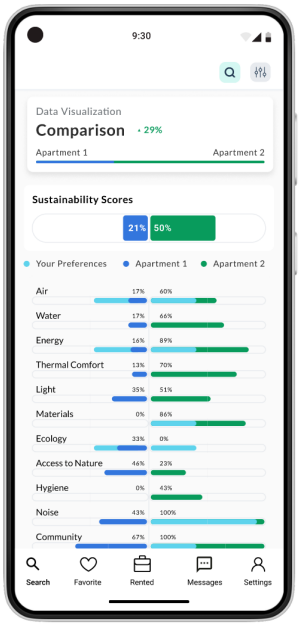

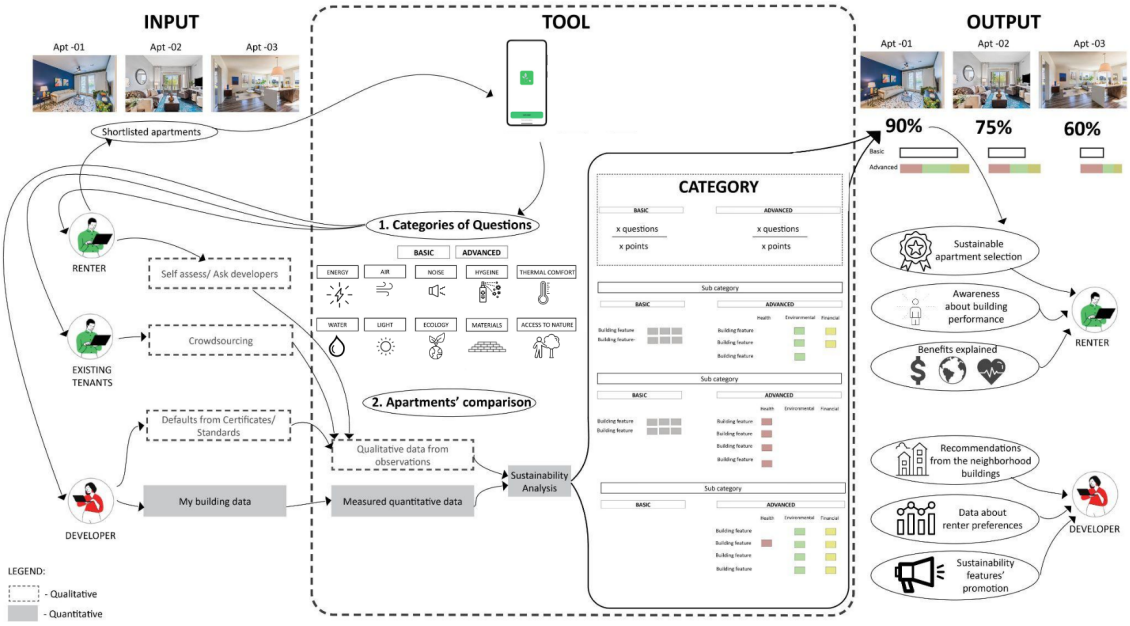

Is Your Apartment Sustainable?

Analytical Toolset to Evaluate the Health of Apartments and Increase Sustainable Building Practices in Rental Markets

Master of Science in Sustainable Design Thesis, Spring 2023

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Is your Apartment Sustainable?

Acknowledgement

We would like to start off by emphasizing that this thesis has only been possible with the combined effort of our advisors, mentors, classmates, friends for which we are eternally grateful. The weekly presentations with Prof. Dana Cupkova, Sinan Goral and Kushagra Varma have been refreshingly insightful, encouraging and motivating, to say the least. Bi-weekly meetings with Prof. Vivian Loftness have been inspiring sessions of knowledge about sustainability. Prof. Valentina and Prof. Nina Baird have helped us stay grounded with their constructive criticism every time we sounded utopian. Our classmates and friends have been a reliable sound board throughout the research and this process would not be half as enjoyable without them.

A special mention to our families who support us unconditionally and who cannot wait to test our prototype! We thank you for reading this thesis and we will be more than happy to discuss your thoughts and opinions about our thesis.

We acknowledge the School of Architecture, College of Fine Arts to provide us with the coursework and platform to support this study.

Abstract

In the current apartment rental market, energy efficiency of buildings is not typically a primary consideration for renters. The European Union has attempted to address this market failure by providing information on energy consumption and CO2 emissions to potential building users. This rationale is underpinned by the idea that informed users may prioritize efficient buildings and, if needed, they would even be willing to pay a market premium for them because of energy savings, environmental conservation, and more subtle health benefits. The development of various standards and certificates has also been dedicated to defining the specifications of a green building. However, this information is often geared towards professionals and may not be easily accessible or understandable for renters. Renters may not be aware of the specifications and design characteristics that influence a building's energy, environmental performance, or effects on occupants' health. This research aims to bridge this gap by enabling renters to make an informed decision based on the performance of the apartment they wish to rent. This is achieved by developing a software application that provides a curated set of metrics for comparing the energy, environmental, and occupant health performance of multi-family apartment buildings. The first part of the research involved curating relevant metrics from various standards, developing a benefit-based definition, and creating a scoring system to compare apartments. The second part involved testing the hypothesis through renter surveys and the development of a prototype. By introducing performance metrics as a purchasing factor, this research may also increase demand in the market for more efficient and sustainable buildings. Ultimately, this application will enable the evaluation of buildings in the rental market based on their performance characteristics, in addition to design aesthetics, locational benefits, price, and unique luxury features.

Keywords: *sustainability; green certificates; energy performance certificate; green building premium; building metrics; EPC; property investment; property valuation; property value; cash flow; real estate; review; sustainable development*

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1: List of Figures

2: Abbreviations

EU: The European Union
IEQ: Indoor environmental quality
P.M. levels: Particulate matter levels
WTP: Willingness to Pay
USGBC: US Green Building Council
WWR: Window to Wall ratio

3: Definitions

GB: Green Building: A GB usually refers to a building that considers and minimizes its impact on the natural environment and human health, utilizes considerably less water and energy than a non-GB, generally has higher levels of indoor air quality, and accounts for some measure of the lifecycle impact of choices amongst different kinds of building materials, furnishings, and furniture (Yudelson, 2009a).

EPC: Energy performance certificates (EPCs) are a rating scheme to summarize the energy efficiency of buildings. Home energy performance rating charts.

Certified buildings: A certification is a globally recognized symbol of sustainability achievement and leadership. For e.g., LEED Certification.

Kyoto Protocol: The Kyoto Protocol operationalizes the United Nations Framework Convention on Climate Change by committing industrialized countries and economies in transition to limit and reduce greenhouse Gasses (GHG) emissions in accordance with agreed individual targets.

4.1: Introduction

The construction industry has a profound impact on the natural environment, public health, economy, and productivity (US Green Building Council (USGBC, 2003)) and the buildings have a crucial role in preventing anthropogenic climate change, as they are responsible for 40% of the world's energy consumption and carbon emissions [1]. This calls for an urgent need to increase the rate of sustainable building construction in the real estate market. A study conducted by Darko states there are four factors that affect adoption of sustainable buildings in the market which are regulations, certifications, demand from clients and awareness. Of these four, certifications commands the most attention from building developers and will therefore be fleshed out in the subsequent paragraphs.

Considering the certifications factor, it is found that the value of certifications vary in different markets. There are multiple green building certifications in the market, created with different intentions and goals like LEED, Well building standard, EPC and NABERS amongst others. The adoption of green certificates has been quicker in the U.S. as compared to other parts of the world. Holtermans et al. (2019) noted that by 2014, approximately 40% of the assets in the 30 largest U.S. office markets had gotten LEED or ENERGY STAR certification. However, this is not the case in all property markets, and there are obstacles hindering the adoption of green certificates. While there is broad agreement regarding the advantages of green certificates (GC), there is a dearth of research investigating the cost-effectiveness of the investments required to get certification when compared to the number of studies examining the benefits of GC. Not all markets may view GC as equally desirable. For instance, even without certification, standards are high and construction quality is good for the Nordic nations. As a result, certificates may have less informational value than in some other markets where construction quality fluctuates significantly.

Therefore, it becomes imperative to understand the importance of certification to the two most essential players of the real estate housing market; developers and renters. The financial benefits of certification for the developers is dependent on multiple factors in the real estate market, ranging from the quality of construction, cost of the project to the neighborhood value of the project. Compared to non-certified buildings, certified buildings appear to be of higher quality. For instance, Robinson et al. (2015) noted that only 2% of homes sold for less than $26 million were verified, compared to over 35% of properties with transaction prices exceeding $60 million. The results of the studies that were looked at were clearly biased because better buildings are more likely to get certified. According to Eichholtz et al. (2010), less expensive sections in metropolitan areas and smaller, lower-cost regions had greater rent surcharges. Robinson et al. (2017) also noted that, whereas rental premiums were present in low and moderate-value buildings, they were absent in (certified) high-value buildings. They speculated that the lesser volume of certificates in these segments compared with the high-value segment may cause this. It is no longer seen as something that makes high-value structures stand out because having a certificate is now the norm. For instance, Olaussen et al. (2017) investigated apartment prices in Norway before and after introducing Energy Performance Certificates (EPC). They discovered that apartments that appeared to have a price premium for a better energy rating sold for a premium before the market's introduction of

the energy certificate system. Over time, it has been seen that the supply of sustainable structures is growing, which lowers rent premiums. Compared to more developed markets like the U.S. and the U.K, Costa et al.'s (2017) research showed that green certificates increased rental surcharges in developing markets, which may be because of the greater scarcity of certificates and lower sustainability criteria in emerging nations. Thus, the financial benefit for developers from certification reduces as more buildings get certified.

