What are the general public's needs, concerns and views about energy efficiency retrofitting of existing building stock? A sentiment analysis of social media data

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Abstract

Energy efficiency retrofitting of existing buildings (EEREB) is critical to combating climate change. While policy interventions that seek to encourage widespread EEREB adoption benefit from a deeper understanding of public retrofit decision behaviour, studies that *comprehensively* evaluate the general public's sentiments towards EEREB are lacking, contributing to a lack of understanding of the public's needs, concerns and views. This study aims to evaluate the general public's needs, concerns and views about EEREB. A total of 3,306 data of the general public's views were collected from the social media platform YouTube, pre-processed and analyzed using the Model-based clustering and a text mining technique. Results showed nine areas of public concerns: ventilation, energy efficiency, indoor environment quality, comfort and occupant behaviour, cost involved, community engagement, technology use, implementation knowledge, and social impact. The general intention to retrofit is mostly driven by personal choices, not regulations per se, although some climate-dependant factors strongly impact public sentiments. Moreover, the recognition of benefits and public support for EEREB was attached to the understanding of cost saving and payback period and finding reliable supply-side actors for retrofit works, respectively. Overall, the public reported positive sentiments (56%) toward EEREB. Novel insights into the general public's needs, concerns and views have been uncovered in this study, which policymakers can utilize to better advocate for EEREB.

Keywords: Energy efficiency, retrofitting, existing buildings stock, sentiment analysis, social media

1. Introduction

The world is confronted with a three-pronged challenge that combines elements of climate change resilience, energy security, and long-term sustainability. The existing building stock plays a major role in both the cause of and solution to these challenges (World Economic Forum, 2022). This is because, during the service-life of buildings, the operations and maintenance phase, the stock of existing buildings account for approximately 75% of greenhouse gas (GHG) emissions and energy consumption, with new buildings only contributing 25% of embodied emissions and energy use (World Green Building Council, 2021). Some existing buildings could be termed "*sick buildings*" – not safe for humanity and nature. Hence, these buildings need urgent revamping. A significant reduction in energy demand from existing buildings is a cost-effective and efficient alternative solution to the three challenges (Kelly, 2009). Improved people's health, well-being and quality of life are additional co-benefits, as are cost savings from reduced energy use and bills. Energy efficiency retrofitting of existing buildings (EEREB) has been implemented as a priority by many national and city governments around the world. For example, the Department of Energy (DOE) of the United States awards $32 million for next-generation building energy retrofits (DOE, 2022). Likewise, to achieve the ambitious goal of reducing the country's emissions by at least 68% by 2030, the UK government has set policy goals to enhance the thermal and energy performance of the existing housing stock (Department for Business Energy and Industrial Strategy, 2020).

Although governments' involvement in pushing EEREB is instrumental, without a strong collective effort, one which heavily involves the general public support and accelerating commitments, EEREB is likely to be confined largely to a small cohort of government projects or stuck in a rut of excessive government intervention. Consequently, several policy interventions/instruments have been used to persuade the general public to undertake energy

retrofit (e.g., regulation, knowledge and information, incentivizing and training) (Galvin, 2014; Liu et al., 2020). Public support for energy retrofits is low despite governmental efforts, and this is true in both developed and developing countries (Huang et al., 2021; Liu et al., 2022). It is argued in the literature that the current design of policies does not do enough to account for the variety of elements that go into the decisions that the general public makes regarding retrofits. (Achtnicht and Madlener, 2014; Kerr et al., 2018). Overcoming this barrier requires a *full* understanding of the general public's decision behaviour from a broader perspective and context. It is important to mention that knowledge about public perceptions and responses does not guarantee support or acceptance, its absence is likely to results in failure (Boudet, 2019). Also, while acknowledging that people without expertise on the topic should not drive energy efficiency initiatives and policy decisions, it should be highlighted that energy efficiency measures are embedded in social habits and contexts (i.e., the mundane practices of everyday life) (Judson and Maller, 2014; Sunikka-Blank et al., 2018), necessitating a *comprehensive* understanding of the aspirations and preferences of the general public when it comes to their homes and indoor requirements. Haines and Mitchell (2014) emphasized the importance of ensuring that the technical solutions being offered meet the needs and aspirations of occupants. This is crucial for promoting the adoption of policy goals for EEREB and also enables business and technology developers to effectively target the right users. It also should be clarified that the general public's needs, concerns, and views not only drive energy efficiency policies but also help facilitate effective communication between policymakers, stakeholders, including energy auditors and retrofit professionals, and the public, and guide the educational efforts that are crucial for promoting widespread retrofitting.

Several studies have attempted to understand the general public's sentiments toward energy retrofit, yet they have limitations (Hwang et al., 2017; Tjørring and Gausset, 2019; Huang et al., 2021). First, prior studies were conducted using structured questionnaire surveys and/or

interviews. This approach presents limited explanation and conceptualization of the public's needs, concerns and views, inability to obtain sentiments and feelings of people at the time of influence, and the possibility of tampering with interviewees' answers (Wu et al., 2021). It also fails to address the concerns of the wider population. Moreover, only the views of experts or specific groups of homeowners who are already interested or had completed building retrofits are mostly considered. Thus, the general public's views and concerns are not fully understood, which may result in the relationship between public retrofit decision behaviour and policy design being undermined. For example, Hwang et al. (2017) surveyed and evaluated the perceptions of only 90 residents who had completed a pilot program on green retrofit in Singapore. Similarly, Tjørring and Gausset (2019) investigated homeowners' perceptions of energy retrofits by interviewing only 12 homeowners who had received energy retrofit advice in Denmark. Although these studies, at least in part, have helped to improve the design of retrofit policies, a more holistic and varied understanding of the opinions of the general public could be more beneficial. Second, the existing studies are mainly focused on a single country or city, lacking a global-wide sentiment orientation. Liu et al. (2022) highlighted that for a better appreciation of how the general public makes sense of energy retrofit, it is critical to have comprehensive perspective, a compiled collection of diverse city-scale population sentiments. Such an orientation is beneficial for decoding and harnessing multiple motivations and needs, especially the social requirements and cultural values, for the optimization of policies for advancing the EEREB practice. In summary, the general public's needs, concerns and views about EEREB have yet to be *fully* investigated.

To fill this knowledge gap, this study aims to evaluate the general public's needs, concerns and views toward EEREB using social media, YouTube, data. A rapidly expanding field of study and innovation is the use of social media for information crowdsourcing, providing a huge and potentially relevant data source (free and publicly accessible) much faster than

conventional survey methods can report. The popularity of YouTube provides an excellent channel for disseminating pertinent information and promoting environmentally friendly and sustainable lifestyles. It helps to capture the reality of the general public's views of a practice. This study makes a significant contribution to the field of knowledge by offering a more *aggregated* and *heterogeneous* understanding of the general public's views toward EEREB. As a result, it provides a strong foundation for modelling energy efficiency decisions in existing buildings. Furthermore, this study can help policymakers and authorities hone the publicity and policy aspects of EEREB promotion. That is, policymakers can devise more appropriate interventions or fine-tune existing policies by integrating the socio-economic and cultural considerations of the general public into the technical interventions and best practices to create more energy efficiency benefits for residents.

2. Literature review

2.1. Retrofit and public acceptance

The longevity of existing building stock – typically 50-100 years – and the rise in energy consumption in buildings indicate that EEREB is crucial (Gram-Hanssen, 2014). Encouraging the general public to retrofit their buildings is the best way to reduce energy consumption, especially in residential buildings (Judson and Maller, 2014). It is generally acknowledged that public acceptance is a crucial component for the large-scale implementation and successful market penetration of retrofit. (Tsoka et al., 2018). The term "*public acceptance*" is often used in energy retrofit; however, clear definitions are barely provided in the existing literature. From the social acceptance theory, Williams and Mills (1986) defined two concepts: "*public*", representing the individual being and interacting groups of society such as consumers and producers, and "*acceptance*", referring to the active involvement regarding new technology. Devine-Wright (2007) highlighted that "*acceptance*" is motivated by a combination of personal, psychological, and contextual factors. Huijts et al. (2012) also found that public

126 acceptance positively correlates with behavioural aspects, which are highly impacted by local
127 authorities' decisions. For a better appreciation of the existing literature, grounded on the
128 understanding of the above conceptualizations, public acceptance in this study denotes the
129 attention and active involvement of the general public (homeowners and residents) toward
130 energy retrofit. It is thus influenced by their motivations or decision behaviour.

131 There is much research on building energy retrofit and public acceptance (Gram-Hanssen,
132 2014; Tjørring and Gausset, 2019; He et al., 2019). A comprehensive survey of these studies
133 highlights that public acceptance of energy retrofit is shaped by a variety of factors such as
134 demographics (e.g., educational level, age, household type, etc.), family dynamics (e.g., stage
135 of life course, roles, children's interests, etc.), experience (i.e., past retrofit experience), beliefs
136 and consequence (generally considered as drivers), dwelling characteristics, authorities and
137 policies, social influence, among others (Liu et al. 2015). For example, while some studies
138 (e.g., Azizi et al., 2019; Abreu et al., 2020) found that younger and higher educated
139 homeowners seem to be more environmentally conscious and mostly implement energy
140 retrofit, other studies provided a contradictory result (Urban and Ščasný, 2012; Trotta, 2018).
141 According to some studies, demand for energy retrofits is also responsive to retrofit costs,
142 relative energy prices and income (Alberini et al., 2013; Friedman et al., 2018). Jakob (2006)
143 claimed that energy retrofit, to a large extent, is driven by technical and occasional factors,
144 rather than income, age, or education. In another study, Tjørring and Gausset (2019) noted that
145 the primary motivation for an energy retrofit is perhaps not saving money but social. In
146 addition, the motivation or feedback obtain from social networks (e.g., friends, neighbours, and
147 others) is regarded as an important source of information to stimulate energy retrofit (Abreu et
148 al., 2017). Homeowners trust this kind of information, which inspires confidence in retrofits
149 implementation (Liu et al., 2022). Meanwhile, the lack of valuable retrofit information has been
150 noted in extant studies (Alam et al., 2019; Jia et al., 2021). Mora et al. (2015) concluded that

for a greater public interest, the definition, benefits, and limitations of energy retrofit need to be better communicated. While policy interventions are recognized as the largest mechanism for promoting energy retrofits (Kerr and Winskel, 2020), there are still concerns that the scope of current policy initiatives is insufficient to achieve long-term goals.

