of the different steps is presented below:

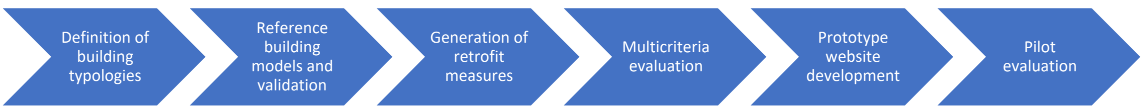


Figure 1. The methodology used to create the online tool.

2.1. Definition of Building Typologies

The first step in developing the moisture-safe energy calculator, which is based on a pre-simulated database, is to define building typologies representative of the UK housing stock. The number of reference buildings is directly related to the accuracy of the data generated by the online tool for homeowners; the greater the number of reference buildings is, the more accurate the results are. However, increasing the number of building typologies makes the development of the tool extremely time-consuming, which is an inherent limitation of the pre-simulated database approach. Hence, a compromise should be reached between the number of simulations and the accuracy of the data provided to homeowners. The reference buildings developed by Bennadji et al. [23] as part of the European project Stronghouse and based on the European project EPISCOPE [15] were adopted in this paper to represent the housing stock of the UK for their geometric data, construction, and energy-related properties.

This study considered 20 building typologies split into five construction periods (pre–1919, 1919–1944, 1945–1964, 1965–1980, post–1980) and four building sizes, including single-family house (SFH), terraced house (TH), multi-family house (MFH), and apartment block (AB). The assumptions regarding building typologies in Bennadji et al. [23] took into consideration the current condition of the housing stock as opposed to the EPISCOPE project, where the energy efficiency characteristics of building typologies have been defined for un-modernised conditions.

2.2. Creation and Validation of Energy Models of Building Typologies

Energy models were developed using the Standard Assessment Procedure (SAP), which is the methodology used by the UK government to assess and compare the energy and environmental performance of dwellings. SAP quantifies a dwelling's performance in terms of energy use per unit floor area, a fuel-cost-based energy efficiency rating (the SAP Rating) and emissions of CO_2 (the Environmental Impact Rating). Other SAP outputs include space heating demand, total delivered energy, cooling load, and so on. PAS 2035 recommends using Full SAP for retrofit assessments [22]. The assumptions regarding building typologies can be found in Bennadji et al. [23].

To validate the energy models, the calculated energy efficiency ratings (the SAP Rating) of the building typologies were compared with the median energy efficiency rating from statistics as it is the only indicator available for building typologies in the four UK countries.

Moreover, it was not possible to compare the SAP rating of the 20 building types separately as the data available in the statistics indicates median SAP ratings for different UK countries either per dwelling type or per dwelling age, and there are no data that combines these two factors in a matrix of typologies. Median SAP ratings were retrieved from the office of national statistics for England and Wales [24], the Scottish house condition survey 2019 [25], and the Northern Ireland house condition survey 2016 [26].

Therefore, to allow the comparison of the calculated data and the statistics, median energy efficiency scores were calculated per dwelling type and per dwelling age. So, for example, the median calculated SAP score for SFH represents the average calculated SAP scores of 5 building types (SFH Pre–1919, SFH 1919–1944, SFH 1945–1964, SFH 1965–1980, and SFH Post–1980). Similarly, the median calculated SAP score for buildings built pre–1919 represents the average calculated SAP scores of 4 building types (SFH Pre–1919, TH Pre–1919, MFH Pre–1919, and AB Pre–1919).

The comparison of median SAP scores from statistics and calculated median SAP scores is presented in Table 1. The result of the comparison reveals an overestimation of about ± 10 EPC points, which is considered acceptable as indicated in Crawley et al. [27] which compared values from the UK national database of all registered EPCs for properties that have had more than one EPC.

Table 1. Comparison of median SAP rating from statistics and calculated median SAP rating.

	Median Energy Efficiency Scores (MEES) from Statistics					Calculated MEES	
Dwelling Type	**England**	**Scotland**	**Wales**	**Northern Ireland**	**UK**	**UK**	**Difference MEES**
SFH	63	61	62	65	62.75	68	5.25
TH	65	65	62	68	65	69	4
MFH	72	67	58	74	67.75	73	5.25
AB	72	68	70	77	71.75	74	2.25
Dwelling Age							
Pre–1919	57	56	55	52	55	66	11
1919–1944	57	62	59	61	59.75	70	10.25
1945–1964	64	64	62	64	63.5	70	6.5
1965–1980	63	66	64	67	65	71	6
Post–1980	71	73	73	72	72.25	77	4.75

2.3. *Generation of Retrofit Measures*

The generated retrofit measures took into consideration three areas of improvement, which were the building envelope, the building services, and renewable energies. The measures targeted a level close to nearly zero building energy requirements, following the concept that if a retrofit measure is implemented, it must be highly energy efficient to avoid missed opportunities, especially in a step-by-step retrofit which represents about 80% of retrofits in reality [28]. In fact, a building that starts with a shallow retrofit will likely never achieve a high level of energy performance in the future, which is called "the locked in effect" [29]. Retrofit measures were evaluated individually and in packages to take into consideration the integrated effect. The saving attributable to a package of improvement measures will be less than the sum of the savings attributable to individual measures.

For each housing type, one pre-retrofit simulation was performed, between eleven (for single-family and terraced houses) and five (multifamily houses and apartment blocks) single Energy Efficiency Measures (EEMs), and one application of all EEMs for a total of about 157 simulations. The list of the selected energy improvement measures included exclusively measures that are commonly implemented in UK retrofitting projects.