In the case of renters, multiple studies focus on analyzing if they are willing to opt for buildings with certifications or buildings with specific building features. Reichardt et al. (2014) found that savings in operating expenses explained approximately 50% of the rent premium. They suggested that the other half of the premium could be explained by intangible benefits, such as increased employee productivity. Jang et al. (2018) found that tenants were more likely to rent if they had a certification, but that having a higher certification score didn't make them more likely to rent. Robinson et al. [3] researched which sustainable building features tenants were most willing to pay for in their sample of almost 3000 leases in 300 buildings across the U.S. According to their results, tenants valued improved indoor air quality, access to natural light, and recycling possibilities most highly among the identified green features. The certification of buildings was ranked 14th out of 18 features. According to the results of Robinson et al. [3], access to public transportation, walking distance to services, natural light, premium HVAC systems, and electric car charging stations had significant independent rental premiums in their sample, which included almost 200 buildings and information on approximately 2250 leases. In their study about the green preferences of business tenants in Helsinki, Finland, Karhu et al. [6] found similar signs. Their takeaways demonstrated that location (in an environmental context) was ranked first, followed by energy efficiency and teleconferencing possibilities. Certification was ranked as the least important of the listed sustainable building features. Based on the reviewed studies, tenants will pay for desirable building features associated with sustainable buildings, not just certification itself.

On the other hand, personal benefits from green features affect tenants' willingness to pay for certifications and sustainable property features. This is key to motivating established property investors to improve property sustainability. Although the market is going to decrease the value of the property as certifications become more common, the only way to keep the prices up is by introducing to the renter the other building features that can have a benefit on their health and productivity, that the renters can benefit from. Matisoff et al. (2016) found factors that could cease people from choosing sustainable buildings, such as a lack of incentives, support, information, demand, regulations, and market failures. This lack of knowledge amongst renters is the gap in the current state of studies and practice where real estate developers and investors can make the most of it, which will push the industry towards green building adaptation. Thus, improving sustainability in built environments is important for real estate investors as well, who can choose to affect the world for the better by investing in sustainable properties which will give them an edge over non sustainable buildings [2]. This is because renters with more knowledge about better performing buildings will choose buildings with greener attributes as compared to other buildings. Renter's prioritizing buildings with sustainable features also links back to the last two factors identified by Darko, as stated in the beginning - demand from clients and awareness for adoption of sustainable buildings. Thus,

this thesis focuses on increasing awareness of renters about green building attributes in the real estate market.

By increasing awareness, this thesis will have two major impacts on the real estate market. First, once the renter has a better understanding of green buildings and the benefits they can gain from it, they will select more sustainable buildings to live in. Secondly, as a byproduct of this first impact, the increase in demand for better performing buildings will result in a more sustainably driven rental market which will also be beneficial for the developers.

To achieve these goals, a mobile application is proposed that will enable a renter to make a comparison between their short listed properties based on performance. For instance, if a renter has three apartment buildings short listed as their choices, they will be able to select the better performing building which will be judged on the basis of technical sustainability metrics that are defined in the field of building science. The App will be designed keeping in mind that it is not meant for technical experts in the field but renters from outside the field of building science. It will help the renter pick a better performing building out of their choices, while at the same time increasing their awareness about building performance.

4.2: Literature Review

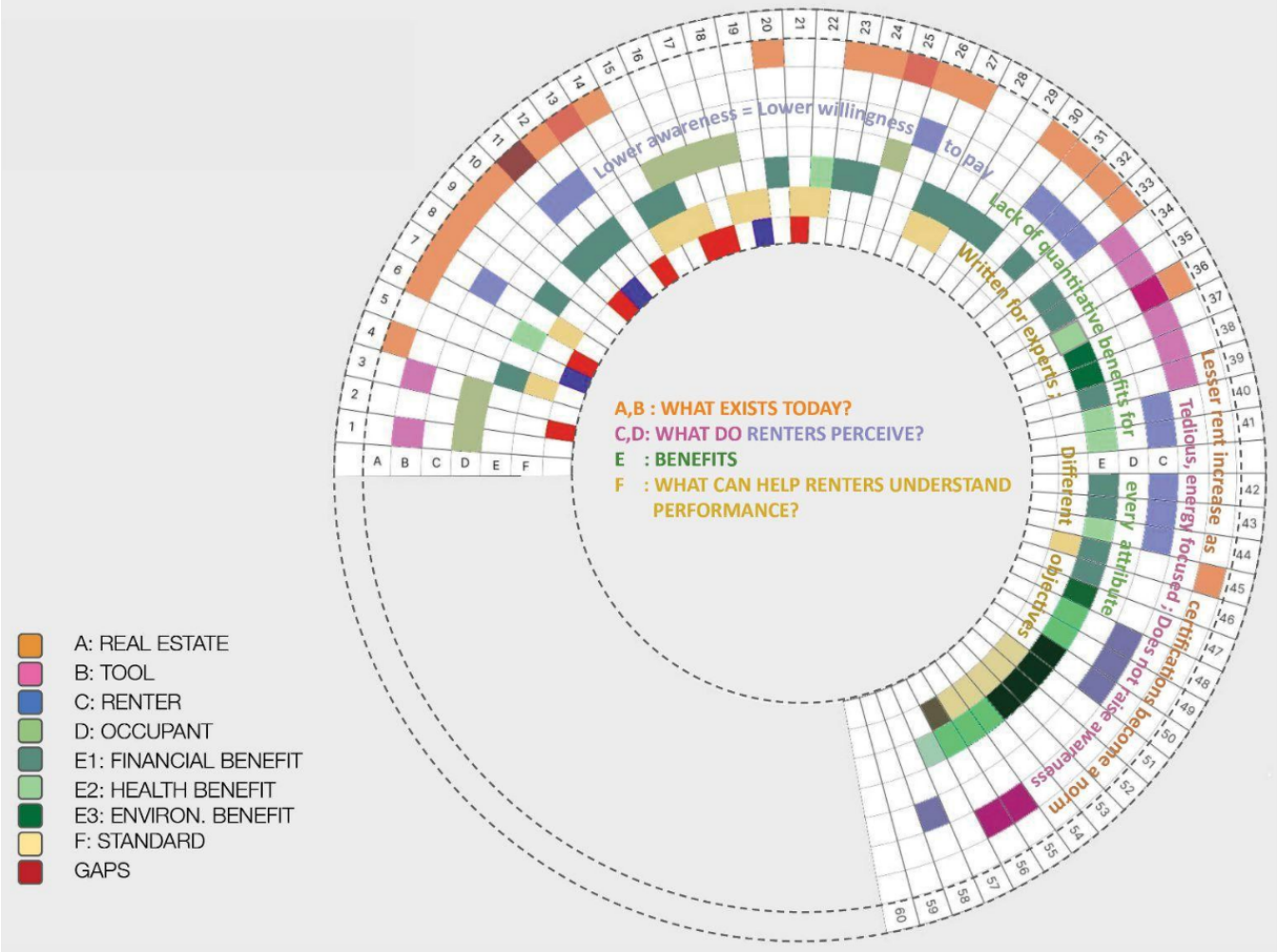


Fig 1: Literature Review diagram

Factors considered by Renters today

When a renter goes into the market looking for an apartment, they have a certain set of criteria in mind. A study conducted by Apartment Guide (2019), surveyed renters about the most important factors when they look into renting apartments[4]. 44% of the respondents said a price that fits their budget mattered the most. Location was the next important factor for 29% of respondents, followed by a pet-friendly place, accessibility for seniors/disabilities, and family-appropriate housing. Regarding what they take note of when looking at apartments, price was most important, followed by neighborhood, whether utilities are included (39%), specific amenities (31%), aesthetic features (29%), and property management (24%) [4]. Additionally, a real estate guide recommends that renters look at the location, price, size, number of bedrooms, kitchen layout, appliances, age, and maintenance [5]. It becomes clear from these studies that price and location are the top two aspects, as one would expect. However, unlike other products/gadgets in the market, the performance of the building is not taken into consideration by most of the renters before they rent an apartment.

The study conducted by Ramesh Koeri (2016) takes the previous work further by surveying the renters about certain factors amongst others, that hint towards building performance. It measures the factors influencing customer choice in renting apartments in Bangkok, by surveying customers who had the experience of renting an apartment or currently renting it. A couple of factors that will provide an insight for this web based tool and that were statistically significant in influencing the decision are 1) price - electric/water cost, repair maintenance cost, 2) physical environment - has presence of greenery and 3) brand perceived quality - if they use a good material and if it is well maintained. This is indicative that renters are responsive to building performance factors if they believe they have something to gain from it. Unfortunately, there isn't enough awareness/knowledge in the market about the green attributes of a building for a renter to make an informed decision.

Existing tools and their Limitations

To address the lack of awareness about building performance, certain existing tools, certificates and services have been developed by different bodies to help a renter assess the performance of the apartment. In the EU, the EPC (Energy Performance certificate) has been made compulsory by law to be provided to the buyer/renter for the apartment. EPCs are on a comparison scale from A (most effective) to G (least effective). It was developed with the intention of providing crucial help to consumers when choosing products that use less energy. "In 2019, the energy label was recognized by 93% of consumers and 79% considered it when buying energy efficient products" according to Special Eurobarometer 492 [7]. The EPC not only shows the current status of energy efficiency, but also shows the improvement options, their costs and the associated cash savings. This is useful for the owner when looking for ways to improve the energy efficiency of the property[7]. It lists the Energy Use Intensity (EUI) and a Carbon Dioxide Exposure rating. In addition, the heating, cooling and hot water costs per year are given. On the downside, according to research by Võsa, K.-V. et al (2021), it seems that among other factors mentioned, there is no mention of the building's IEQ or water

consumption. The energy rating is area dependent and may not be accurate as it does not take occupancy into account. The study also mentions that EPC uses default values in certain cases to reduce assessment costs which may be misleading to the buyer [8].