2.2. Retrofit policy design and a heterogeneous population

Most theories in the field of policy design to encourage energy retrofit are based on research on behaviour and decision-making. Prior studies have found that policy interventions are influenced by rational choice interpretations of behaviour (Wilson and Dowlatabadi, 2007; Maller and Horne, 2011). These models present actors as largely self-interested, rational, and eager to seize opportunities that are most cost-effective (Jackson, 2005). Policies emanating from this perspective are inclined toward the costs and benefits of retrofit (Kerr et al., 2018), disregarding the non-financial influences on behaviour and dismissing the importance of the social context in which decisions are made (Ackerman, 2008). Other theories such as behavioural economics and social practice contradict rational choice expectations. While behavioural economics research sees individuals as hesitant to enter a substantive decision-making process (Gigerenzer and Todd, 1999), social practice theory treats actors as a "crossing point for practice" – wherein individuals are no longer seen as the focus of inquiry (Karvonen, 2013). Individual behaviour and the resulting energy demand, according to the latter interpretations, are the result of socio-technical context rather than individual agency. The above theories therefore suggest that the increase in information available on possible options is crucial, in order to influence individual behaviour.

Numerous studies have emphasized the need for research to be situated more within the context of domestic life (Kerr et al., 2018; Tjørring and Gausset, 2019), as the previously mentioned explanatory factors only have a direct and immediate impact on behaviour (Wilson et al., 2013). Regular calls to view homeowners as heterogeneous rather than homogeneous are

176 also learned (Wilson and Dowlatabadi, 2007; Stieß and Dunkelberg, 2013). Following the call,
177 many studies have segmented retrofit populations by demographics, specifically by age and
178 tenure (e.g., Azizi et al., 2019; Abreu et al., 2020). Although these studies offer the chance to
179 identify the people making retrofit decisions and develop more targeted policy interventions,
180 they are limited in terms of diversity (consider only the views of a subgroup of the general
181 public – so-called "experts") and comprehensiveness (lack a global-wide sentiment
182 orientation). The extant literature does not adequately investigate what is known about the
183 general public perceptions and attitudes towards EEREB. Mora et al.'s (2015) study was the
184 only one that specifically analyzed public perceptions, but it focused on seismic improvements
185 for disaster risk reduction rather than energy retrofitting with seismic upgrades. Hence, to
186 derive a greater understanding of public sentiment, it is critical to have comprehensive
187 perspective, a compiled collection of diverse city-scale population sentiments about EEREB.
188 This goal is achieved using EEREB-related data from YouTube.

189 **3. Methodology**

190 This study analyzed social media data retrieved from YouTube to assess how the general
191 public feel about EEREB, rather than other social media platforms such as Facebook, Reddit
192 and X (formerly known as Twitter). The justification for this is that compared to the other
193 social media platforms, YouTube is the most popular video hosting website (Balakrishnan and
194 Griffiths, 2017), suitable for facilitating and promoting environmentally friendly and
195 sustainable lifestyles. Moreover, YouTube has over 2 billion monthly active users and almost
196 43% of all global internet users access YouTube each month (Dean, 2021). Lastly, YouTube
197 is home to huge construction and architectural related channels such as the "The B1M" with
198 2.640 million subscribers, "Modern Builds" with 1.730 million, "Fix This Building That" with
199 1.500 million, among others. The overall methodological framework is shown in Fig. 1 below

and described in detail next. All tests, including data retrieval, data pre-processing, sentiment analysis, clustering, and topic modelling were carried out using the RStudio programme.

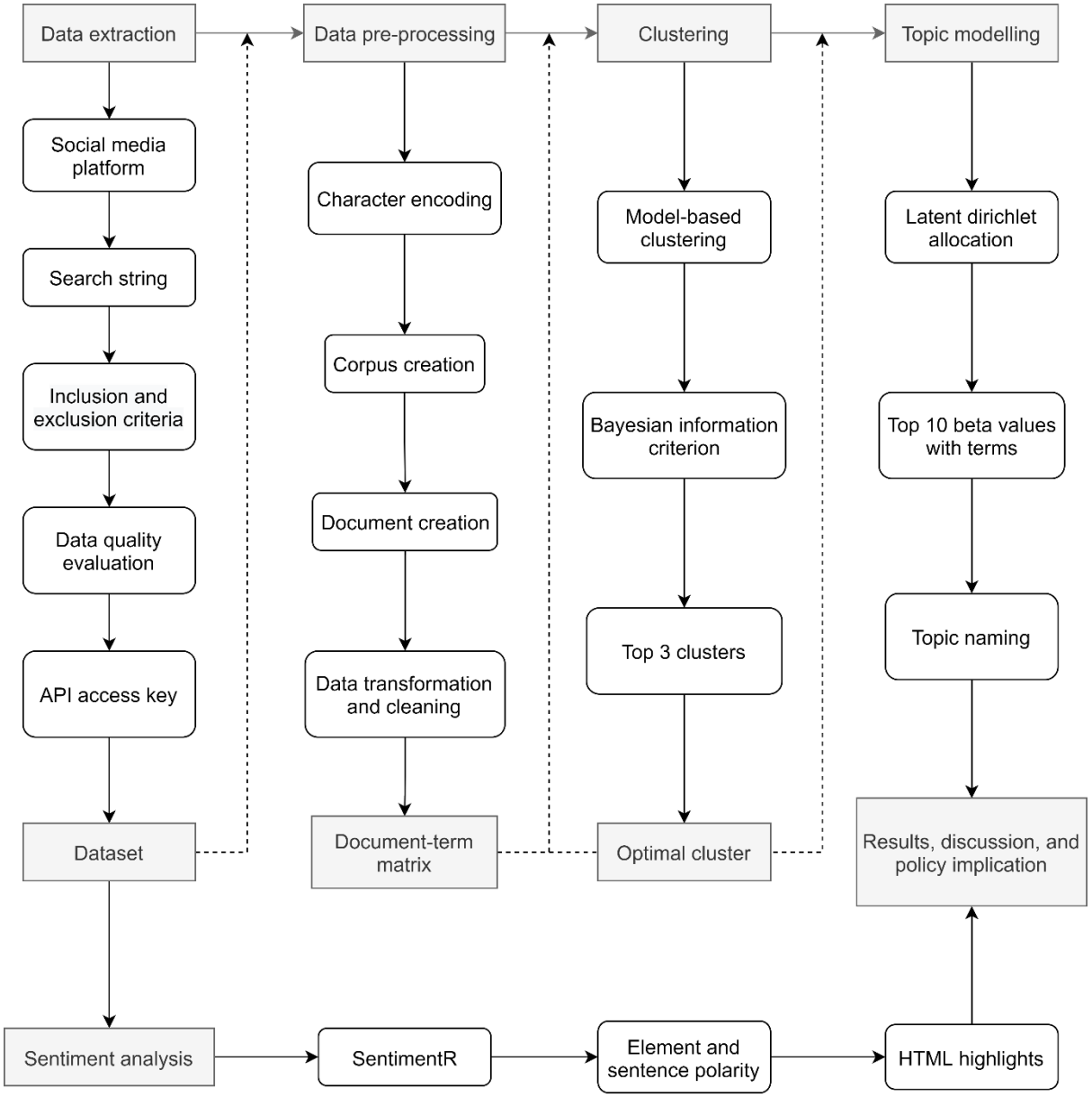


Fig. 1. Methodological framework for modelling social media data.

3.1. Data extraction

On April 18, 2022, a YouTube search for the term "energy efficiency retrofitting of existing building" was conducted using a list of conditions. If a video had more than 1,000 views, five or more comments, and the subject matter was on retrofitting of existing structures for energy efficiency, it was chosen for further investigation. This is because such videos have gained

significant public attention. Moreover, to guarantee a certain degree of interest, interaction, and topic appropriateness of the subject matter, this inclusion criterion was crucial. Videos that were not in English, unavailable, or duplicated were also removed. This filtering process led to 31 potential videos of interest. The videos were further evaluated using an adapted version of the Medical Quality Video Evaluation Tool (MQ-VET) to fit the research purpose and industry (Guler and Aydin, 2022). Currently, there are no officially validated instruments available for assessing the quality of construction-related YouTube videos. However, there are a number of measurement tools used in the medical field that have been adapted in other contexts and disciplines. Popular among them are the DISCERN instrument and Journal of the American Medical Association (JAMA) benchmark tools (Charnock, 1998; Silberg et al., 1997). Nevertheless, these instruments have been criticized as not being suitable for evaluating videos on YouTube, primarily because the tools were developed to assess written information or websites, but not videos. The MQ-VET was designed for both medical professionals and the general population to assess the quality and content of a YouTube video (Guler and Aydin, 2022).

All the 31 potential videos were evaluated independently by two authors with at least eight years of practical experience in construction and four or more years of engaging with the industry in retrofitting of existing buildings. The 15-item validated instrument, MQ-VET, was used to assess the quality of information on the EEREB in the YouTube videos. As recommended for the MQ-VET evaluation tool, ratings from 1 point (strongly disagree) to 5 points (strongly agree) was used for this assessment. Afterwards, a composite mean score is calculated to establish the overall quality the 31 videos as very poor (16-26), poor (27-38), fair (39-50), good (51-62), and excellent (63-75) (Cassidy and Baker, 2016; Szmuda et al., 2020). Some of the items in the questionnaire are “The video covered the basic concepts of the subject” and “The information in the video is clear and understandable” (Guler and Aydin, 2022). Out

of the 15 items in the survey, only two questions that specifically mentioned “medical” were modified to read “retrofitting of existing buildings”. For example, “The medical terms used were well-explained”, was modified to “The retrofitting of existing buildings terms were well-explained”. Nine of the videos had their composite mean scores within 38 to 46 and hence were removed, while the remaining 22 videos had their composite mean scores within 60 to 72.

The 22 videos on retrofitting existing buildings for energy efficiency were chosen, and their video identifications (IDs) were collected. The vosonSML package was used to secure the YouTube Application Programming Interface (API) using the video IDs. An accompanying Google developer API key was used to authorise entry to the YouTube API. The vosonSML kit includes techniques for gathering information from social media and creating networks for study (Gertzel et al., 2022). The number of comments that could be gathered had no upper bound. Following the extraction procedure, 3,306 data (including threads and replies) were gathered, resulting in almost two million views of the videos. Fig. 2 gives a thorough summary of the data. Generally, there were an average of 150.278 comments, with at least 8 and at most 584 comments. There were an average of 112,640.455 views, a minimum of 1,229 and a maximum of 480,979.