The retrofitting measures were customised to each building typology. For example, an ASHP was simulated for single-family and terraced houses, while a new efficient boiler was simulated for multifamily houses and apartment blocks. The general assumptions of the retrofit measures and the energy simulations are detailed in Supplementary Material S1 (General assumptions of the retrofit measures).

2.4. *Multicriteria Assessment of Renovation Alternatives*

To provide users with sufficient information to help them proceed in their renovation journey, individual retrofit measures and packages of solutions were evaluated according to the various criteria indicated in PAS 2035. A brief description of the evaluation criteria recommended by PAS 2035 is presented as follows.

2.4.1. Annual Energy Cost Saving

The annual energy cost savings of the retrofit measures were evaluated using the SAP method. PAS 2035 recommends using Full SAP for retrofit assessments [22]. Retrofit measures were evaluated individually and in packages to take into consideration the integrated effect. The fuel costs embedded in the SAP energy rating were used and the results for each building typology were expressed in GBP/year.

2.4.2. Capital Cost

The capital cost took into consideration only the cash flow required to execute the renovation work (Gross Capital Cost), while concepts such as the ongoing need for capital upgrades not related to energy efficiency, the avoided capital costs, the cost of savings through design, and the cost of subsidies and incentives were not considered. Assumptions for the capital costs of retrofit solutions were retrieved from the latest updated assumptions published by the UK Department of Energy & Climate Change about the costs of different energy efficiency interventions in existing homes [30], from the cost analysis report of the Retrofit for the Future programme [31] and from other sources [32,33].

2.4.3. The Simple Payback Period

A simple payback period (in years) is the capital cost of the EEM or a package of EEMs divided by the estimated annual fuel cost savings [22].

2.4.4. Disruption Level

The level of disruption to occupants has been recently introduced by the UK standard PAS 2035 as well as the retrofit academy in the retrofit coordinator course as a key element in the evaluation of retrofit solutions [34]. Other scientific studies highlighted the importance of inconvenience and disruption during retrofit activities on the decision of households to invest in energy renovation [35]. Issues such as the duration of the work and the incapacity to occupy the building for a prolonged period are important elements of households' decision process along with other aspects such as cost and energy savings. Hence, it is important that occupants have a clear idea about how the retrofit work will affect their use of the building. Assumptions regarding the level of disruption of each renovation measures were expressed in a qualitative manner. The score of renovations measures were taken from the work carried out by the experts of the retrofit academy (see Table 2).

Table 2. Disruption levels [34].

Disruption	Actions
Minimal	Low-energy lamps, energy-efficient appliances
Low	Heating control, cavity wall insulation, draught stripping, loft insulation
Moderate	Replacement boiler, solar water heating, solar PV panels
High	Replacement windows, whole house ventilation, external wall insulation
Significant	Ground floor insulation, internal wall insulation, new heating installation

2.4.5. Moisture Risks

As mentioned previously, one of the main contributions of this paper is to include an assessment of each suggested retrofit solution in terms of moisture risks.

Moisture safe design does not mean that the risks of moisture are all eliminated; it only means that the causes and consequences of moisture are understood, and that appropriate actions are taken to reduce these risks. Often there will be conflicts between the different objectives (energy saving, moisture, etc.). Therefore, a compromise should be reached, and measures to manage the accepted risks should be installed. In some extreme cases, it is even recommended to not insulate because of the high risk of moisture. Moisture risks can be evaluated using dynamic hygrothermal simulation (WUFI), condensation risk analysis (Glaser method), calculation of the properties of thermal bridges and prescriptive guidance [34]. In this paper moisture risks of each solution were evaluated using the UK perspective guidance "Management of moisture in buildings–Code of practice" BS 5020 [36]. For each retrofit solution, the tool presents the results of moisture risks using coloured icons:

1. Green icon: means that the solution does not present a risk of moisture.

2. Red Icon: means there is a risk, but the situation may not be serious. It is advisable to further investigate the solution by numerical simulations.

The evaluation of each retrofit solution in terms of moisture risks and the information displayed for the user are detailed in Supplementary Material S2 (moisture risks).

2.5. Prototype Website Development

The aim of this step is to deploy the pre-simulated retrofit data on a prototype dynamic website. The content management system Wix was used to developing the Portal. Content management systems such as Wix and WordPress have been widely used in the literature to develop prototype websites. For example, Ali et al. [37] used WordPress for the development of a custom app radiator control system for retrofitting legacy heating systems in existing buildings. Similarly, Carvalho et al. [38] used Wordpress to create a web portal for COVID-19 information in Brazil, which helps users publish, organise, and manage content posted on the web. Merritt & Zhao [39] used WIX in order to develop a website for a prototype supermarket. Authors argued that this method offers an intuitive drag and drop site building which can outline the visual aspects of the site.

The website front end of the proposed prototype in the paper was developed using the free and code-free website builder Wix. The purpose of selecting this method was that it is an easy-to-use editor, the system is intuitive, accessibility is built into the system, and the drag and drop functions make editing pages or updating content fairly straightforward (Figure 2).