Home Energy Score -- a tool developed by the DoE -- was launched in 2012 with the intention to provide home buyers with a reliable tool to help understand their energy efficiency. In return, they hoped it would help improve the performance of the U.S housing stock. It provides the user with an energy score and a list of suggestions with related possible savings if they improve on the suggestions given by the report. The scale is a simple 1 to 10 score which assumes a few default conditions like thermostat setting, number of people, etc [9]. On the downside, this tool only analyzes the energy consumption and does not provide a complete picture to the homeowner about the other performance factors like indoor environmental quality of the house. Additionally for this tool, a user either needs to undergo training to make an assessment of the house or opt for this service. Since this process does not directly address the owner, it is less likely to increase awareness about the green attributes of a house.

Asset score, also developed by the Department of Energy, turned out to be a complex tool without raising user awareness. It has a similar intent as the Home energy score, but for commercial and multi family residential buildings. This software allows the user to compare energy efficiency of buildings and is free to use. It also provides recommendations for energy efficiency upgrades. However, it requires a user to download a software package and understand a guide with steps about how to build the energy model for their building in the software. It involves steps like providing basic building information, building type, inventory of building features, creating a 3d block of the building, adding technical details of construction, lighting, HVAC and other systems of the building and generating a report that should be submitted to the authorities [10]. It can be a useful tool to a user but majority of the users may not opt to develop an elaborate energy model to understand how their building performs without understanding the importance of the green attributes.

Similarly, certain real estate companies are also providing energy efficiency information to home buyers. KB home for instance, provides an Energy Savings Comparison information next to every home layout. This ESC is a comparison between the energy consumption of the house the buyer is chasing compared to a typical US house [11]. They also provide a HERS Index score and Energy Star certificate for the house. Additionally, they also provide a slider with an estimate of savings over the years for the house they pick as compared to a typical home. They claim that usually the buyers see energy savings of an average of 80% for their homes as compared to a typical US home. This interactive energy data is provided on their website as a part of the house details. This is informative data that a user can use to compare KB Home houses, however like the previous tools, it does not provide IEQ information or raise awareness/provide knowledge in buyers to encourage them to invest in green attributes.

There are a handful of initiatives as stated above that intend to assist buyers, renters, and owners in learning more about their building's performance. However, most of them only account for energy use and most importantly, they fail to raise awareness amongst the building users about building performance. The question arises if this lack of awareness/knowledge is

one of the major reasons why renters do not consider green attributes while renting an apartment.

Renters and Willingness to Pay (WTP)

Several research studies, which have been summarized in this section, have investigated renters' willingness to pay for a high-performance building and explored their motivations for paying or not paying. In cases where they are not willing to pay, these studies aim to identify the underlying reasons. One such study is conducted by Hitaj, C et al, that evaluates a dataset of the sales of all apartment buildings having 5 to 19 apartments in Los Angeles County between 1989 and 2008 and the air pollution data from U.S. Environmental Protection Agency's (EPA) AirData monitor queries. They correlate ambient air pollution and apartment building prices. The research results found that higher levels of ambient ozone pollution, lower sale prices for apartment buildings, which is consistent with renters' negative valuation for air. The results of this study conclude that renters were willing to pay $14 to $52 in constant 2010 dollars for a 1% reduction in 1990 ambient ozone pollution levels as measured by the 1 hour maximum value in Los Angeles [26]. Thus, the renters' negative valuation of the air and hence the willingness to pay highlights that the renter's awareness played a role towards this green investment. It also shows that a renter is willing to pay for a personal health gain.

The same results are validated by a study conducted in Nanjing, China that showed that although the socio-economic status of homebuyers determined their WTP, all socio economic groups were willing to pay for an unpolluted environment and for non toxic construction materials [12]. The study also used very clear terminologies like toxic materials which even got the lower socio-economic group to be willing to pay for the attribute. This emphasizes the importance of conveying the importance of the green attribute to the consumer.

Similarly, Anastasia Njo et al carried out a study to understand the willingness to pay of the public with relation to their awareness of green apartments. The results showed that 83.846% of respondents understand green building, where 38.532% are willing to pay 5% and 39.755% are willing to pay 6%-15% to get a green apartment from the total purchase price. The findings from the study were that if the individual had higher environmental awareness, their WTP was higher. This environmental awareness mainly included sorting of trash, use of energy saving lamps, and waste treatment systems. However, they did not evaluate if the respondents understood green attributes of a building but nonetheless, it successfully demonstrated that higher awareness led to more WTP. Similar to the previous findings, this study also found that people were more interested in attributes that gave them personal gains as compared to environmental gains. [13]

In another study, Yung Yau found a direct correlation between perceived importance of the attribute and willingness to pay. They found that 70% of people were willing to pay for LED light and water saving fixtures and their perceived importance for these attributes was also high. Another important conclusion was that the WTP for green housing attributes was motivated by economic incentives like payback periods in addition to moral reasons [14]. Thus, the provision of life cycle cost analysis can sway the renter to invest in better performing buildings.

In order to understand which green factors in a residential building affect the renter's decision, a study in Singapore researched a residential real estate property that had undergone a few green retrofits. They found that 56% percent of the people were willing to pay for more retrofits because of the following reasons : to achieve cost savings from lower utility bills in the long run (mean assessment : 4.48), the availability of financial assistance and green loans (4.60), saving the environment (3.98), and higher resale value. Economic considerations which had personal gain was the top priority for the residents. The most popular green features they were willing to pay for was something that they had already experienced like LED lights (91% residents) and low flow water fixtures(87% residents). Low e film windows had the lowest preference because its benefits were unknown to them[15]. This again proves that awareness and prior experience increased their willingness to pay and their preference. This is also confirmed by a paper mentioned earlier by Ramesh Koeri (2016) about real estate factors that matter, where the results showed that statistically significant factors that affect a customer's choice are information from others and from past experience [5].

From these multiple studies, it can be concluded that the different factors affecting WTP are user awareness/knowledge, prior experience, information from others, perceived importance, personal gain - financial and health. To provide the renter with these factors, it is important to identify the benefits that the renter can gain from a better performing building. These benefits will provide the renter with the personal benefits and explain the importance of the green attributes in their apartment.

Benefits which interest the renter

The benefits of living in a better performing apartment can be numerous. They can be broadly categorized into three categories as also suggested by the BIDS tool - Financial, Health and Environmental [17]. One of the most common financial benefits is reduction in utility bills from less energy use. This has been validated through various studies. One such study was done by Kim J. et al (2014) where they studied the results of energy consumption for two types of house in Los Angeles, California - one with green features and one without. The following retrofits were added to the house : electrical vehicle charging stations, alternative building power supply by solar panel technology, ENERGY STAR® qualified hard-wired fixtures, and high-efficiency water heater, cooling, and heating systems. Post these retrofits, they found a 54.60% savings per billing cycle compared to that of the house without retrofits. This resulted in an average savings of $214.76 per billing cycle for the user. [18] However, these figures were predictions based on real data and not a real case study. These results were predicted from a multiple regression statistical model which was based on data collected from 110 single family houses located in Los Angeles. This can indeed be a useful method to predict savings, which will be explored in the methodology section. The study also provided life cycle cost analysis for the PV panels would break even after eight years of the 25 year cycle with a $1,043 /year profit then onwards. Such LCCA can be useful in convincing the user to invest in green attributes.

Researchers from the previously mentioned study about a residential estate in Singapore found that the newly installed outdoor street LED lighting had reduced energy consumption by at least 50 percent, compared to traditional lighting systems; the elevator energy regeneration systems used 20 percent less energy than those conventional lifts and the same was reflected in the energy bills of the estate. [15]

Reduction in energy also directly implies reduction in the greenhouse gas emissions of the apartment. This counts as one of the most important environmental benefits amongst others. In 2005, Takama et al. In a case study of the Next21 residential building in Osaka, Japan, a 27 percent increase in CO2 emissions, and a 74 percent reduction in NOx gas production, a 27 percent reduction in building-wide energy consumption, are firmly due to a combination of advanced mechanical systems and strategies Design including absorption chiller, fuel cell, reinforced insulation and passive solar heating.[19]

A good volume of studies also covers the health benefits of better performing buildings. In a study conducted in single family homes in Cook County, IL and IN, they found that by increasing the ventilation rate from 39 cfm to 79 cfm , there was a statistically significant reduction in headaches in children by 31% and Psychological distress score in adults reduced by 32%. [18] In another study , they installed air purifiers with a pre-filter, an active carbon filter and a HEPA filter in households and found a 9.12% increase in asthma control in children [20].These studies have been carried in homes and comparatively lesser studies have been found for residential apartments. This hints that further research needs to be conducted to quantify similar benefits in apartment buildings.

In a study conducted in Malaysia, Shafiei et al (2021) researched which green benefits was the public most aware about . The research proved that the public was most aware of environmental benefits (3.91 mean) like air and water quality, less about economic(3.58 mean) and social(health) benefits(3.51 mean). The study showed a strong statistical correlation between green awareness and WTP (R Square: 0.825, sig: 0.000). In sync with previous findings, the most important features for the public were the ones that gave them personal benefits like IEQ, energy efficiency and greenery [21]. There can be multiple such benefits for different green attributes under the three categories as stated above. These benefits will help educate the renter about the importance of their respective green attributes.