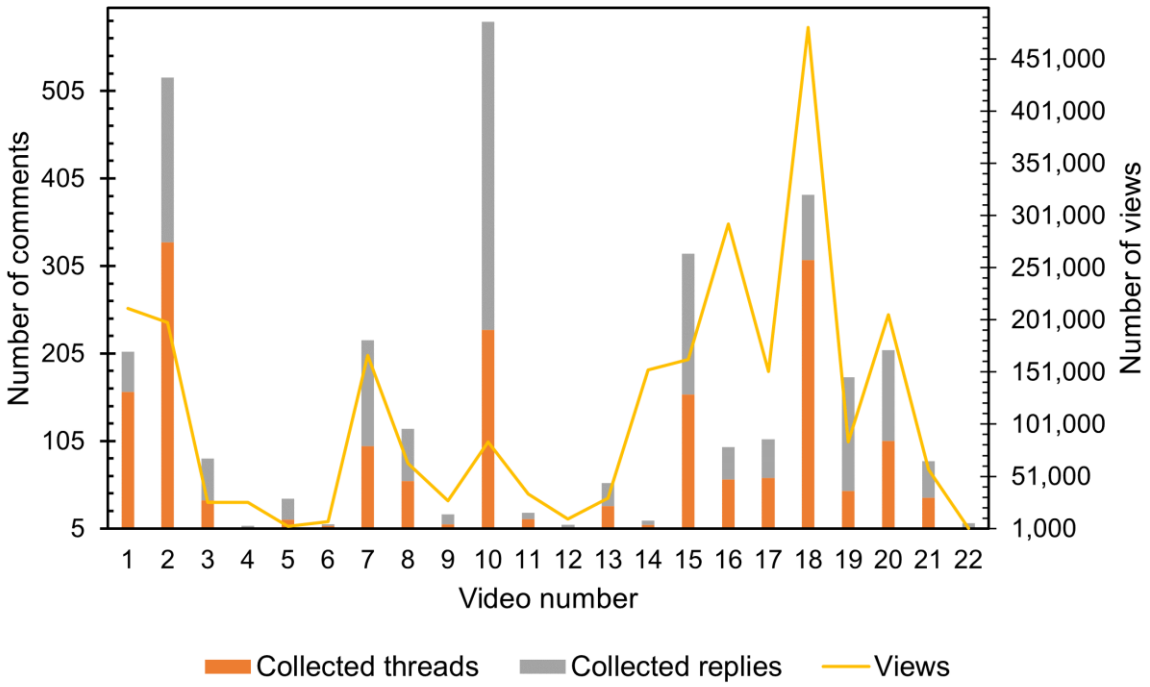


Fig. 2. Description of collected YouTube data on EEREB.

3.2. Data pre-processing

The dataset was cleaned and transformed using the text mining framework provided by the "tm" package (Feinerer, 2020). This process was to clean and convert the raw data into a format that can be used by the subsequent modelling tools. To do this, first, the character vector state of the data was converted to UTF-8 to encode the characters of the data to create a corpus. The vector source function was then applied to the corpus, to interpret each element as a document within the corpus. Transformations in the "tm" package were applied to functions of modifications to all elements of the corpus (Feinerer, 2020). This included, removal of extra whitespaces, removal of English stopwords such as "the", converting all cases to lower case, removing numbers, uniform resource locators (URLs), and irrelevant punctuations such as multiple use of "?" in a repeated way. The class "DocumentTermMatrix" was further used to create a term-document matrix from the corpus. This associates each row with a document and columns with a term (Feinerer et al., 2008).

3.3. Clustering

Traditionally, clustering methods such as k-means and hierarchical clustering are used to determine certain data points in a dataset as belonging to a group. Before initialising these heuristic algorithms, "k", that is the number of clusters, must be pre-determined. However, this suggests a certain level of subjectivity that may influence the results. A significant flaw with the popular k-means algorithm is that it is sensitive to the first partition choice and may reach a local minimum of the criterion function value if the starting partition is improperly selected (Jain et al., 1999). In other words, k-means algorithm rests heavily on the initial position of the cluster centres and if not selected correctly, may not be the best possible solution. A more robust alternative is the model-based clustering which offers a chance for each data point to belong to a cluster. This unique clustering algorithm uses finite mixture models to perform clustering (McNicholas, 2016). The model-based clustering also addresses the statistical choice problem by automatically determining the number of optimal clusters.

For this study, model-based clustering was employed to iteratively fit the term document matrix derived from the dataset by optimising the distribution parameters so that the data points are allocated to a distribution of that cluster. This was applied by employing "Mclust", an R package implementation of model-based clustering (Fraley and Raftery, 2002). "Mclust" offers methods for simulating from normal mixture models with a range of covariance structures as well as functions for parameter estimation using the expectation-maximization (EM) algorithm (Scrucca et al., 2016). Upon initialising the model, the algorithm employs the Bayesian Information Criterion (BIC) to determine the optimal number of clusters. The BIC continues to be the model selection criterion of choice in most scenarios (McNicholas, 2016).

3.4. Topic modelling

A text mining technique called topic modelling adopts a variational EM method to identify the latent thematic structure among a collection of texts (Blei, 2012; Blei et al., 2003). The

most straightforward and popular topic model is Latent Dirichlet Allocation (LDA) (Jiang et al., 2016). “Topicmodels” package is an implementation of LDA available in R (Hornik and Grün, 2011). This study applied the "topicmodels" package to the DocumentTermMatix to find hidden themes in the data and organise the words in the matrix under each theme. The number of topics k has to be specified prior to estimation. Based on the model-based clustering, k is fixed at nine within the LDA function. The variational EM is then used to estimate the latent variables by making inference on variational posterior probabilities (Hornik and Grün, 2011).

3.5. Sentiment analysis

Sentiment analysis is a branch of research that examines negative, neutral, and positive opinions, attitudes, emotions, and judgments about an item. It is one of the main areas for data mining and natural language processing (NLP) research (Liu, 2012). The growing interest in this research topic is related to the exploding volume of opinionated data on social media sites, such as Reddit, X, Facebook, and YouTube. The foundation of social media research today is sentiment analysis. Due to the vast amounts of unstructured data present in social media, automated systems are required in order to extract the subjectivity and polarity from such data. The ordinary human reader finds it challenging to recognise, extract, and summarise sentiments in the vast amounts of written content on social networking platforms, making sentiment analysis important (Liu, 2012).

People's perspectives on the energy efficiency of retrofitting existing buildings were analysed using the “SentimentR” package developed by Rinker (2019). This package was used to calculate the text polarity sentiment of each sentence within a comment as well as an average sentiment of the whole comment. SentimentR was considered as the package of choice for this study due to its capacity to account for valence shifters such as negators (e.g., no, not, never). Negators can change the polarity of a text (Dadvar et al., 2011). As a result, the treatment of negators is considered as a critical issue in sentiment computation. At the sight of a negator,

most sentiment analysis packages may inverse the polarity and classify the sentence as conveying negative opinions without considering the scope and context. Currently, all other packages fail to correctly account for negators, with the sole exception of SentimentR (Naldi, 2019). For example, in Fig. 3, SentimentR correctly classified c#10 and c#1,638 as expressing a negative opinion, with c#1,638 having a more negative weighting. Whereas c#137 and c#498 have complex integrations of negators, SentimentR is capable of noticing the impact of these negations to properly classify the comments as conveying positive opinions.

To implement SentimentR, first the "get_sentences" function in SentimentR is used to extract all sentences from the 3,306 comments text data. Afterwards, the "sentiment" and "sentiment_by" functions are applied on the extracted sentences to derive both the polarity scores for each sentence in a comment and the average sentiment for that comment. Overall, 8,757 sentences were derived from the 3,306 comments. Next, the "highlight" function was used to wrap the average sentiment scores associated with each comment into a highlighted HyperText Markup Language (HTML) file. As shown in Fig. 3, a green colour indicates a positive sentiment and pink suggests a negative sentiment. Neutral has no highlights.