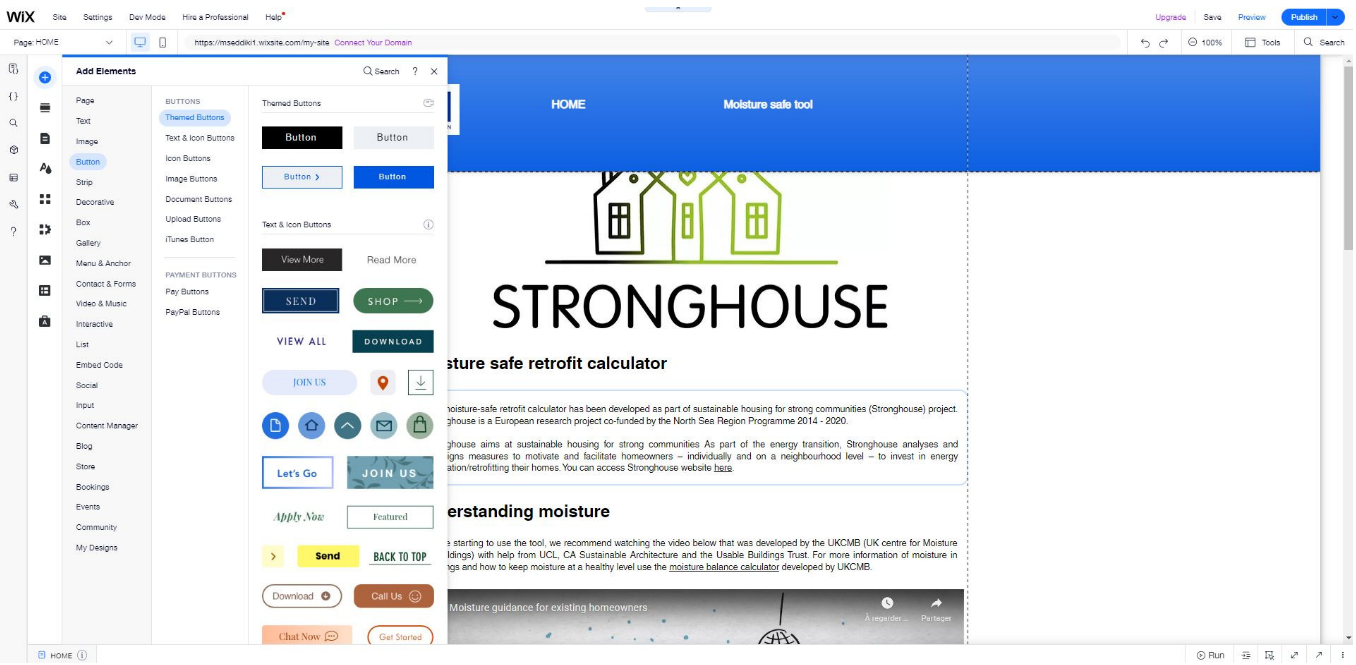
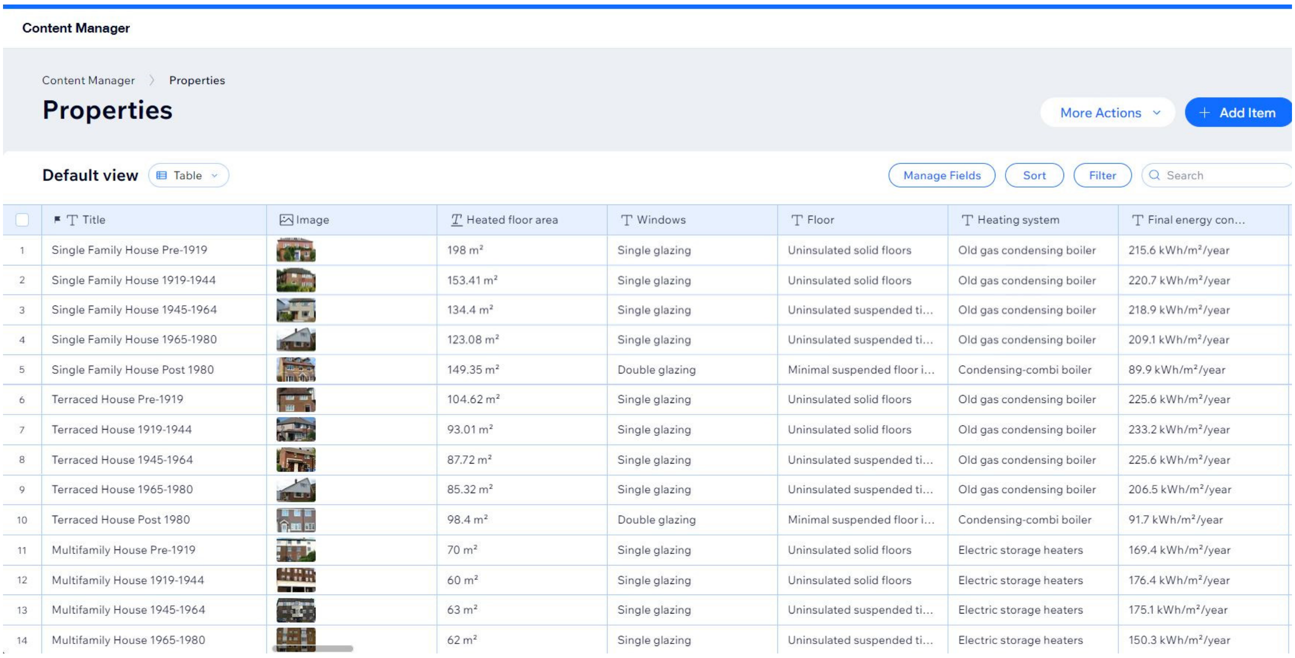


Figure 2. Wix drag-and-drop functionality.