Sustainability metrics to guide the Renter

For the purpose of our study, it becomes imperative to identify the green attributes that will provide similar financial, health and environmental benefits to an apartment renter. In order to do so, five of the known green building standards and certificates are evaluated to extract the performance metrics that relate to apartment buildings : High performance building magazine, Home energy score by PNNL, Leed v4.1 : Operations and Maintenance, Leed v4.1 : BD&C, IECC 2021, Well building standard v1 2016, Ashrae 2022 (90.1, 55, 62.2).

Because these six certificates have been developed with different goals, it's imperative to understand how their performance metrics can contribute towards building this software application. Home energy score by PNNL focuses on the physical performance attributes , i.e, its construction and systems.[22] It focuses on evaluating the performance of the construction like the materials used, R value of all walls, slabs, the SHGC value of the window glazing, the heating system, cooling system, DHW system and PV system if any. Leed v4.1 : Operations and Maintenance, on the other hand, is a more comprehensive standard which covers location and transportation, energy efficiency, water efficiency, IEQ, materials and construction, cleaning policy, pest management policy.[23] A standard like the Wells v1 2016 contributes to adding metrics that directly affect human health.[24] As an example, this includes inclusion of physical activity spaces in the building and metrics related to biophilia amongst others. Environmental Performance Certificate is similar to the PNNL score where it focuses on the energy performance of the building. It captures the energy usage, the performance of the building construction and systems.[7] The high performance building Magazine, because it is a magazine and not a standard, evaluates the building on different metrics for every project based on which metrics are more relevant to the project. In addition to the standard metrics of energy usage , construction and systems, it highlights the relevant metrics like demand control ventilation , controls, coffered ceilings. It also highlights passive techniques used by the building like evaporative cooling, cross ventilation, integration of courtyards [25]. This can be a useful feature for the proposed tool as it can raise awareness among the renters about the passive techniques. Evaluating these distinct standards provides an extensive base for further development of this performance comparison tool.

4.3: Research question

How can a renter be best informed to choose a more efficient and healthier apartment based on its performance?

The literature review aimed to address the question of how to assist renters in selecting a more sustainable apartment from their shortlist. As revealed by the gaps in the literature, very little research has been done to empower renters in this regard. The study aimed to develop a framework to support renters in making informed decisions and promoting sustainable buildings in the rental market. The research question was based on the following hypothesis.

4.4: Hypothesis

If renters understand the building performance, then they will choose more carbon and IEQ efficient apartments. This, in turn, will create a greener rental market by increasing demand and encouraging developers to construct more sustainable buildings.

4.5: Solution/System diagram

Figure 2 illustrates the operational system diagram of the application. There are three stakeholders involved - the renter, the existing tenants and the developer. The process begins with the renter shortlisting their choice of apartments based on their preferences. The software application would then provide a list of questions under different categories to the renter, existing tenants and the developers. The renter and the existing tenants would usually answer the more qualitative questions which can be answered by observing the apartment while the developer would answer more technical quantitative questions like the efficiency of the HVAC system or the R value of the walls, etc. All their answers will be recorded in the application and will be analyzed with a scoring system which will be explored in detail in the next chapter. The application will provide final scores for the shortlisted apartments which will help the renter make an informed decision based on the performance of the apartment. The renter will gain knowledge about sustainability and building performance in the process, learning which benefits they can obtain from different building features and which of their shortlisted apartments provide those benefits. The developer will receive a list of recommendations based on the better performing buildings in the neighborhood, they would receive data about what renters prefer in the market about sustainability and they get a platform to promote their sustainable building features.

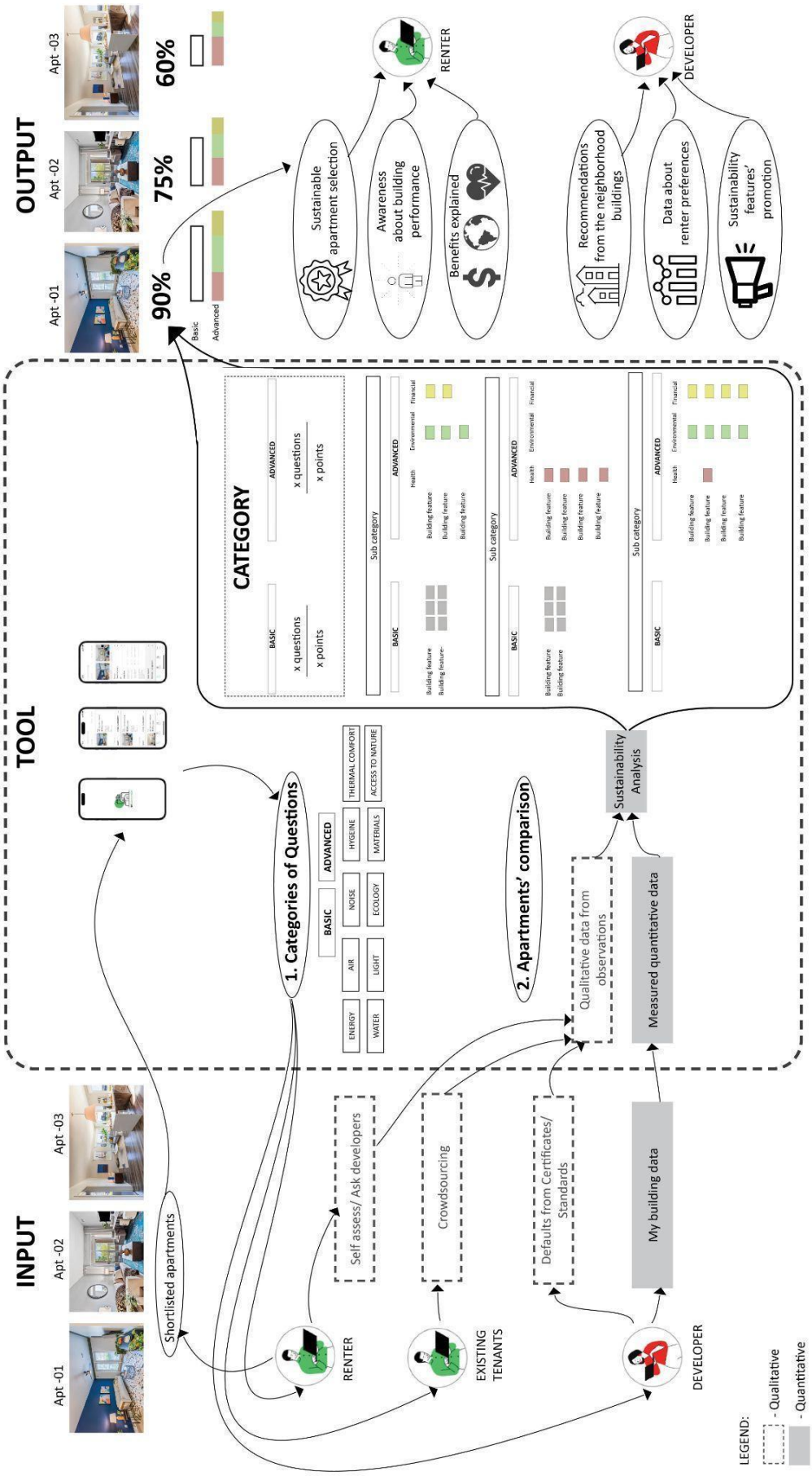


Figure 2. Systems diagram

4.6: Methodology

The methodology to develop this software application is broadly classified into two halves- development and testing + prototype. The development phase consisted of three parts, i.e., selection of metrics, humanizing the metrics and development of comparison score. The testing and prototyping phase focused on testing the hypothesis and developing the prototype.