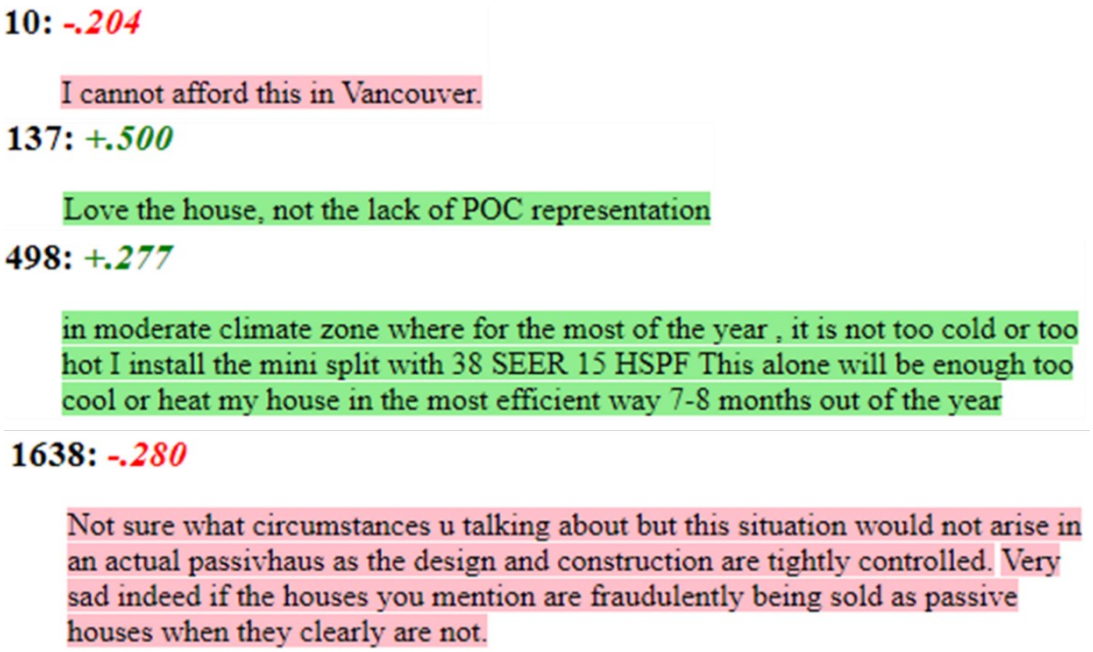


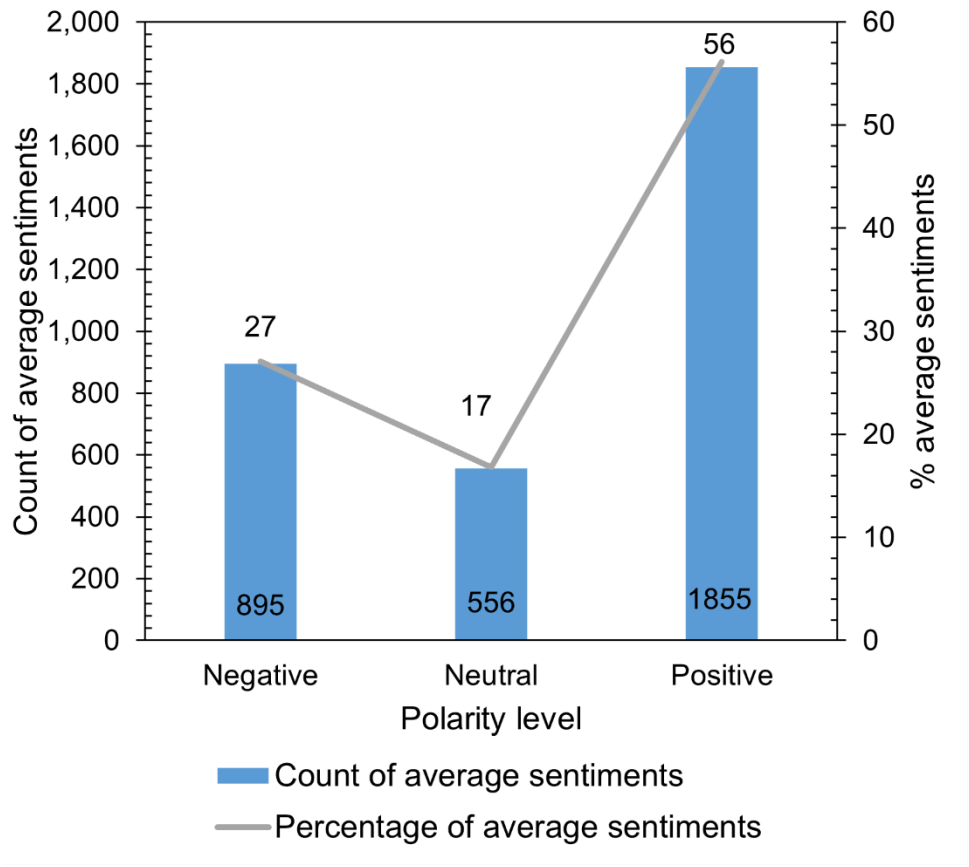
Fig. 3. SentimentR accurate polarity recognition on sample comments with negators.

4. Analysis and Results

4.1. Assessment of sentiment polarity

Figure 4 shows the results of the sentiment analysis procedure. Overall, majority (56%) of the comments towards EEREB were positive, 27% were negative and the remaining opinions were neutral (17%).

Considering that there are different degrees of sentiments in a given polarity group, it is crucial to understand whether all public opinions toward energy efficiency retrofitting of existing buildings are expressing the same level of negativity or positivity. To illustrate this, a density plot, as shown in Fig. 5, is used to depict the degree at which the average sentiment scores are spread in a polarity group. Afterwards, the mean of each polarity group was computed and used to determine the number of comments and their average sentiment scores that seem to be clustered around the neutral polarity. This yielded a mean of -0.161 for the negative polarity group, 0.000 for the neutral and 0.242 for positive. Conservative thresholds were then generated to classify sentences into sub-polarity groups. Average sentiment scores greater than -0.161 were classified as very negative; negative if their scores are between -0.161 to -0.000; neutral is 0.000; positive if they are between 5.666E-18 and 2.424E-01, and very positive is above 2.424E-01. In Fig. 6, 557 comments were classified as very negative which appear to be denser near the mean of the neutral sentiment scores. On the other side, 1,096 comments were clustered near the mean of the neutral sentiment scores. Using the sub-polarity level criteria, Fig. 6 shows that majority (33%) of the comments expressed positive sentiments towards EEREB, 23% were very positive, 17% were negative, 10% were very negative, and the remaining 17% of the comments were neutral.



353 **Fig. 4.** Polarity levels of YouTube data on EEREB.

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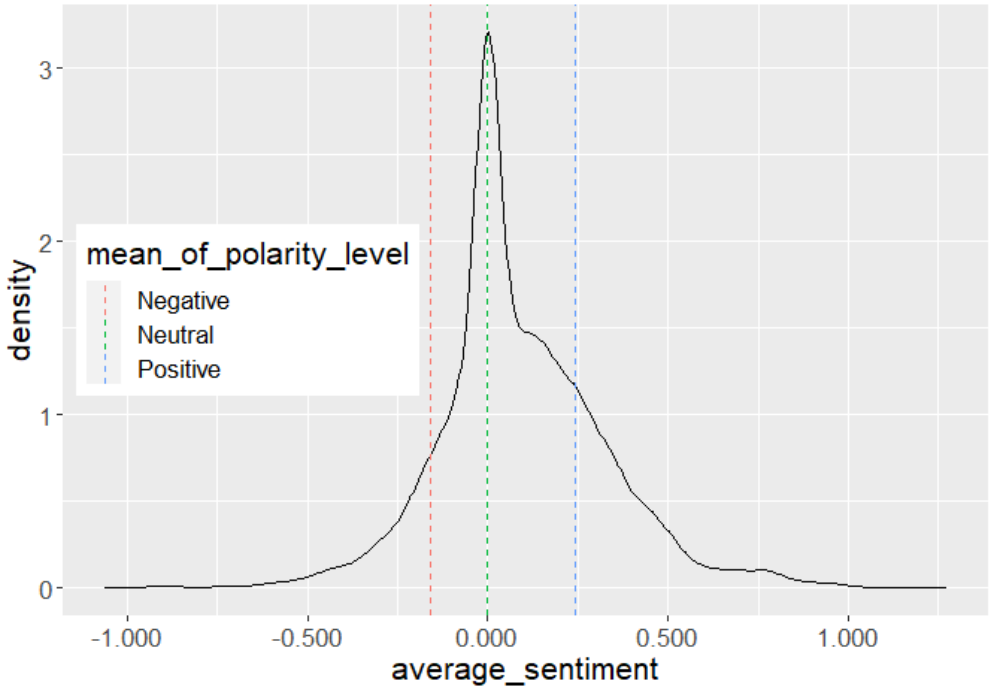

355 **Fig. 5.** Density plot of average sentiment scores of YouTube data on EEREB.

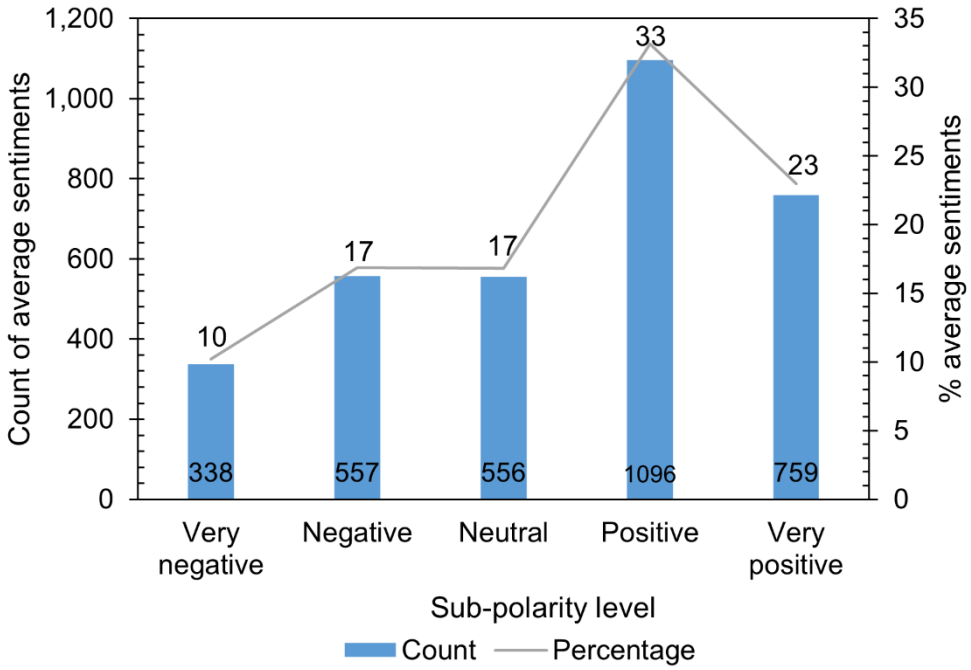

Fig. 6. Sub-polarity levels of YouTube data on EEREB.

4.2. Model-based clustering

Fig. 7 shows a BIC plot where 14 different statistical models were applied to fit the data. The higher the BIC value, the more variance explained by the associated cluster. After a computational search through all the 14 models, the multivariate mixture model, an ellipsoidal covariance with an equal volume, equal shape, and varying (EEV) orientation was deemed as the best model by the BIC criterion. Hence, the abbreviations in Figure 7 suggest the volume, shape and orientation of the cluster density that has been constrained to be equal (E), spherical (I), and varying (V) (Gormley et al., 2023). The BIC plot suggests that the best clusters are 4, 8 and 9. Cluster 8 had a BIC value of 33,799.680, cluster 9 had 27,106.306 and cluster 4 had 4000.042. These suggested clusters served as a guide in a thorough review of the EEREB literature and content analysis of the 3,306 YouTube data. After this examination, nine clusters were deemed optimal to account for the statistical variability and philosophical dynamics in EEREB literature.