The website back end was developed using the content manager Wix functionality. Content collections were created to store information about retrofit measures. The content is stored in a grid layout made up of items (rows) and fields (columns) (Figure 3).



	Title	Image	Heated floor area	Windows	Floor	Heating system	Final energy con...
1	Single Family House Pre-1919		198 m²	Single glazing	Uninsulated solid floors	Old gas condensing boiler	215.6 kWh/m²/year
2	Single Family House 1919-1944		153.41 m²	Single glazing	Uninsulated solid floors	Old gas condensing boiler	220.7 kWh/m²/year
3	Single Family House 1945-1964		134.4 m²	Single glazing	Uninsulated suspended ti...	Old gas condensing boiler	218.9 kWh/m²/year
4	Single Family House 1965-1980		123.08 m²	Single glazing	Uninsulated suspended ti...	Old gas condensing boiler	209.1 kWh/m²/year
5	Single Family House Post 1980		149.35 m²	Double glazing	Minimal suspended floor i...	Condensing-combi boiler	89.9 kWh/m²/year
6	Terraced House Pre-1919		104.62 m²	Single glazing	Uninsulated solid floors	Old gas condensing boiler	225.6 kWh/m²/year
7	Terraced House 1919-1944		93.01 m²	Single glazing	Uninsulated solid floors	Old gas condensing boiler	233.2 kWh/m²/year
8	Terraced House 1945-1964		87.72 m²	Single glazing	Uninsulated suspended ti...	Old gas condensing boiler	225.6 kWh/m²/year
9	Terraced House 1965-1980		85.32 m²	Single glazing	Uninsulated suspended ti...	Old gas condensing boiler	206.5 kWh/m²/year
10	Terraced House Post 1980		98.4 m²	Double glazing	Minimal suspended floor i...	Condensing-combi boiler	91.7 kWh/m²/year
11	Multifamily House Pre-1919		70 m²	Single glazing	Uninsulated solid floors	Electric storage heaters	169.4 kWh/m²/year
12	Multifamily House 1919-1944		60 m²	Single glazing	Uninsulated solid floors	Electric storage heaters	176.4 kWh/m²/year
13	Multifamily House 1945-1964		63 m²	Single glazing	Uninsulated suspended ti...	Electric storage heaters	175.1 kWh/m²/year
14	Multifamily House 1965-1980		62 m²	Single glazing	Uninsulated suspended ti...	Electric storage heaters	150.3 kWh/m²/year

Figure 3. Data entered into Wix Content Manager.

2.6. Pilot Evaluation

The pilot study involved semi-structured interviews with homeowners that were asked to test the online tool before the interviews. The objectives of the pilot evaluation were to investigate (1) users' acceptance of and satisfaction with the developed retrofit calculator, (2) effects of the tool on moisture awareness and behaviour, and (3) effects of the tool on the willingness to invest in energy efficiency. The pilot also aimed to collect feedback about the tool and requirements for user interface design.

Semi-structured interviews have been wildly used in the literature to test pilot new web-based tools [40–42]. The main advantage of conducting interviews is that they provide in-depth information, as they allow the interviewer to expose information regarding the online tool that are unlikely to be captured through questionnaires [43].

2.6.1. Participants

The potential testers were recruited through a snowball sampling method, which means the author identified a few testers through convenience sampling who then indicated the contact information of other potential testers and so forth. Eligible participants (i) were homeowners; (ii) were located in the UK; (iii) were able to read English proficiently, and (iv) were able to give informed consent. A number of studies in the literature have successfully used snowball sampling in order to pilot online tools [43–45]. From May 2022 to July 2022, a sum of 15 homeowners were interviewed. The participants were aged between 30 to 65 years and had a broad range of educational backgrounds. Their properties were built from pre–1919 to post–1980.

2.6.2. Data Collection and Analysis

Participants were contacted via email and provided with the following information: (1) an information letter outlining study details and requirements of participants; (2) a link to the web-based tool (https://mseddiki1.wixsite.com/my-site); and (3) a consent form. The interview questions included: "Was the tool easy to use?" and "What did you think of the amount of information in the tool?" Participants were also asked what they liked or disliked about the website, how it could be improved, and how the tool affected their understanding of energy improvement options and moisture risks in a retrofit project.

Supplementary Material S3 contains the interview guide used in this research. To verify the guideline for the interview, pilot interviews of two homeowners were carried out before the formal semi-structured interview (the pilot interviews were not included in the sum of 15 respondents). The results of the pilot interviews helped to improve the guideline for the interview.

Interviews were conducted and recorded using Zoom and transcribed into electronic documents. Interviews lasted between 30 and 45 min. Content analysis using the software NVivo has been adopted to analyse the qualitative data from interview transcripts. Content analysis has been commonly used in piloting of tool studies [43,46,47]. Content analysis was chosen as it allows a descriptive approach in both coding of the data and its interpretation of quantitative counts of the codes [48].

3. Prototype Demonstration

The user interface is crucial, as it is the connection between a person and the system. As homeowners are unlikely to be knowledgeable about moisture risks inherent in retrofit projects, a simple web-based moisture-safe retrofit decision-making tool has been developed for them. Some of the interface forms are shown and explained below. Additional details are available on the tool's website [49]. The tool interface and procedure for its operation involve three basic steps:

Step 1: Aims to present the tool and educate homeowners on moisture management in buildings.