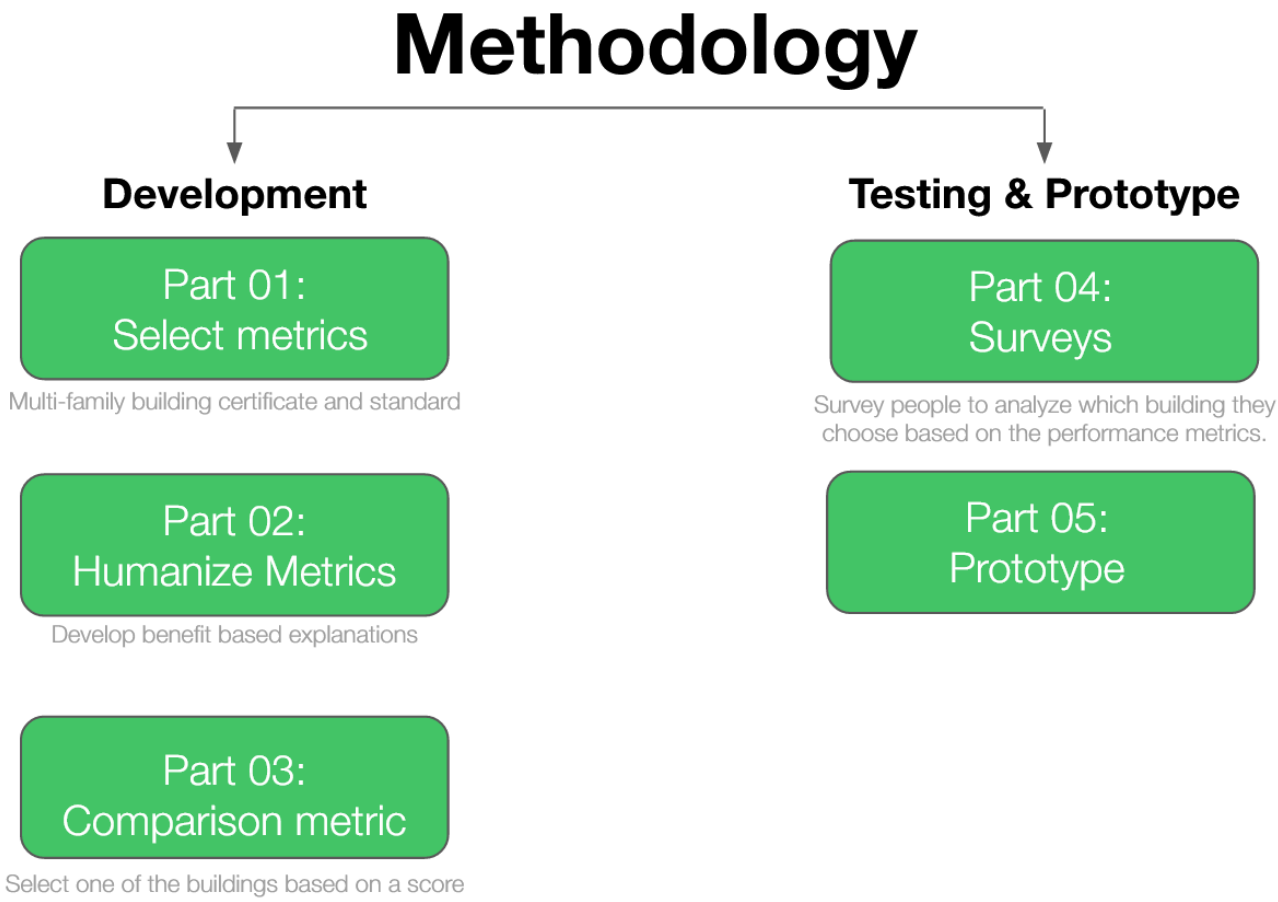


Figure 3. The methodology process

4.6.1 Development

Part 01: Selection of metrics

The first step involves identifying and shortlisting relevant building performance metrics for multi-family apartment rentals. This was achieved by examining multiple certificates and standards related to multi-family housing, including LEED v4.1-O&M, LEED v4.1-BD&C, Well standard v1, EPC, Ashrae 55 2020, Ashrae 62.2 2022, Ashrae 90.1 2022, AIA COTE_V_1.5.3, PNNL Home energy score, and IECC 2021. Performance metrics for multi-family buildings were compiled from all of the above standards/certificates, along with detailed information for each metric. This approach ensured that all aspects of multi-family buildings were covered and provided a comprehensive base for the application. By studying the different certificates and standards, a rich set of questions was developed for the application. The metrics were classified into eleven broad categories, including light, air, water, thermal comfort, energy, noise, access to nature, hygiene, ecology, materials, and community, as seen in Figure 4, along with their subcategories. This granular structure helped in defining a framework for the application. The developed structure was used as a base to create a comparison score and educate the users of the application. A detailed study of the different certificates and standards can be found in Appendix A.

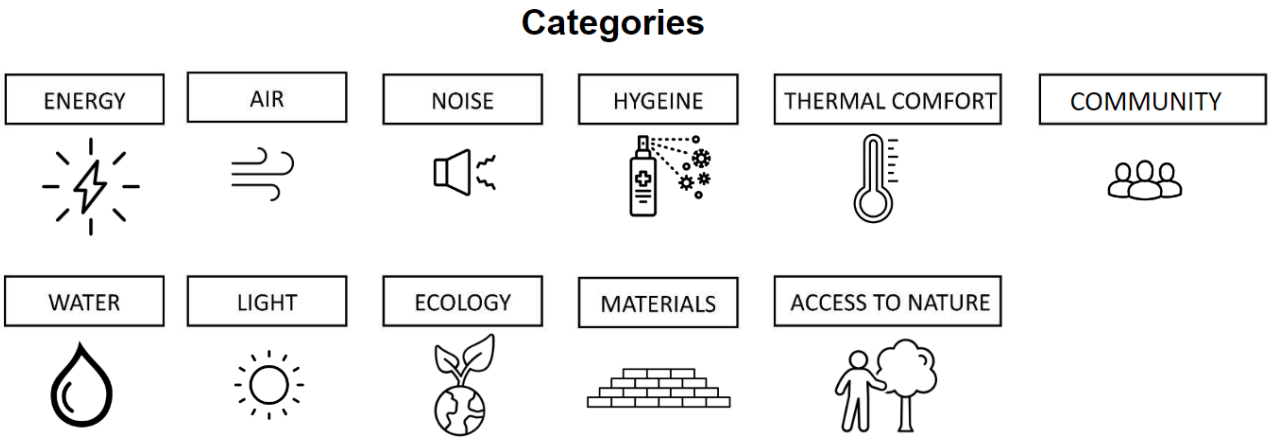


Figure 4. List of Categories and their icons

Part 02: Humanize metrics

The second part of the methodology focused on humanizing the technical metrics and making it more under stable to renters and non-experts. As observed in the literature review, increasing awareness, and understanding among renters is crucial [3]. It was also found that the consumers responded the most when they saw a personal benefit - financial or health. Hence, in this part, a benefit-based explanation of every metric has been developed for the renter and the same has been provided against every metric in the application. An example of this would be “Ventilation rate” which is a technical metric. The explanation provided for this metric is “Increased ventilation rate means more fresh air to breathe which is proven to reduce respiratory and allergic diseases in the occupants.” Environmental, health, and financial symbology is attributed to each benefit to make them easier to grasp. A legend that outlines the symbology can be seen in Figure 5.

Part 03: Comparison score

To select a better performer across the short-listed buildings, renters would require a comparison score to draw conclusions. As described in the 4.5. Solution section, a list of questions under categories will be provided to the different entities (renters, existing tenants, developers). Every question will be about a specific building feature/metric which will help compare the different buildings. As seen in the different certificates and standards, there are certain prerequisite metrics or features that a building must have as the very basic and then there are certain advanced features a building can must continue improving its performance. Similarly, for the purpose of this application, the questions are divided into basic and advanced questions. In order to ensure that all buildings are being compared for their most essential aspects in terms of performance, the framework addresses basic questions that are worth a flat total of 3 points each. Additionally, the framework includes optional advanced questions, which provide opportunities for scoring more points based on how many of these advanced questions are answered for a particular building. The number of points allotted to advanced questions varies based on how many of the three impacts they address: health, environmental, and financial. Figure 6 illustrates that basic questions receive a total of three points each, while advanced questions can earn up to 3, 2, or 1 point(s), depending on how many of the three impacts they cover. The questions are of two types - binary or multiple choice. Binary questions receive either all points or 0 points, while multiple choice questions can earn gradient points based on the chosen answer.

Figure 5. Legend for benefits

CATEGORY

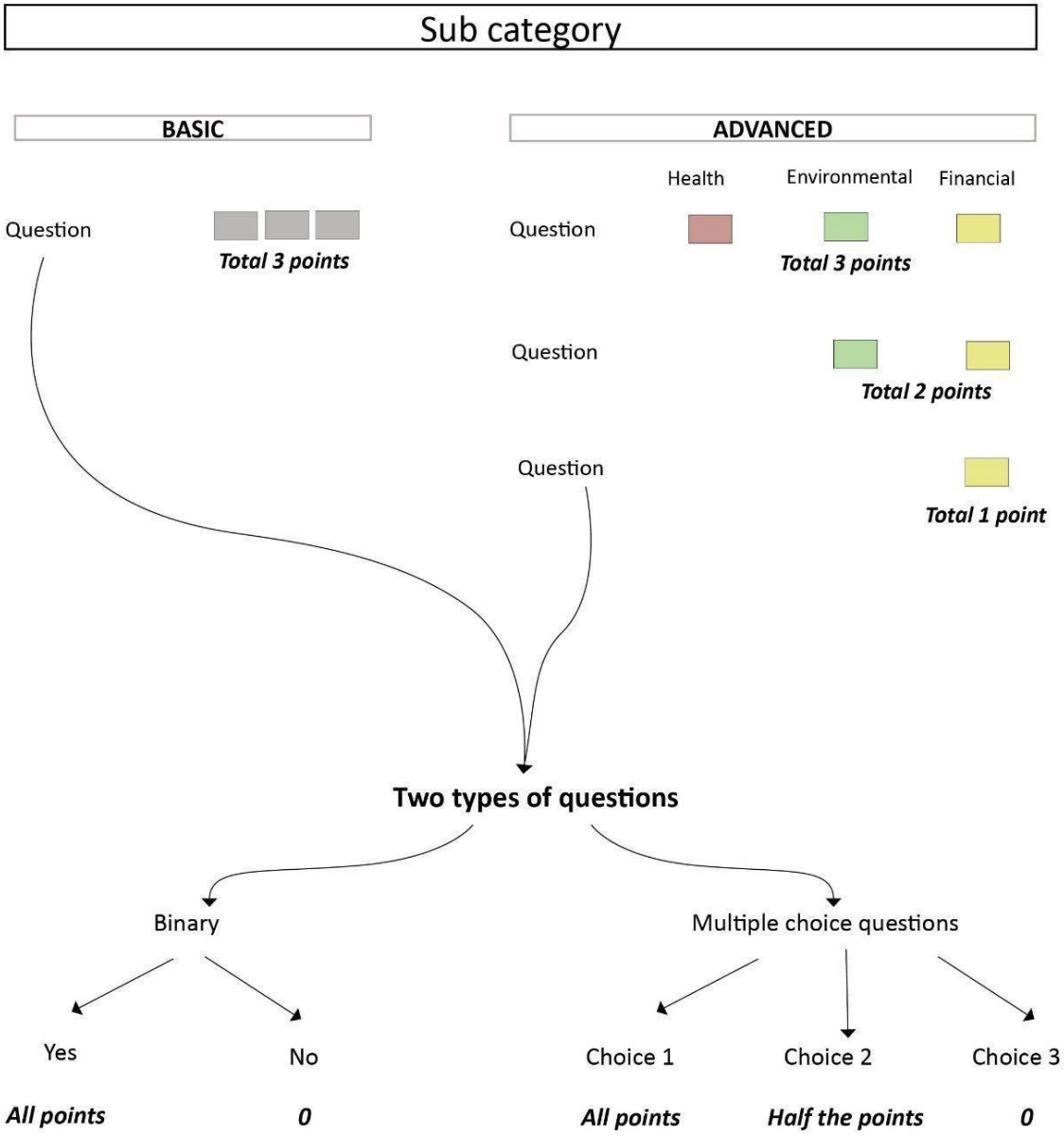


Figure 6. Template of Scoring and type of Questions

Based on the logic explained above, the scoring system has a total of 33 basic questions with a total 100 points and a total of 80 advanced questions with a total of 150 points. This comes to a total of 113 questions and 250 points, as seen in Figure 7. This scoring system helps us provide a final percentage score for the chosen building.