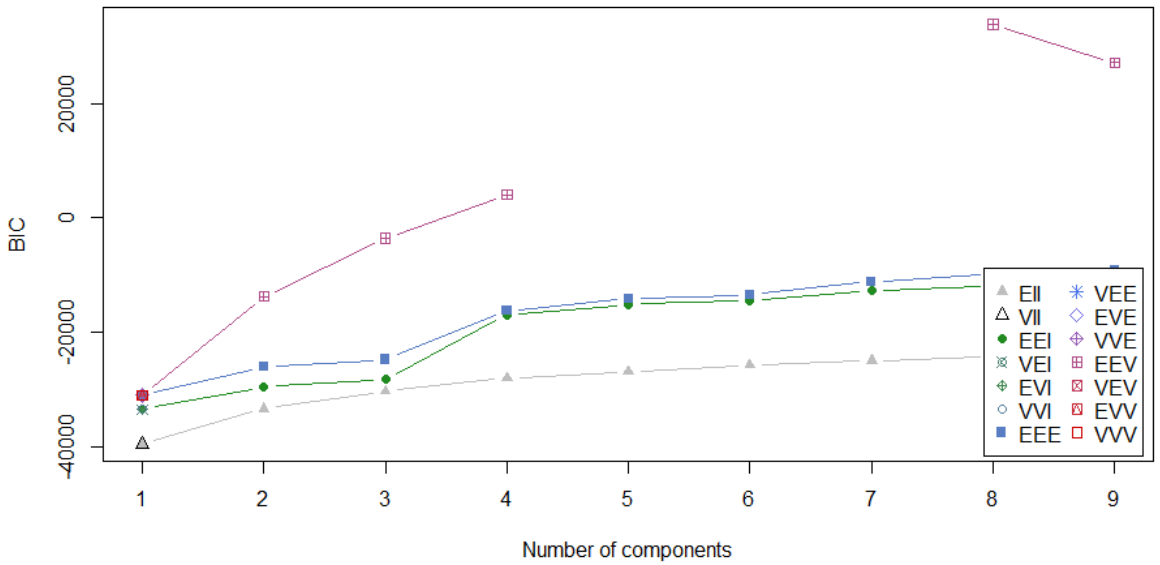

Fig. 7. BIC plot using model-based clustering on YouTube data on EEREB.

4.3. Allocation of topics

The LDA analysis procedure yielded 729 terms after removing all terms whose sparsity is greater than 0.980%; each term was linked to a topic. Beta values were further assigned to each term, suggesting that the higher the beta value, the higher the probability of that term appearing in a document. Fig. 8 illustrates the top ten beta values in each topic and their corresponding terms.

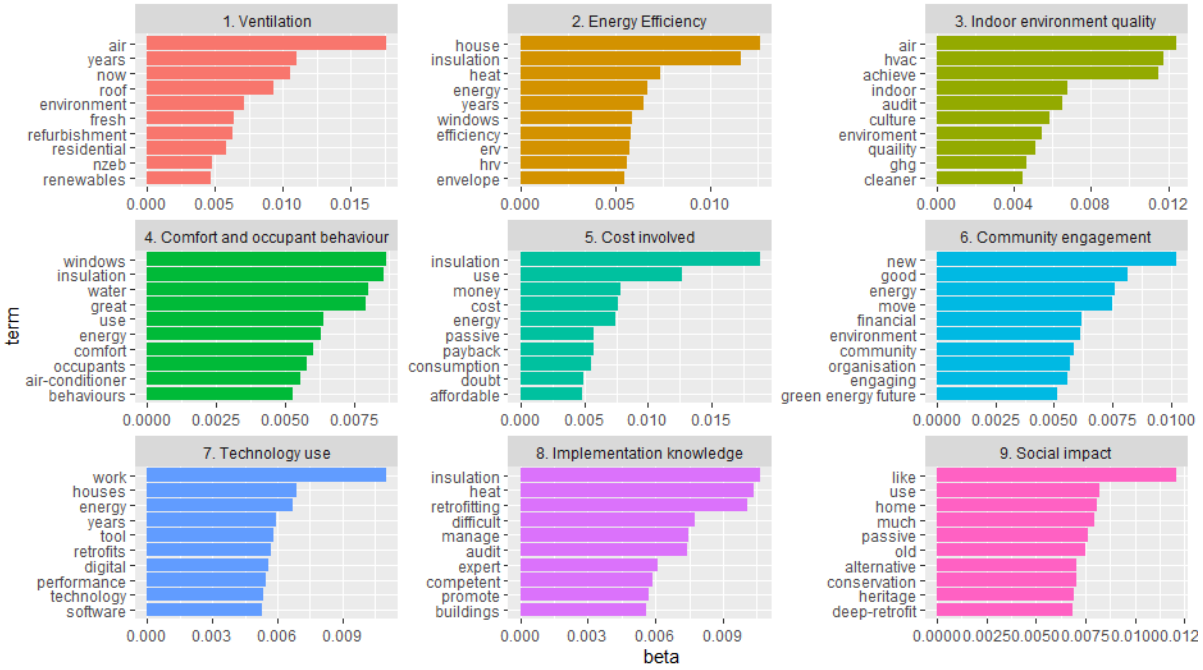

Fig. 8. Nine topics on EEREB buildings using beta-top values and associated terms.

5. Discussions

Based on the Latent Dirichlet Allocation model, the associated terms were clustered into the following nine topic domains: (1) *Ventilation*, (2) *Energy efficiency*, (3) *Indoor environment quality*, (4) *Comfort and occupant behaviour*, (5) *Cost involved*, (6) *Community engagement*, (7) *Technology use*, (8) *Implementation knowledge*, and (9) *Social impact*. The topics are listed chronologically shown in Fig. 8 (i.e., 1-9). For clarity purposes, examples from the data are added, with no edits made, even when the commenter's comments inadvertently contain typos. This is to demonstrate the exact views of the public. Each referenced comment is coded as c#1, c#2, c#3, etc. Table 1 below shows the topics and associated aspects addressed in the commenter's comments.

391 **Table 1.** Topics and associated aspects addressed in the commenter's comments

Topic	Aspects	Code	Commenter's comments
Ventilation	- Comfortability and healthy home - Roofing and ventilating system - Lack of information on retrofit technologies - Conservative mindset	c#169	"*(…) a tight home with excellent mechanical ventilation would have no drafts or cold spots. It would be extremely comfortable to live in. And quiet! The home also brings in filtered fresh air rather than air leaking all through the structure, so the indoor environment is also going to be much healthier to live in.*"
		c#1,626	"*Ventilation is vital to the functioning of both buildings and people.*"
		c#1,066	"*Better a roof then the whole house.*"
		c#292	"*I've been thinking of doing a metal roof since my shingles are past dead, (…)*"
		c#732	"*I'm interested to know more about the heat exchange ventilation system for energy efficiency reno.*"
		c#1,277	"*I am a bit worried about living in an airtight space: what if Coronaviruses in the future dictate excessive ventilation?"*
		c#44	"*Why do they need that ventilation system? If they have so many windows, they could just open them.*"
		c#1,381	"*The biggest problem is the conservative attitude of the average person who doesn't know about heat pumps, ventilation, insulation etc.*"
Energy efficiency	- Personal choice matters - Improve energy efficiency - Occupants' health and well-being	c#1,303	"*Whether it is required by law or not, I am taking steps to greatly improve the energy efficiency in my house (…)"*
		c#532	*"(…) I have been planning a project to implement some air-sealing in my attic.*"
		c#460	"*Want to help your energy efficiency? Attic fan will help tremendously.*"
		c#169	"*(…) it would be extremely comfortable to live in. (…) a better indoor environment is far less expensive than paying for chronic health conditions.*"
Indoor environmental quality	- Better indoor environment - Cut costs and increase comfort - Effects of HVAC systems on occupants	c#237	"*I do HVAC and have been recommended a lot of blower wheel cleanings lately.*"
		c#339	"*(…) I recently got a new HVAC unit (…)*"
		c#261	"*(…) I try to open my windows as much as possible year-round. I only run my air when it's over 88°, or the humidity gets over 20%. And the heat when under a sunny 50° or cloudy 60°.*"
		c#414	"*(…) I don't use the A/C, usually.*"
		c#1,277	"*I am a bit worried about living in an airtight space*"

		c#336	"*What is your take on UV lights in the HVAC thinking about SARS, MERS and Virus (...)*"
		c#299	"*For indoor air quality, in addition to using HVAC systems you may want to address why indoor air quality is poor to begin with. How about spending (...) to upgrade building materials that use fewer toxic chemicals that won't off gas into your home. Think about all the glues, formaldehyde, etc. in typical materials.*"
Comfort and occupant behaviour	- Buildings with adequate ventilation and insulation - Satisfaction matters most - Controlling indoor climate - Dependant on renewable energies (e.g., solar PV) - Regulatory support	c#169	"*The home also brings in filtered fresh air rather than air leaking all through the structure, so the indoor environment is also going to be much healthier to live in. (...)*
		c#1,816	"*Imagine all the houses (...) converted this way, there will be more healthy and greener homes.*"
		c#611	"*Comfort is always a thing.*"
		c#177	"*(...) better controlled indoor air quality may also reduce the risk of some health conditions. And it also provides a much more comfortable home to live in.*"
		c#1,428	"*The only thing I'd like to see added would be active energy harvesting with solar PV or hot water (or air) systems (...)*"
		c#75	"*(...) It's illegal in many states in the U.S. Imagine that: illegal to harvest rain that falls on your roof.*"
Cost involved	- Retrofitting is costly - Retrofitting vs. new construction cost/benefit analysis - The payback period and feasibility of retrofitting	c#1,553	"*The insane cost of retrofits is a problem. What the world needs is a much cheaper way to retrofit old housing without tearing them down to the frame.*"
		c#122	"*In a project like this, it would be nice to see the data in the construction costs between the full retrofitted house and a rebuild, and the subsequent saving in energy/consumables costs*."
		c#818	"*There must be a cost/benefit analysis step against retrofitting an old house versus demolition and starting from scratch (...)*"
		c#1,144	"*(...) the payback could be over 50 years. I wonder how much a retrofitted home will costs. (...)*"
		c#800	"*I would certainly pay far more for a home that was this comfortable.*"