Figure 4 shows "My home page", which is the very first phase of the decision process. In this phase, the tool provides information concerning the moisture-safe retrofit calculator, moisture in buildings, the importance of moisture management in a retrofit project, the consequences of moisture unbalance retrofit, and the user interface of the tool.

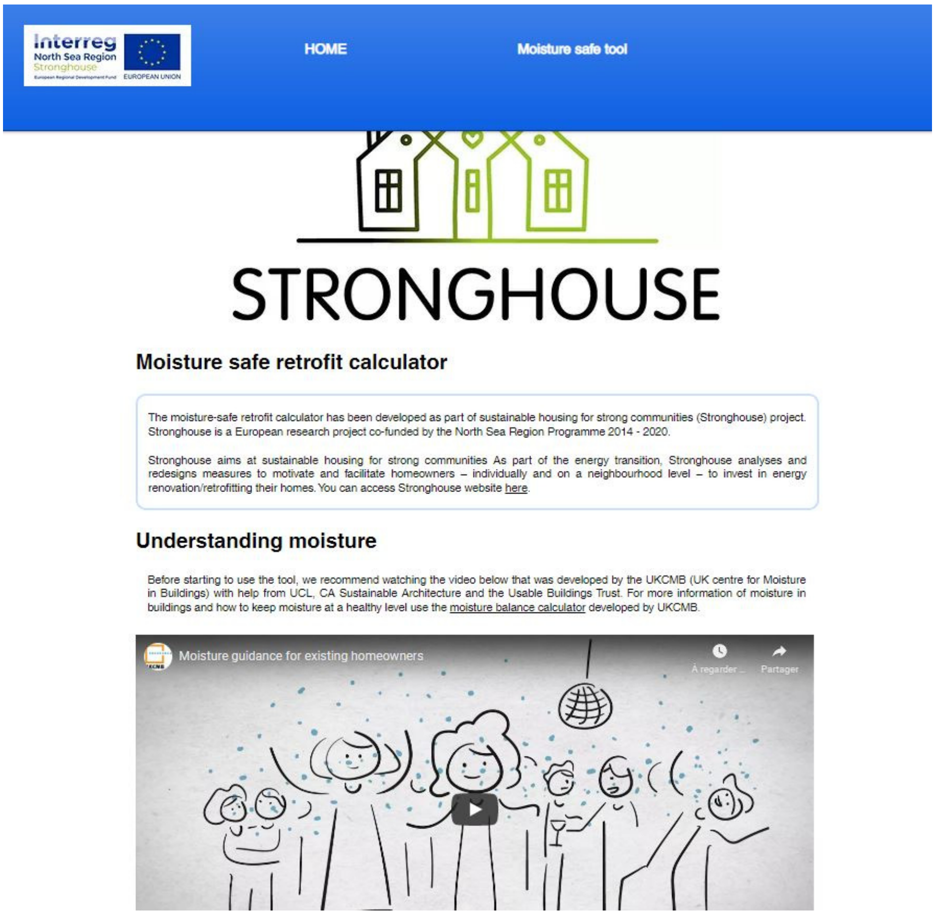


Figure 4. My home page.

Step 2: Input the building type.

In this step, users are asked to select their dwelling type (Figure 5). The tool automatically provides information regarding existing specifications and energy improvement solutions according to the selected building type. The tool considers 20 building typologies split into five construction periods (pre–1919, 1919–1944, 1945–1964, 1965–1980, post–1980) and four building sizes, including single-family houses, terraced houses, multifamily houses, and apartment blocks. Single-family houses encompass detached houses and bungalows. Terraced house includes end and mid terraced houses as well as semi-detached houses. Multifamily house includes converted and low-rise flats. Apartment block includes purpose built and high-rise flats. The reference buildings are based on the European project EPISCOPE [15].

Figure 5. Select your dwelling type page.

Step 3: Display the results.

This step shows the output results of the system. The first section, "Existing specifications", of the results page provides information on the existing specifications of the selected building type, which are based on assumptions in Bennadji et al. [23] and based on Loga et al. [15]. The displayed data (Figure 6) includes property size, type of windows, walls, roof, floor, heating system, ventilation, airtightness, final energy consumption, and Energy Performance Certificate (EPC).

The second section, "Your suggested energy efficiency home improvements", provides a list of suggested energy efficiency home improvements (Figure 7).