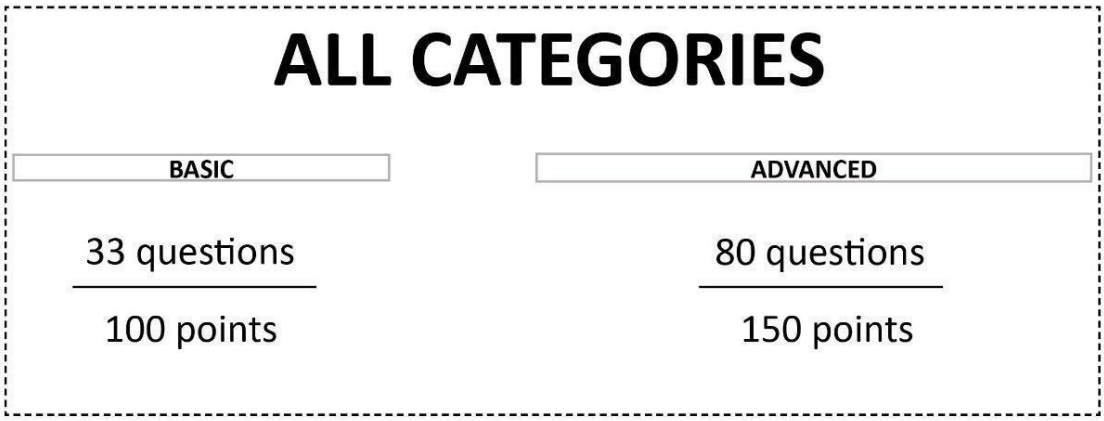


Figure 7. Total scores

A detailed breakup under every category and their subcategories has been provided in Figure 8 to Figure 17 below. The total number of maximum points that can be gained under every question has been denoted in these diagrams. As it can be seen from these diagrams, the basic questions/metrics have a standard three points, and the advanced questions / metrics keep varying based on their impact. For instance, the energy subcategories mostly have an environmental and financial impact, whereas the light category has health, environmental and financial impact. A detailed example under the light category of ratio of window height to room depth would have a health impact as more light has proven to have a positive health impact on its occupant. Sufficient daylight would lead to reduced usage of artificial light by occupants, resulting in lower energy consumption and associated environmental and financial benefits. The evaluation process considered each question and its respective impact. The air category was found to have significant health impacts, while within the water category, water quality had a notable health impact, and water usage had environmental and financial implications. Under thermal comfort, the envelope section represents the most important features of the building with all three impacts. Hygiene, noise, and access to nature denote health impacts. Ecology and materials denote environmental and financial impacts. All these points add up to the total mentioned above in Figure 7.