Community engagement	- Community-wide retrofit and impact - Good public-motivation schemes - Policymakers push for community participation	c#3,165	"*It will be interesting to see what whole community solutions will come, as that is still a problem for the time being (...)*"
		c#1,769	"*(...) Lobbying will ensure that massive energy schemes will still serve the majority over intelligently designed community schemes.*"
		c#3,022	"*The politicians should be people who built a real engagement in the community.*"
Technology use	- Varying retrofit technology adoption - Climate factors and retrofit technology anxiety - High cost of retrofit technologies	c#110	"*I like the rainwater catchment, cisterns, greywater reuse, and the triple-insulated windows.*"
		c#246	"*I'm replacing my breaker panel, replacing my furnace and adding an a/c, swapped out leaking water valves, cleaning and sealing ducting, and replacing old, rotten single pane windows that are in my basement.*"
		c#377	"*Tools like water misters over a/c units, heat pumps for hot water, air exchange (are well known). (...) I also hunger a bit for some truly new material and technologies.*"
		c#693	"*(...) hyperheat is cool. (...) if you're in a warm climate, you don't even need it.*"
		c#1,756	"*If you build with modern technology, you can absolutely retrofit any house in any place (...)*"
		c#55	"*(...) until the cost of this technology comes down it will be hard for the average homeowner to do this.*"
Implementation knowledge	- Lack of a knowledgeable and competent workforce - Trust issues	c#1,233	"*(...) the idea finding a competent and knowledgeable construction company that speaks the standard and then the cost of it, due to the limited numbers of qualified trades, fills me with dread. (...) but even finding an average builder is a stressful procedure.*"
		c#330	"*(...) you can get an energy audit free from the Mass Saves program. They will also give you lots of freebies like led light bulbs, and they will subsidize most of the cost of insulation or give you a no-interest loan for a new heating system.*"
		c#210	"*(...) but these half-butt 'energy auditors' trying to sell windows, or something are destroying the true service.*"
		c#492	"*(...) can I trust the energy audits that are done by the state retrofit programs? And can I trust the work done by the contractors they hire to do the retrofit on the house?*"
		c#275	"*I appreciate the deep irony of Matt recommending an independent energy auditor who won't try to sell you a product.*"

Social impact	- Retrofit and conservation gap - Building refurbishment is impractical	c#1,767	"*(...) retrofitting is very expensive and comes with very serious implications for the conservation value of historic buildings.*", "*You can't just extend ancient rooves, or cover up ancient facades, without destroying the building itself. (...) the lack of thought about our heritage is seriously disappointing.*"
		c#1,771	"*(...) we have a large body of historic and period buildings in this country, and I don't want to see them destroyed. The world is full of blandness in the build environment, and I don't think destroying our interesting and varied heritage is the way forward. Look at the gables of most houses (...) Look at the verge (...) Note the roof overhang. Now tell me how external insulation is going to work.*"
		c#1,774	"*(...) that mass produced modern buildings need excusing, doesn't sit terribly well with the notion that we can happily lose almost all of our heritage.*"
		c#1,017	"*Why would bringing an old building up to code be a scam?*"
		c#1,512	"*(...) and ultimately the climate emergency is at least as important as keeping old buildings looking old, so it should be a consideration, not a veto.*"

5.1. Ventilation

Under this topic, the public exhibits significant concerns with the current ("*now*") state (in terms of "*years*") of their homes and most importantly, the supply of "*fresh air*" in the occupied zones of their building. The majority of the public was enthusiastic to comment on the benefits of ventilation control mechanisms (specifically mechanical ventilation) and systems – replacing indoor air with fresh air outside the building "*environment*" for EEREB. For example, c#169 and c#1,626 respectively stated: "*(…) a tight home with excellent mechanical ventilation would have no drafts or cold spots. It would be extremely comfortable to live in. And quiet! The home also brings in filtered fresh air rather than air leaking all through the structure, so the indoor environment is also going to be much healthier to live in.*" and "*Ventilation is vital to the functioning of both buildings and people.*" Both comments (i.e., c#169 and c#1,626), respectively, obtained positive sentiment scores of 0.167 and 0.121. Improving the air quality in homes is both an energy efficiency technique and a necessary step to meet the health and comfort needs of the occupants. It is commonly believed that the impact of ventilation loss, which refers to the heat lost through air changes per hour, in existing buildings is relatively minor when compared to transmission loss. Transmission loss refers to the heat that escapes through surfaces such as walls, windows, and roofs. Therefore, there has been a preference for building insulation retrofits over ventilation retrofits. It is important to note that even in well-insulated buildings, ventilation losses are the main cause of energy losses (Stabile et al. 2019). Further investigation is necessary to determine the most effective retrofit strategies or technologies for ventilation retrofits. Another interesting finding is that while EEREB has been mainly upgrading lighting and controls, and air conditioning system performance, some of the public showed more interest in replacing their roofing system. For example, c#1,066 (with a positive sentiment of 0.302) and c#292 (with a negative sentiment of 0.091) respectively stated: "*Better a roof then the whole house.*" and "*I've been thinking of*

doing a metal roof since my shingles are past dead, (...)". Further, most of the comments, especially from those in the cold climatic areas (e.g., Canada, US, and Sweden), were connected to the feasibility of installing MVHR - mechanical ventilation with heat recovery. For instance, c#732 (with a positive sentiment of 0.254) stated: "*I'm interested to know more about the heat exchange ventilation system for energy efficiency reno.*" Conversely, other commenters shared mixed feelings about this whole energy retrofit approach and the expected consequence. For example, c#1,277 and c#44 with negative sentiment scores of 0.338 and 0.037, respectively, stated: "*I am a bit worried about living in an airtight space: what if Coronaviruses in the future dictate excessive ventilation?"* and "*Why do they need that ventilation system? If they have so many windows, they could just open them.*" The least discussed interests under this category include nZEB – nearly zero energy building, and renewables. This is understandable because they are new promising strategies for reducing reliance on fossil fuels that result in GHG emissions (Omrany et al., 2022: Tetteh et al., 2022). These comments show that while a proportion of the public seems to be more interested in ventilating their home, the sentiments of others appear that there is a lack of information on the implementation of ventilation retrofit for energy efficiency. For instance, c#1,381 (with a negative sentiment of 0.391) stated: "*The biggest problem is the conservative attitude of the average person who doesn't know about heat pumps, ventilation, insulation etc.*" In fact, the lack of retrofit knowledge and information for homeowners has been a persistent impediment to increasing awareness about energy efficiency (Jia et al., 2021). It makes energy retrofitting activities appear too complex and unattainable.

5.2. Energy efficiency

Energy efficiency is among the most highly discussed and important topics in the field of existing building retrofit (Amirkhani et al., 2021). Specifically, possible ways to save energy or reduce energy consumption are usually discussed by experts and homeowners. The data

449 suggests that households are more likely to plan out what they want to do and not by any
450 regulations. For example, c#1,303 (with a positive sentiment of 0.609) and c#532 (with a
451 positive sentiment of 0.257) respectively stated; "*Whether it is required by law or not, I am*
452 *taking steps to greatly improve the energy efficiency in my house (...)"* and *"(...) I have been*
453 *planning a project to implement some air-sealing in my attic.*" Another point of notice is that
454 while some of the publics are more energy-conscious and recognize energy savings and retrofit
455 in terms of the use of more energy-efficient or less energy-consuming systems, others seem to
456 be more interested in the non-energy benefits of those efficiency systems. For example, c#460
457 (with a positive sentiment of 0.275) and c#169 (with a positive sentiment of 0.168) respectively
458 stated: "*Want to help your energy efficiency? Attic fan will help tremendously.*" and "*(...) it*
459 *would be extremely comfortable to live in. (...) a better indoor environment is far less expensive*
460 *than paying for chronic health conditions.*" More importantly, the shift of focus toward non-
461 energy benefits is crucial as prior studies have highlighted that the sole focus on the economic
462 and environmental benefits for energy efficiency retrofits promotion can negatively affect
463 implementation rates (Weiss et al., 2012; Pombo et al., 2019). Therefore, increasing the general
464 public awareness of non-energy-related benefits could be more beneficial in promoting
465 EEREB.

466 *5.3. Indoor environment quality*

467 Undoubtedly, people spend much of their time indoors (estimated roughly 90%) and thus,
468 the environmental condition of buildings (i.e., indoor environmental quality – IEQ) is of great
469 concern to the public. It is therefore understandable that the general public was keen to explore
470 and comment on this topic. Most of the comments were centered around HVAC – heating,
471 ventilation, and air conditioning systems installation for inhabitable indoors. For example,
472 c#237 (with a positive sentiment of 0.134) and c#339 (with a positive sentiment of 0.233)
473 respectively stated: "*I do HVAC and have been recommended a lot of blower wheel cleanings*

lately." and "*(...) I recently got a new HVAC unit (...)*" To reduce cost and achieve comfort at the same time, the majority of the public showed interest in employing a hybrid approach (i.e., combining HVAC system and opening windows) for fresh air. For example, c#261 (with a positive sentiment of 0.039) and c#414 (neutral sentiment – 0.000) respectively stated: "*(...) I try to open my windows as much as possible year-round. I only run my air when it's over 88°, or the humidity gets over 20%. And the heat when under a sunny 50° or cloudy 60°.*" and "*(...) I don't use the A/C, usually.*" This suggests that the public not only understand the possible implications of IEQ retrofit, but also aim at cutting cost or reducing energy bills significantly. IEQ factors such as indoor air quality and lighting quality have been identified as the most significant factors affecting people's physical and mental health, as well as their emotional and social wellbeing (Cincinelli and Martellini, 2017; Ortiz et al., 2019). The public expressed concerns about the airtightness of spaces due to the HVAC retrofit and its implications on occupants' health, as IEQ is growing in significance in the post-COVID-19 world. For example, c#1277 (with a negative sentiment of 0.338) and c#336 (with a negative sentiment of 0.125) respectively stated: "*I am a bit worried about living in an airtight space*" and "*What is your take on UV lights in the HVAC thinking about SARS, MERS and Virus (...)*." Most of the comments also were recommendation for improving the indoor air quality. As an example, c#299 (with a positive sentiment of 0.077) stated: "*For indoor air quality, in addition to using HVAC systems you may want to address why indoor air quality is poor to begin with. How about spending (...) to upgrade building materials that use fewer toxic chemicals that won't off gas into your home. Think about all the glues, formaldehyde, etc. in typical materials.*" This suggests that multiple factors determine the quality of the indoor environment. This necessitates the use of multidisciplinary approaches, in which the interactions between buildings, HVAC systems, health, and IEQ are examined.