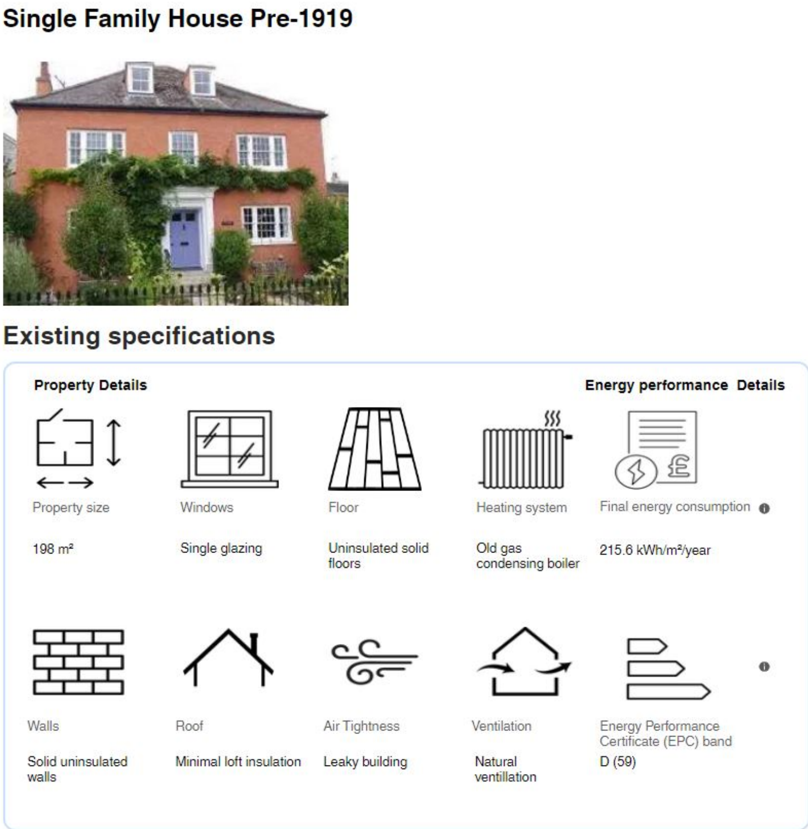


Figure 6. Existing specifications section.

Your suggested energy efficiency home improvements

Click "i" to find out more about moisture risks related to each solution.

Type of improvement	Find out more	Estimated cost	Yearly savings	Payback period	Disruption	Risk of moisture
Floors						
Solid floor with insulation beneath the floor	i	£14,748	£130	113 years	Significant	✓
Solid floor with insulation above the floor	i	£14,748	£130	113 years	Significant	%
Suspended timber floor with insulation between the joists	i	£7,374	£130	57 years	Significant	%
Walls						
Internal wall insulation	i	£11,600	£650	18 years	Significant	%
Cavity wall insulation	i	£1,200	£480	3 years	Low	✓
External wall insulation	i	£20,000	£650	31 years	High	✓
Roofs						
Warm pitched roof (Insulation between rafters)	i	£3,500	£540	6 years	Low	✓
Cold pitched roof (Insulation at ceiling level)	i	£955	£540	2 years	Low	%
Windows and doors						
Replacement of windows doors + mechanical ventilation	i	£32,000	£1,384	23 years	High	✓

Figure 7. Your suggested energy efficiency home improvements section.

Each solution is evaluated individually in terms of estimated cost, yearly savings, payback period, disruption, and risk of moisture. In addition, users can click the "i" icon to learn more about moisture risks related to each solution (Figure 8). Information includes simplified explanations of moisture risks as well as mitigation strategies.

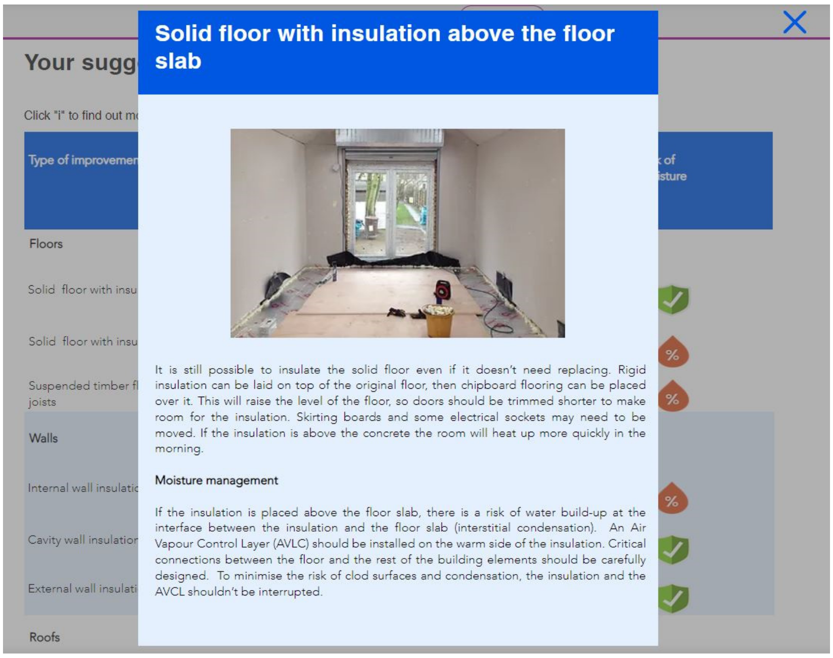


Figure 8. "i" icon to learn more about moisture risks related to each solution.

In the third section, "Upgrade recommendation summary", the upgrade recommendation summary (Figure 9) shows the effect of undertaking all of the improvement measures listed in your suggested energy efficiency home improvements table. Again, the package of solutions is evaluated in terms of estimated cost, yearly savings, payback period, disruption, and risk of moisture.