Figure 8. Energy: basic and advanced metric and their scores

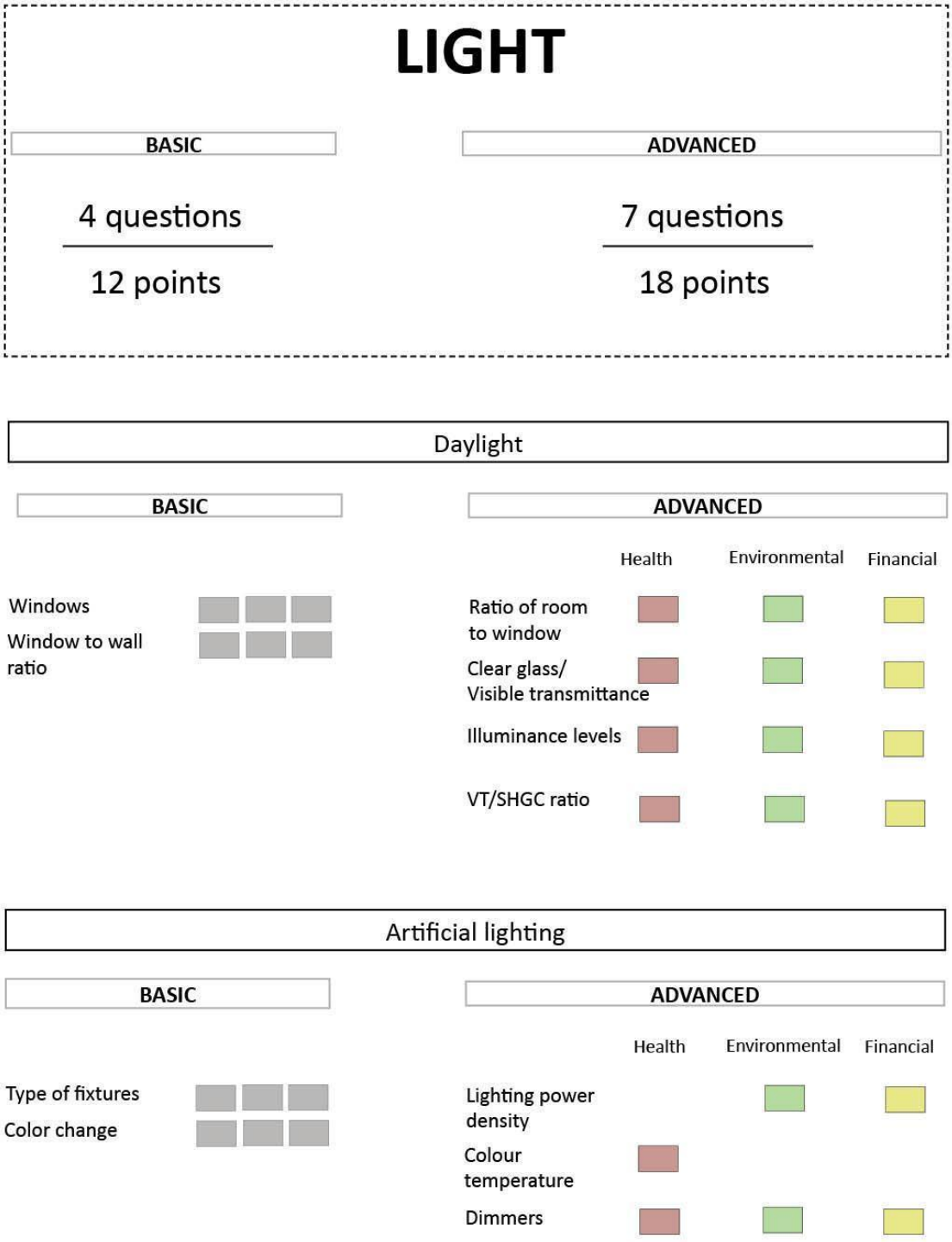


Figure 9. Light: Basic and advanced metric and their scores

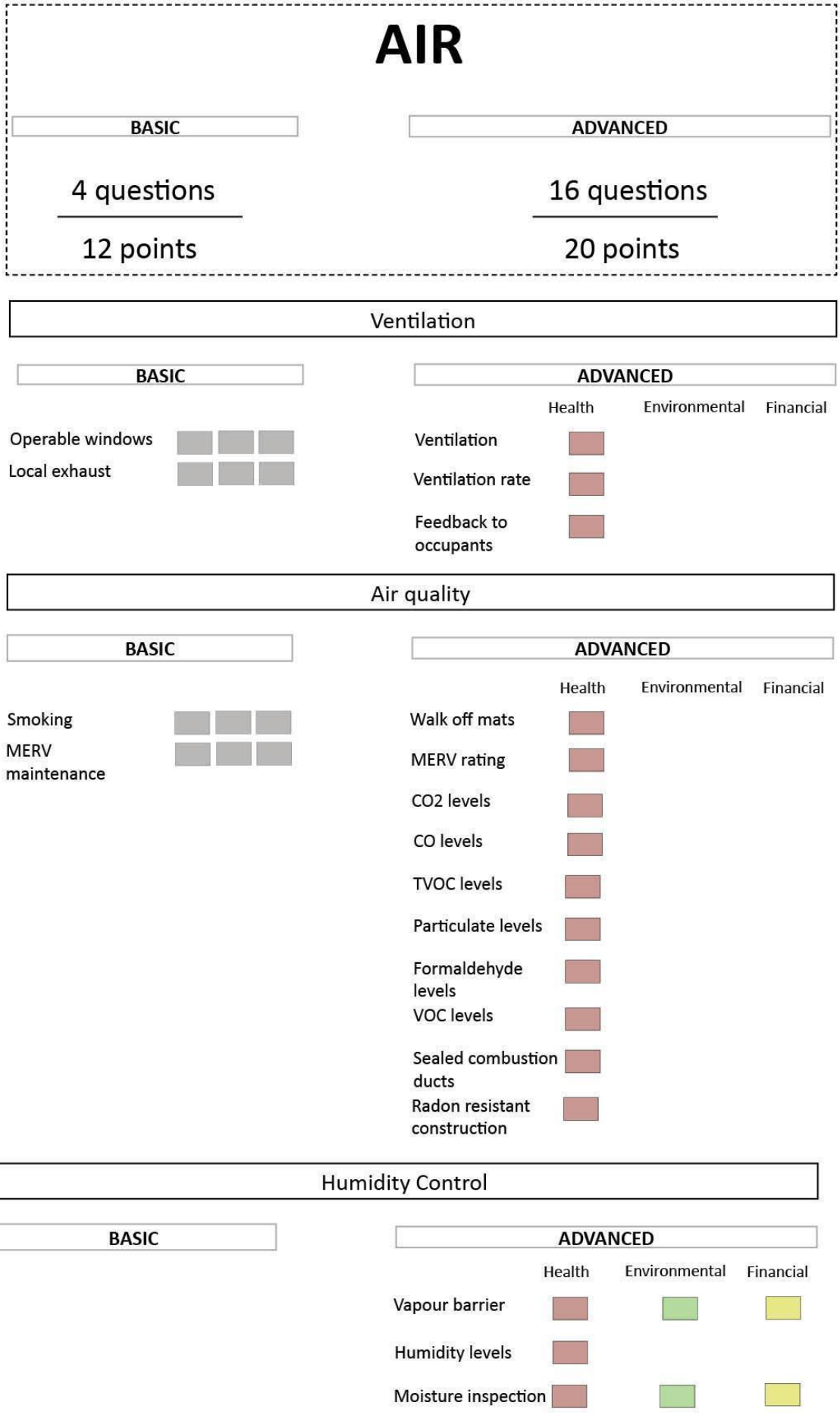


Figure 10. Air : Basic and advanced metric and their scores

Figure 11. Water : Basic and advanced metric and their scores

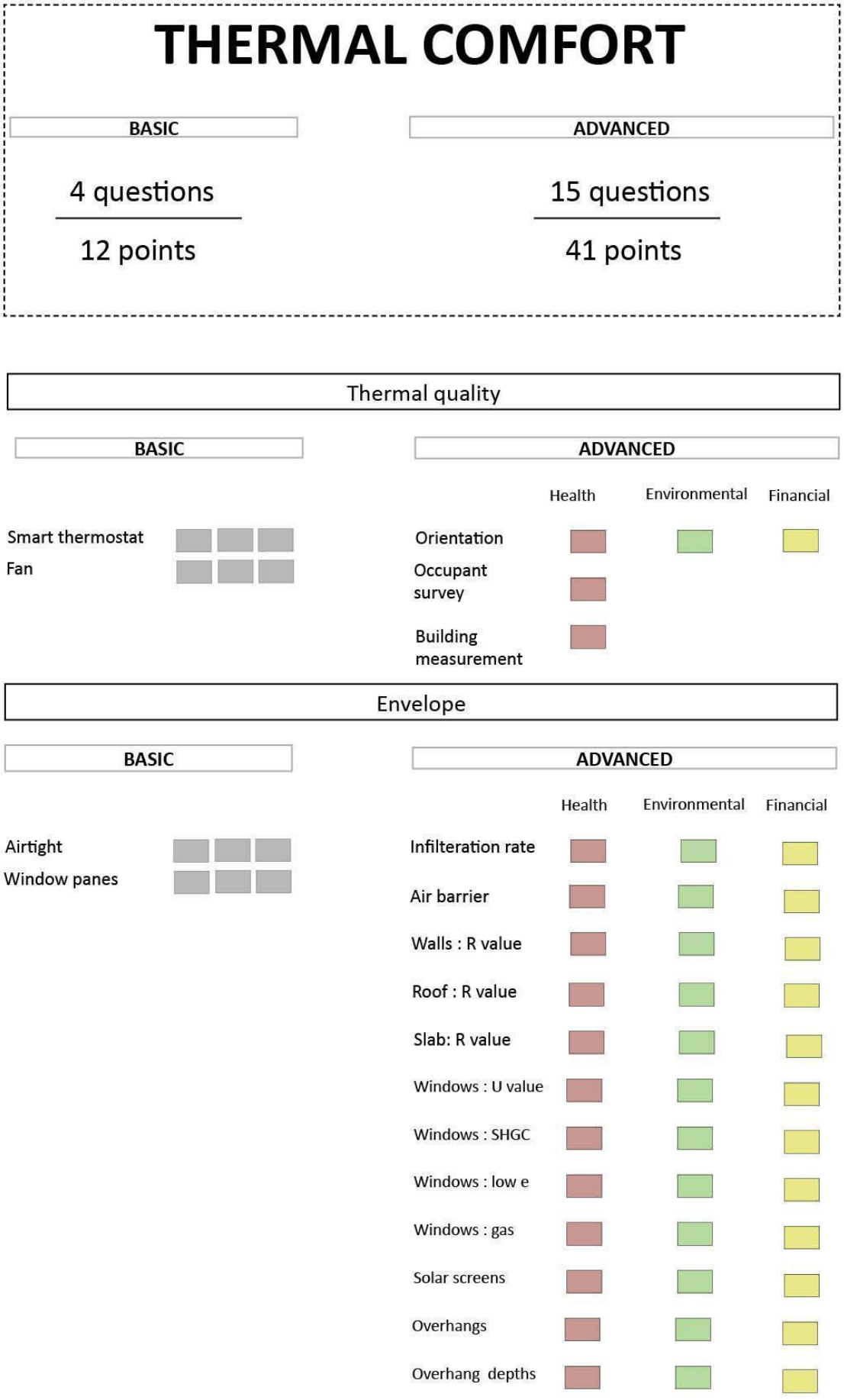


Figure 12. Thermal comfort : Basic and advanced metric and their scores