5.4. Comfort and occupant behaviour

In recent times, the impact of EEREB on occupants is considered as strong as the economic and environmental. Jafari et al. (2019) highlighted a number of impacts that energy retrofit may have on occupants and users. For example, EEREB measures usually reduce air exchange which may cause health problems for occupants. In this regard, c#169 (with a positive sentiment of 0.006) and c#1,816 (with a positive sentiment of 0.260) respectively stated: "*The home also brings in filtered fresh air rather than air leaking all through the structure, so the indoor environment is also going to be much healthier to live in. (…) to get a better indoor environment is far less expensive than paying for chronic health conditions.*" and "*Imagine all the houses (…) converted this way, there will be more healthy and greener homes.*" However, through better occupant behaviour or control for temperature and ventilation, occupants' comfort and satisfaction may increase. For instance, c#611 (with a positive sentiment of 0.335) and c#177 (with a positive sentiment of 0.182) respectively added: "*Comfort is always a thing.*" and "*(…) better controlled indoor air quality may also reduce the risk of some health conditions. And it also provides a much more comfortable home to live in.*" This finding is consistent with the study by Kerr et al. (2018), who identified that improving comfort in the home is always at the forefront of households' minds, rather than aesthetics. Another interesting finding is that while the majority of the public sees comfort to be only connected to the indoor environment, others feel satisfied when renewable materials are used (e.g., solar). For example, c#1,428 (with a negative sentiment of 0.313) stated: "*The only thing I'd like to see added would be active energy harvesting with solar PV or hot water (or air) systems (…)*." In addition, by increasing the use of natural lighting/water, EEREB may reduce occupants' fatigue and energy use and bills, which indirectly brings convenience and comfort to homes. Nevertheless, in some parts of the world, harvesting resources such as water is illegal. For example, c#75 (with a negative sentiment of 0.265) stated: "*(…) It's illegal in many states in*

the U.S. Imagine that: illegal to harvest rain that falls on your roof." As mentioned earlier, focusing on the effects on users and occupants is essential because the value residents receive may have a significant impact on their willingness to invest in EEREB. Azizi et al. (2019) emphasized that factors other than the potential for energy savings are what drive consumers to adopt energy-efficient measures. Therefore, occupants are typically interested in improvements in indoor climate, such as improved thermal comfort through insulation, improved air quality through the use of an air conditioner and improving window condition, better access to daylight, etc.

5.5. Cost involved

Cost is one of the critical elements that drive EEREB implementation. Previous research has found that resistance to change, a lack of awareness and knowledge, and a high cost are all significant barriers to raising awareness and increasing energy efficiency retrofit (Bjørneboe et al., 2018; Jia et al., 2021). The issue of high cost was raised by the general public. For instance, c#1,553 (with a negative sentiment of 0.064) stated: "*The insane cost of retrofits is a problem. What the world needs is a much cheaper way to retrofit old housing without tearing them down to the frame.*" However, most of the public was much concerned about the payback period and whether it is worth it to retrofit their homes. Mixed sentiments (negative and positive) were obtained. For example, c#112 (with a negative sentiment of 0.013), c#818 (with a negative sentiment of 0.157) and c#1,144 (with a positive sentiment of 0.522) respectively stated: "*In a project like this, it would be nice to see the data in the construction costs between the full retrofitted house and a rebuild, and the subsequent saving in energy/consumables costs*.", "*There must be a cost/benefit analysis step against retrofitting an old house versus demolition and starting from scratch (…)*", and "*(…) the payback could be over 50 years. I wonder how much a retrofitted home will costs. (…)*." While most of the comments seem to come from those who are passionate to undertake energy retrofit, in several cases comments from people

549 who are already interested in retrofit indicated that the price was justified. For example, c#800
550 (with a positive sentiment of 0.067) stated: "*I would certainly pay far more for a home that*
551 *was this comfortable.*" This implies that only a small number of people will have the
552 opportunity for energy retrofit overall, making it more challenging to promote energy retrofit.
553 Therefore, this finding offers profound directives for policymakers to increase the awareness
554 and implementation of energy retrofit by involving the public who are already interested, as
555 frontliners, to persuade or convert those currently unenthusiastic about EEREB.

556 *5.6. Community engagement*

557 In order to transition to low carbon communities, community participation in energy
558 efficiency upgrades of existing buildings is essential. Previous studies have mentioned that
559 until the general public aggressively accelerate commitments, energy efficiency upgrade is
560 likely to be stuck in the rut of government excessive intervention (Karvonen, 2013; Kerr et al.,
561 2018). Although there is relatively little discussion on this construct, the few comments thus
562 far highlight the urgency of domestic energy retrofit to bring about significant changes in the
563 housing stock. For example, c#3,165 (with a positive sentiment of 0.201) and c#1769 (with a
564 positive sentiment of 0.555) respectively stated: "*It will be interesting to see what whole*
565 *community solutions will come, as that is still a problem for the time being (...)*" and "*(...)*
566 *Lobbying will ensure that massive energy schemes will still serve the majority over intelligently*
567 *designed community schemes.*" According to Karvonen (2013), the most effective approach to
568 achieving significant and lasting improvements in the energy performance of existing homes
569 within a community is to establish an expert panel. This panel would be responsible for
570 identifying the specific barriers that are relevant to the local area. Once these barriers are
571 identified, the panel will then focus on building trust among homeowners in order to implement
572 a retrofit strategy that is agreed upon by all parties involved. Additionally, the panel would
573 provide assistance in selecting qualified building contractors to carry out the necessary work.

Further, while most of the public still believes that the government should be at the forefront of the movement, such as c#3022 (with a positive sentiment of 0.300): "*The politicians should be people who built a real engagement in the community.*", many of them also see the reverse to be true. This suggests that a broader strategy for implementing EEREB is required, one that simultaneously addresses the system of provision and occupants' decision behaviour.

5.7. Technology use

There are several energy-retrofit technologies. Based on the comments, essential retrofit technologies that contribute to the success of energy efficiency and meet the needs of the general public include but are not limited to the application of thermal insulation systems, roof renovation, replacing windows and doors, replacement of water heating system, and replacement of the heating system and air conditioning system. The public shared mixed feelings about technology use. For example, c#110 (with a positive sentiment of 0.139) and c#246 (with a negative sentiment of 0.064) respectively stated: "*I like the rainwater catchment, cisterns, greywater reuse, and the triple-insulated windows.*" and "*I'm replacing my breaker panel, replacing my furnace and adding an a/c, swapped out leaking water valves, cleaning and sealing ducting, and replacing old, rotten single pane windows that are in my basement.*" Aside from that they were concerned about energy-efficient equipment/tools and much anticipation to welcome new technologies. For example, c#377 (with a positive sentiment of 0.532) stated: "*Tools like water misters over a/c units, heat pumps for hot water, air exchange (are well known). (...) I also hunger a bit for some truly new material and technologies.*" The public also agreed with earlier studies that the characteristics of the building and the regional climate determine retrofit technologies and measures that are applicable. (Li et al. 2017; Tan et al., 2021). For example, c#693 (with a positive sentiment of 0.184) stated: "*(...) hyperheat is cool. (...) if you're in a warm climate, you don't even need it.*" Some argued that modernized technologies could be applied anywhere regardless of climate or building type. However, this

is mostly affected by cost as mentioned earlier. For example, c#1756 (with a positive sentiment of 0.389) and c#55 (with a negative sentiment of 0.033) respectively stated: "*If you build with modern technology, you can absolutely retrofit any house in any place (…)*" and "*(…) until the cost of this technology comes down it will be hard for the average homeowner to do this.*" In summary, the findings indicate that homeowners who are interested in retrofitting mostly desire deep energy savings retrofit, as thermal envelop (wall, roof and window) improvement is seen as the major retrofit technology (Benzar et al., 2020). Furthermore, there is a call for modernized retrofit technologies such as renewable technologies (e.g., solar-energy systems) for energy efficiency retrofit.

5.8. Implementation knowledge

For an effective and viable energy retrofit implementation, the importance of involving those with retrofit knowledge is crucial (Alam et al., 2019). Monitoring and auditing to find energy-saving opportunities are not only costly but also challenging, requiring decisions from advisors and installers. Most of the comments associated with this topic discussed the stressful nature of identifying professionals to carry out retrofit work. For example, c#1233 (with a positive sentiment of 0.048) stated: "*(…) the idea finding a competent and knowledgeable construction company that speaks the standard and then the cost of it, due to the limited numbers of qualified trades, fills me with dread. (…) but even finding an average builder is a stressful procedure.*" Some also expressed positive concerns by involving energy auditors mostly supplied by the government. For example, c#330 (with a positive sentiment of 0.190) stated: "*(…) you can get an energy audit free from the Mass Saves program. They will also give you lots of freebies like led light bulbs, and they will subsidize most of the cost of insulation or give you a no-interest loan for a new heating system.*" Another surprising concern raised by the public was that some of the energy auditors or consultants, including public consultants, cannot be relied on because they are too self-centered or focused on their monetary interests

rather than driving solutions that are most appropriate for the efficient operation of the public. For example, c#210 (with a negative sentiment of 0.582) and c#492 (with a positive sentiment of 0.222) respectively stated: "*(...) but these half-butt 'energy auditors' trying to sell windows, or something are destroying the true service.*" and "*(...) can I trust the energy audits that are done by the state retrofit programs? And can I trust the work done by the contractors they hire to do the retrofit on the house?*" This mistrust ultimately introduces some degree of hesitation amongst homeowners regarding whether to invest in energy retrofit or not. A further point of concern was the need to employ reliable external or independent energy auditors to take retrofit assessments and construction. For example, c#275 (with a positive sentiment of 0.055) stated: "*I appreciate the deep irony of Matt recommending an independent energy auditor who won't try to sell you a product.*" Similar observations were made by Alam et al. (2019) in the case of two States within Australia.