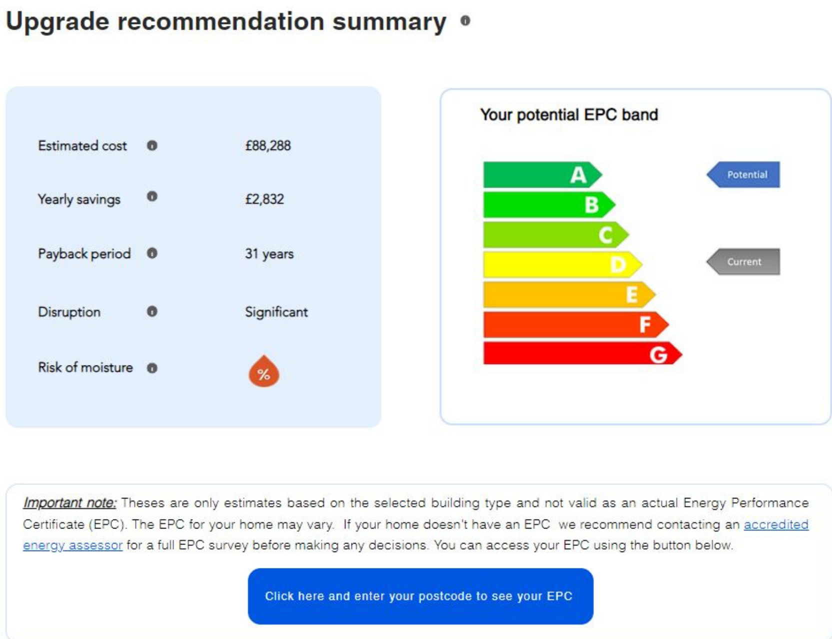


Figure 9. Upgrade recommendation summary.

The fourth section, "Your step-by-step retrofit plan", provides advice regarding the sequencing of the renovation work in the case where the package of solutions cannot be implemented at once (lack of time, money, too much inconvenience, or any other reason). This section introduces the concept of a "medium-term improvement plan" according to the British standard for domestic retrofitting PAS2035.

The tool only aims to raise homeowners' awareness on energy improvement options and moisture risks related to a retrofit project. The results presented by the tool are only estimates and not valid as an actual EPC.

To continue their renovation journey, homeowners would have to contact an accredited retrofit coordinator. Hence, the fifth section, "What's Next?" provides useful links to help homeowners find an accredited retrofit coordinator, determine how they can pay for improvements, and explore hints and tips on dealing with damp and condensation.

4. Discussion

This article describes the development and pilot testing of a web-based moisture-safe retrofit decision-making tool for homeowners. The discussion section is organised into four sections, including the three focal points of this study: user acceptance and satisfaction, increased awareness about moisture, willingness to pursue a renovation project, and the study's limitations. We illustrate our findings with representative quotes from participants.

4.1. User Acceptance and Satisfaction

The pilot-testing phase revealed that the tool was positively received, with all participants reporting that the website was easy to use and easy to navigate. The majority of participants found that they could understand the information.

Participants highlighted the importance of a retrofit tool to combine text explanations with visual illustrations (P1: "you can better understand with images"). "These findings are in line with those by Kok and Barendregt [50]. Participants agreed that data entry was easy and not too time-consuming.

Preferably, online retrofit tools should not require users to enter technical details (P3: "I was thinking maybe I need to measure space in my home [. . .] what kind of windows do I have, or what sort of walls, do I have, so the website did that, for me, by just saying just give us what type of property and we'll do the rest which is a relief because you don't want obviously to overload the user with the burden of finding out all these technical details"). In fact, it is argued that many people prefer a quick-test calculator over a more comprehensive version [51].

Participants indicated that the tool would have been more accessible if it had been adapted to phones' displays (P7: "I have tried to open the website on my mobile phone, but it didn't work"). Indeed, scholars have argued that mobile-like advice tool should be used in energy retrofit communication [44].

Moreover, most participants felt the amount of information was sufficient and that no parts needed to be left out or removed. Participants liked to see the multicriteria evaluation of the retrofit solutions (P11: "the breakdown and the detail provided in terms of the estimated cost and yearly savings and the payback period that was really kind of very helpful in kind of giving me kind of understanding of options going forward"). Participants also appreciated the possibility to click "i" icon to learn more about moisture risks related to each solution (P3: "very much appreciated also to have the additional information next to each of the recommendations, so if I wanted to learn more about each one of the types of improvement, I can go to the to the relevant sites"). They liked that the tool indicates how to find accredited professionals (P9: "The feedback at the end and how to contact a contractor make things easy"). All participants reported that they would recommend the website to other homeowners. This is in line with the study by Collins et al. [52] in which more than 66% of respondents recommended a footprint calculator to others.

4.2. Awareness about Moisture Risks

Most participants indicated that the tool improved their awareness of moisture risks in a retrofit project. This is in line with the findings of Dreijerink and Paradies [53] that online calculators increased participants' awareness of environmental issues. Participants were made aware of different consequences of moisture-imbalanced retrofits (P13: "I was really surprised to know that renovation solutions can lead to dampness"). In that sense, the tool was considered an eye-opener. The new awareness of moisture issues was scary for a few participants (P12: "It was kind of scary for me"). Only one participant said the tool had not increased his awareness (P3: "I would say not by much because obviously here my situation is a little bit [. . .] I had kind of some pre knowledge of some of the options that were available to me"). By educating homeowners on moisture risk issues such as damp and mould, the developed tool is expected to protect homeowners' health.

4.3. Willingness to Pursue a Renovation Project

Most participants reported that using the tool did not increase their willingness to pursue a renovation project. This disagrees with another study in which homeowners evaluated a green home decision-making tool, and it has been found that the tool increased homeowners' willingness to pursue a green renovation [44]. Many participants reported feeling discouraged from investing in energy efficiency measures because of high investment costs and long payback periods of some measures. The discouragement was not related to an increased awareness of moisture issues. P8 said, "holy crap thirty-two grands for windows wow". P3 said, "discouraged is maybe the word, because obviously of the estimated cost and the payback period kind of It makes you think whether it is worth it or not"). For instance, installing solid floor with insulation beneath the floor might show poor return of investment with long payback periods for up to 113 years which exceeds the estimated lifespan of most construction products and buildings themselves. This agrees with a study conducted by Alabid et al. [54] that argued that long payback periods represent one of the main barriers to the implementation of a deep retrofitting approach. The Association for Environment Conscious Building (AECB) argued that to encourage homeowners to invest in a deep retrofit, economic decision-making should not focus only on payback periods and should consider co-benefits associated with improving the energy performance of existing buildings including upgraded health, comfort and perceived wellbeing combined with grants or financial incentives, lower maintenance and running costs, and higher energy prices [55]. Therefore, it may be helpful for online retrofit tools to include co-benefits associated with a retrofit in the financial evaluation in order to reassure homeowners about their investment. Finally, online retrofit tools should not present the users only with the best energy efficiency solutions, which are generally expensive for homeowners. Tools should instead provide users the opportunity to select between a range of retrofit measures (e.g., various thicknesses of insulation, different window types, etc.) from the most efficient to the least efficient solutions in order not to scare homeowners with high investment costs of measure targeting high energy standards (P8: "I think it probably would put me off doing anything, right now, because it it's giving you the most expensive scenario").

4.4. Limitations

Although the developed online tool aims to increase homeowners' awareness regarding moisture issues related to a retrofit project, homeowners cannot rely on decision aids to replace a retrofit coordinator whose job is to oversee the management and design of all retrofit measures [56]. Risks associated with domestic retrofit comprises a much broader range of issues than those addressed by the developed tool, including technical risk such as putting the correct package of improvements in place, managing the interaction between measures, and process risks such as assessing existing dwelling(s) adequately and ensuring that appropriate retrofit designs are developed [34]. Therefore, while the developed tool provides useful and relevant information for homeowners, it is not designed to replace consultation with a retrofit coordinator.

The proposed tool in its actual form has several limitations. It currently considers only a limited number of retrofit measures. A future improvement could be to allow users to select between a range of retrofit measures (e.g., various thicknesses of insulation, different window types, etc.) from the most efficient to the least efficient solutions. Another improvement could be to filter different retrofit options according to budget limitations. Furthermore, to ensure quick and easy data entry, the developed tool is based on a pre-simulated database that includes the most common building typologies in the UK. The user can get an idea of energy-saving options only by indicating the building typology. However, the shortcoming of using a pre-simulated database is that the accuracy of the result is limited. In fact, every house in the UK is unique (occupation pattern, history of modifications, location, etc.). Therefore, it is impossible to generate accurate results for every homeowner based on a pre-simulated database and the displayed information for the users could be significantly different from their actual building data. An alternative way to reach a balance between ease of use and precision of the results is to use automated data collection, as suggested by Bekaroo et al. [57] and Guzman et al. [58]. The future version of the tool could be connected to national EPC databases to collect users' data automatically.

Moreover, the evaluation provided valuable feedback, which will lead to the future development of the proposed tool. Finally, given the small pilot nature of the study, the generalisability of study findings is limited. Further research with larger sample size is necessary.

5. Conclusions

While there are several online tools available to inform homeowners about the benefits of retrofitting, to the best of our knowledge, this is the first study that aims to develop and evaluate an online tool that aspires to raise homeowners' awareness about moisture risks in a retrofit project. Furthermore, the proposed paper extends existing findings by shedding light on the experiences of retrofit calculator users. The paper focuses on the (1) users' acceptance of and satisfaction with the developed retrofit calculator, (2) effects of the tool on moisture awareness and behaviour, and (3) effects of the tool on the willingness to invest in energy efficiency. The results of the pilot study demonstrate that the developed web-based tool has been well received by homeowners. The tool significantly increased participants' awareness of moisture risks related to a retrofit project. Most participants considered the tool an eye-opener, while few of them found it scary. However, another important finding is that the tool did not result in an increased willingness to invest in energy efficiency measures. The discouragement was not related to an increased awareness of moisture issues and was linked to high investment costs and long payback periods of some retrofit measures. The pilot study also generated valuable insights on how to improve the design and development of online retrofit calculators to stimulate the adoption of energy efficiency measures. Future improvements would be to:

1. Include co-benefits associated with a retrofit in the financial evaluation, which will enable retrofit tools to make a stronger case for investment in retrofitting. The co-benefits that may be quantified are the Net Present Value (NPV) calculation, including available grants, operational and maintenance cost savings, carbon savings, thermal comfort, and reduced incidence of asthma.
2. Provide users with the opportunity to select between a range of retrofit measures (e.g., various thicknesses of insulation, different window types, etc.) from the most efficient to the least efficient solutions in order not to scare homeowners with high investment costs of measures targeting high energy standards.
3. Use simple language, a clear design, and use graphics to clarify information.
4. Facilitate easy and quick data entry without asking users for technical details. This can be done by using automated data collection.
5. Use a responsive layout to adapt to various screen sizes.

For future works, the recommendations proposed in this study will be implemented in the future version of the developed tool. Furthermore, large-scale deployment of the proposed tool is envisaged while also planning for feedback from the larger audience. This will also enable a comparison of usability, awareness, and willingness to pursue a renovation project based on the demographic details of the participants.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings12101513/s1, Supplementary Material S1: General assumptions of the retrofit measures; supplementary Material S2: Moisture risks evaluation; Supplementary Material S3: Interview guide.

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