5.9. Social impact

There is still a conflict between retrofit and conservation. Retrofitting historic buildings is contentious because historic elements may be altered or covered up, altering the character of the building. The majority of the general public, particularly those living in historically sensitive areas (e.g., the UK, Austria and Italy), claimed that insulating building surfaces and replacing windows are examples of retrofitting measures that have the potential to alter a building's identity and context. For example, c#1,455 (with a positive sentiment of 0.686), c#1,767 (with a negative sentiment of 1.263) and c#1,771 (with a positive sentiment of 0.212) respectively stated: "*(...) retrofitting is very expensive and comes with very serious implications for the conservation value of historic buildings.*", "*You can't just extend ancient rooves, or cover up ancient facades, without destroying the building itself. (...) the lack of thought about our heritage is seriously disappointing.*" and "*(...) we have a large body of historic and period buildings in this country, and I don't want to see them destroyed. The world*

649 *is full of blandness in the build environment, and I don't think destroying our interesting and*
650 *varied heritage is the way forward. Look at the gables of most houses (...) Look at the verge*
651 *(...) Note the roof overhang. Now tell me how external insulation is going to work.*" This
652 implies that many retrofit technologies are questionable in terms of how well they blend in with
653 the aesthetic of historic buildings and how widely accepted they are (Ascione et al., 2015).
654 There were also comments claiming that energy retrofit does not destroy the architectural and
655 historic significance of the building and questioned the relevance of conserving these buildings,
656 which are detrimental to public health and safety. For example, c#1,774 (with a negative
657 sentiment of 0.046) and c#1,017 (with a negative sentiment of 0.115) respectively stated: "*(...)*
658 *that mass produced modern buildings need excusing, doesn't sit terribly well with the notion*
659 *that we can happily lose almost all of our heritage.*" and "*Why would bringing an old building*
660 *up to code be a scam?*" In several cases, some of the public indicated that finding a balance
661 between heritage preservation and GHG reduction is necessary. For example, c#1,512 (with a
662 positive sentiment of 0.050) stated: "*(...) and ultimately the climate emergency is at least as*
663 *important as keeping old buildings looking old, so it should be a consideration, not a veto.*"
664 These findings highlight the necessity of developing frameworks that will enable discussions
665 and compromises to be made between conservation perception and energy efficiency retrofit.

666 **6. Recommendations for Policy and Practice**

667 The above concerns and perceptions of the public, with varying degrees of relevance,
668 provide concrete evidence for policymakers and relevant stakeholders to revisit energy retrofit
669 policy design and promote retrofit practice worldwide, respectively. Based upon how the
670 general public makes sense of energy retrofit, not restricting it to one-sided preferences, the
671 following recommendations for policy and practice are put forward, in order to accelerate the
672 rate of EEREB practice, step up governments' energy and climate goals as well as provide
673 residents with healthier and comfortable homes. It should be acknowledged that although "local

674 context" matter when developing retrofit policy packages, a compiled collection of diverse
675 city-scale population sentiments should aid in policy development in any country/jurisdiction.
676 It is also beneficial for general retrofit marketing.

677 • The lack of understanding of retrofit technologies and their benefits is a theme that
678 recurs frequently in the commentaries, a finding that resonates with prior studies (Alam
679 et al., 2019; Jia et al., 2021). Therefore, local governments need to intensify publicity
680 efforts by providing both practical and professional knowledge to raise public
681 awareness. Alam et al. (2019) highlighted that developing essential educational
682 resources is key to bringing the potential benefits of energy efficiency retrofits to the
683 public's attention. The provision of useful educational materials that publicize largely
684 non-energy-related benefits of EEREB will significantly raise public awareness.
685 Moreover, public agencies and industry-led bodies promoting energy efficiency
686 awareness and solutions should create websites with the necessary information,
687 highlighting successful retrofit projects completed, sharing relevant research findings
688 and information, and offering centralized high-level supported awareness training
689 programs.

690 • Another distinct and noticeable concern is the challenge of identifying actors (energy
691 retrofit experts including auditors, contractors, and consultants) with the required
692 technical expertise to supply retrofit activities. There exists some evidence in the
693 literature that retrofit supply-side actors are disregarded or overlooked in retrofit policy
694 design (Kerr and Winskel, 2020). As a means of increasing the conversation and
695 attention rate, policy should engage with homeowners and supply-side actors through
696 a variety of "touch points" and trusted messengers – from assessment to
697 implementation. In the USA, for example, policy programs engage with supply
698 contractors on an ongoing basis, to dialogue about what is realistically deliverable.

699 Besides, due to the intensity and risk-averse nature of retrofit supply chains (Gooding
700 and Gul, 2017), policy must offer rewards and remedies that correspond to the supplier's
701 commercial objectives. Furthermore, while workforce training and work inspection –
702 through establishing an intermediary or integrator body – are regarded as critical in
703 several studies (Visscher et al., 2016; Pollo, 2017), another way to build trust in the
704 supply chain is to improve accreditation. It is important to strengthen the general public
705 confidence and prevent the erosion of trust, especially at the promotion and
706 development stage of retrofit. This would no doubt raise interest in retrofit upgrades
707 among homeowners.

708 • It is noteworthy and intriguing to learn that personal preferences – rather than
709 regulations per se – are the main driving force behind retrofitting. Thus, the
710 responsibility for retrofitting lies with the general public. The motivation of the general
711 public, especially homeowners, as decision-makers for their own properties, for
712 retrofitting may not always perfectly align completely with the government targets for
713 decarbonization. Besides, home retrofit projects are typically not completed all at once.
714 Instead, they are implemented gradually over time and tend to occur at specific stages,
715 known as "trigger points." These trigger points may include instances such as a
716 complete system breakdown, when a household relocates, transitioning to parenthood,
717 and moving into retirement (Karvonen 2013; Maby and Gwilliam, 2022). For example,
718 c#782 stated: "*I have down the upgrades over the course of a year. Sprayfoam won't be*
719 *done for another few weeks. Last winter I could wake up and see my breath. Living in*
720 *a house with 0.5 stars is horrible! Also, I was quoted 14k for ducted reverse cycle.*
721 *That's a lot of money I could spend on other improvements and a smaller heating*
722 *solution.*" The current practice is inefficient and inadequate to reach the goal of zero or
723 negative carbon emissions by 2050. While it is commonly acknowledged that low

carbon housing retrofit is typically done as a one-time, whole-house activity, there is potential in considering a phased retrofit approach over several years to achieve significant carbon and energy savings. This approach shows promise, but it is important to also assess the necessary policy support that would be required (Fawcett, 2014). Fawcett (2014) recommended that policies should include appropriate metrics or methods to recognize when a property is undergoing a low carbon retrofit. This recognition can be based on measures of completeness or progress towards a target. To support this policy, it is important to develop an optimal combination of retrofit measures that can effectively enable decarbonization over a period of time. It is also crucial to determine the order in which these measures should be implemented for maximum impact. Furthermore, a commonly adopted approach by the general public is to hire a building contractor, also known as a tradesperson, to carry out the retrofit works. For example, c#1,407 and c#1,231 respectively stated: "*In our situation we did not need an architect because the layout was staying broadly the same (minus a couple of walls). So, we hired the very good local builder.*" and "*(...) if I find someone to retrofit the south and southwest walls halfway up with triple glass french doors and cement/foam blocks. That will solve a fair amount of the many problems this old house has.*" In broad terms, these actors serve as the initial point of contact for homeowners. As a result, they have the potential to play a significant role in influencing homeowners' decisions regarding which retrofit work should be prioritized, ultimately bringing more attention to the potential for energy savings (Maby, 2019). Hence, policymakers should prioritize enhancing the capacity of building tradespeople by providing them with the necessary knowledge and skills. This will enable them to effectively identify opportunities for low carbon retrofitting and successfully implement these initiatives. It will also ensure that every "trigger point" opportunity in the life of a building to make

energy improvements is seized to deliver national policy goals. To enhance effectiveness, policymakers should consider implementing more stringent building regulations for existing buildings. These regulations should focus on setting minimum energy efficiency targets to create a level playing field for building tradespeople in the market.

- As noted, the cost involved in EEREB still limits massive uptake. This, therefore, calls for government action to redesign financial incentive policy packages, aiming to entice and support more people to consider making their homes' energy efficient.

7. Conclusions

This study comprehensively analyzed the general public's needs, concerns and views toward EEREB using social media, YouTube, data. For this purpose, a total of 3,306 data of the general public's views were collected, pre-processed, and analyzed using the model-based clustering and a text mining technique. The model-based clustering analysis confirmed the optimality of nine clusters. Later, LDA was used to cluster the comments into nine topic domains: ventilation, energy efficiency, indoor environment quality, comfort and occupant behaviour, cost involved, community engagement, technology use, implementation knowledge, and social impact. Overall, the public reported positive sentiments (56%) toward EEREB, 27% were negative, and the remaining (17%) were neutral. The results showed that although some unique local variables significantly shape public sentiments, the general intention to retrofit is mostly moulded by personal choices and minimally driven by regulations. The general public considered non-energy benefits such as comfort, health benefits, and cultural value to be something naturally expected from energy retrofit, far greater than energy savings and cost reduction in existing studies. Meanwhile, they preferred energy retrofit benefits should be linked with cost and payback period. Interestingly, the general perception of retrofit and energy savings is not in terms of upgrading or improving the energy performance of an existing

774 building, but of using more efficient or less consuming equipment or systems. While the
775 majority of the public shared negative sentiments toward EEREB due to the lack of retrofit
776 knowledge and information and the associated cost involved, in several cases, some argued
777 that the price was justified. This dissimilarity confirms the need for more targeted strategies,
778 especially for those currently unenthusiastic about retrofit, in order to promote EEREB practice
779 and development. Furthermore, the recognition and public support for energy retrofit were
780 attached significantly to finding competent and reliable professionals to execute energy retrofit
781 activities.

782 The theoretical and practical implications of this research's findings for advancing EEREB
783 are substantial. Theoretically, from a macro perspective, this study assesses a collection of
784 *heterogenous city-scale* population sentiments on EEREB and identifies the retrofit decision
785 behaviour of the general public. The study discusses public opinion on EEREB to a limited
786 extent, analyzing it in the context of geographical – climate-dependant – and scale diversity.
787 Furthermore, this study provides a reference for similar studies on public sentiments toward
788 new products or services. In practice, policymakers could use the findings to fine-tune or
789 formulate more appropriate interventions to meet public preference and promote EEREB.
790 Stakeholders including energy managers/auditors, materials and equipment suppliers and
791 manufacturers, planning and design units, including architects, designers, engineers, and
792 consultants, and construction and supervision units, including contractors will better
793 understand the general public needs and decision behaviour toward EEREB and provide good
794 technical standards and suitable service for them.

795 Although this study provides several benefits for research and practice, the following
796 limitations are worth stating. First, even though this study has contributed to a better
797 appreciation of how the socio-cultural and individual contexts independently and jointly shape
798 the sentiments toward EEREB, caution must be taken in inferring or generalizing the results in

a specific local context. Another key limitation of this study is that it only collected and analyzed data from YouTube. Therefore, future studies should extend the database by including other social media platforms such as X, Reddit, and Facebook to verify, and further, provide insight into public sentiments toward EEREB. Given the limited number of research studies on standardized tools for benchmarking EEREB videos on YouTube, it would be beneficial for future studies to focus on the development, validation, and testing of assessment tools in this area. This will improve the robustness of results through the selection of high-quality YouTube videos.

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