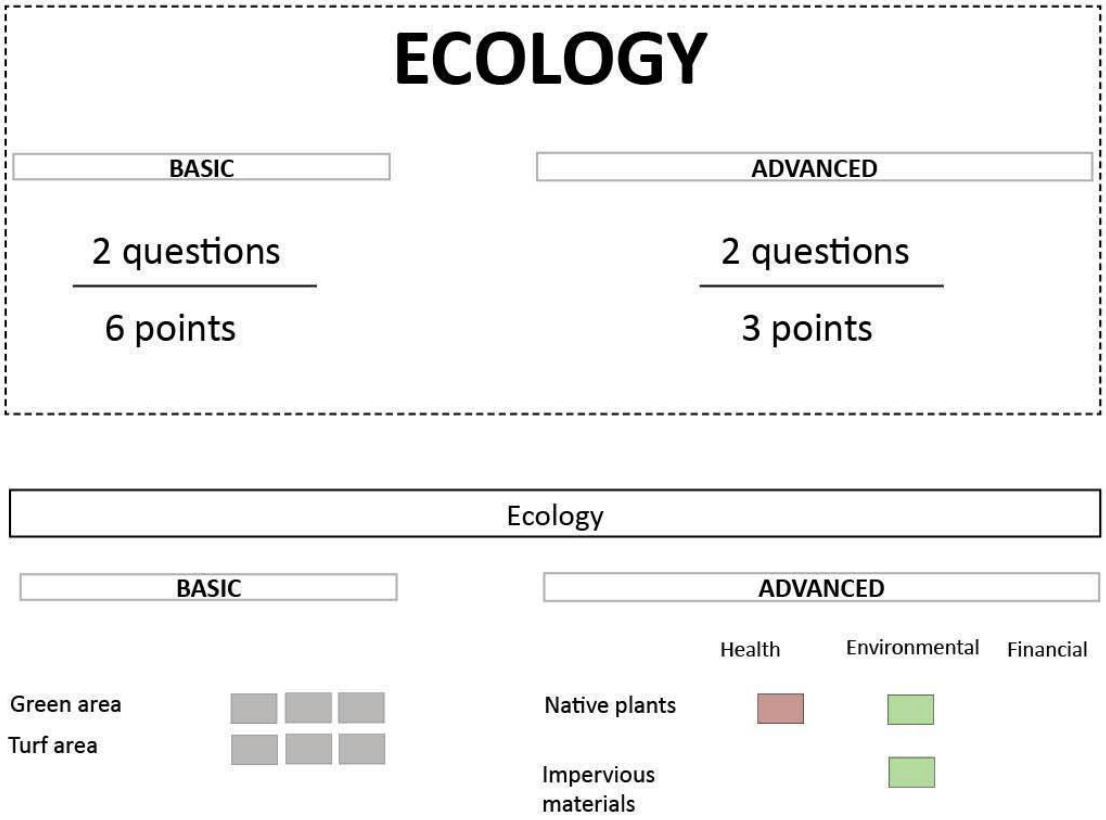


Figure 13. Ecology : Basic and advanced metric and their scores

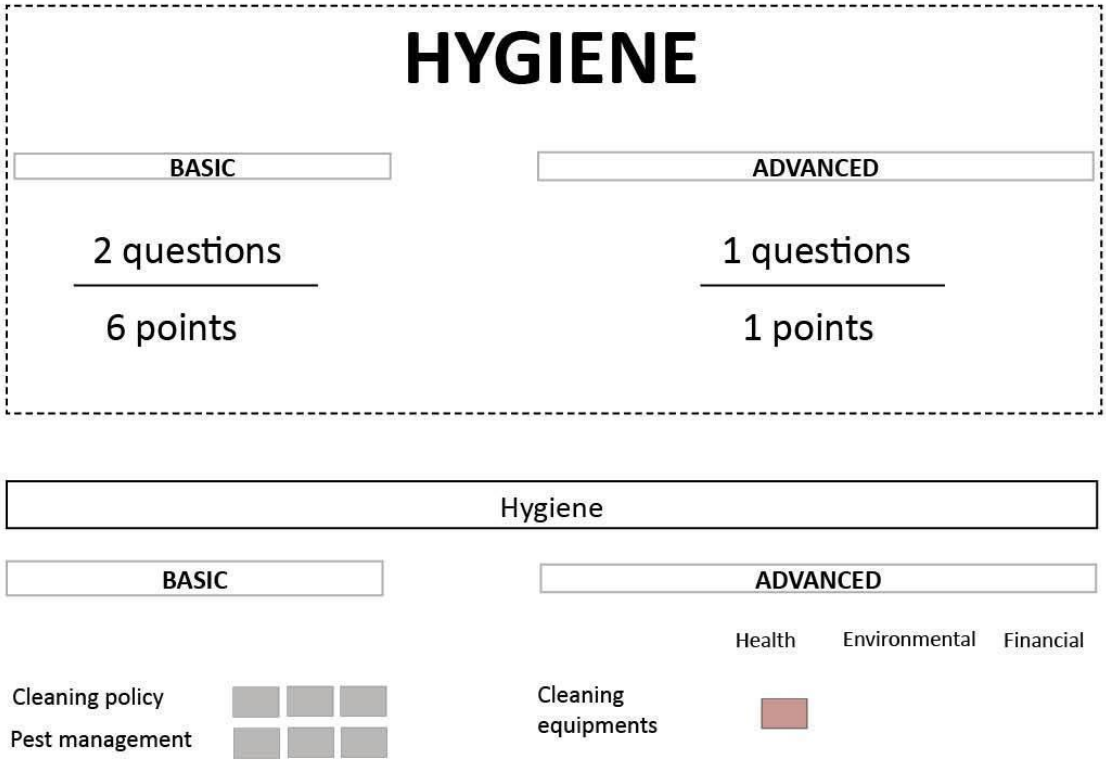


Figure 14. Hygiene: Basic and advanced metric and their scores

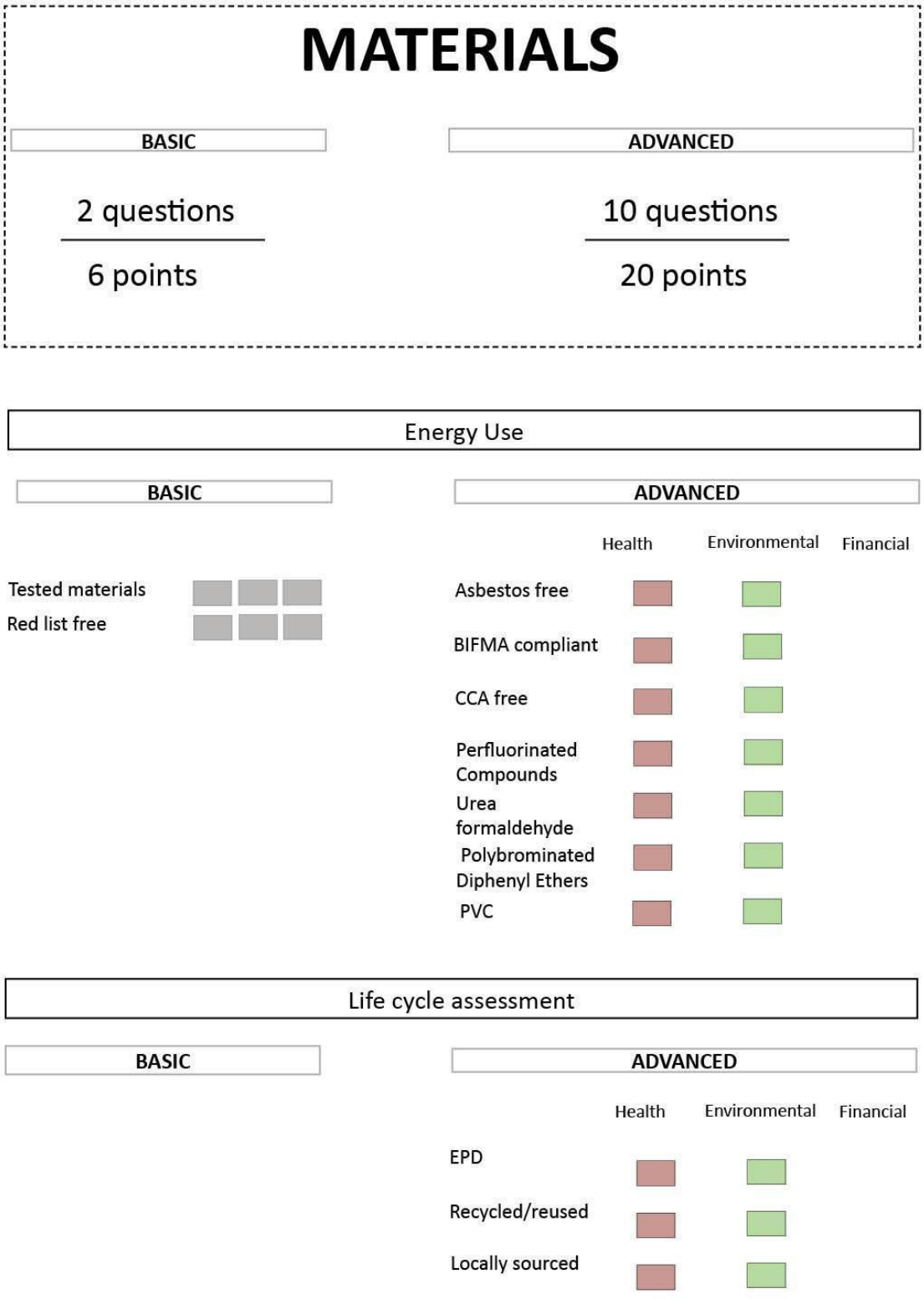


Figure 15. Materials : Basic and advanced metric and their scores

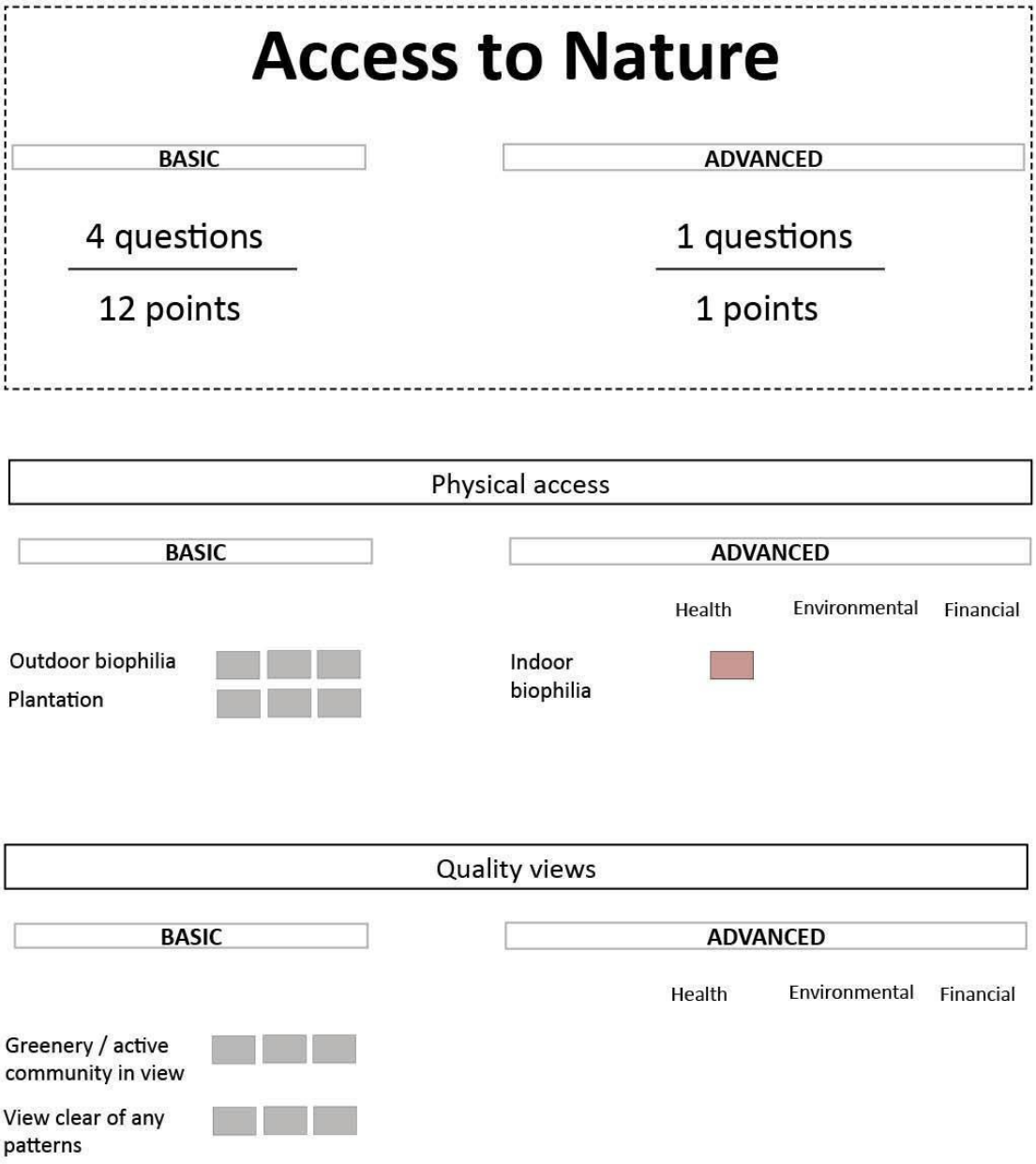


Figure 16. Access to Nature: Basic and advanced metric and their scores

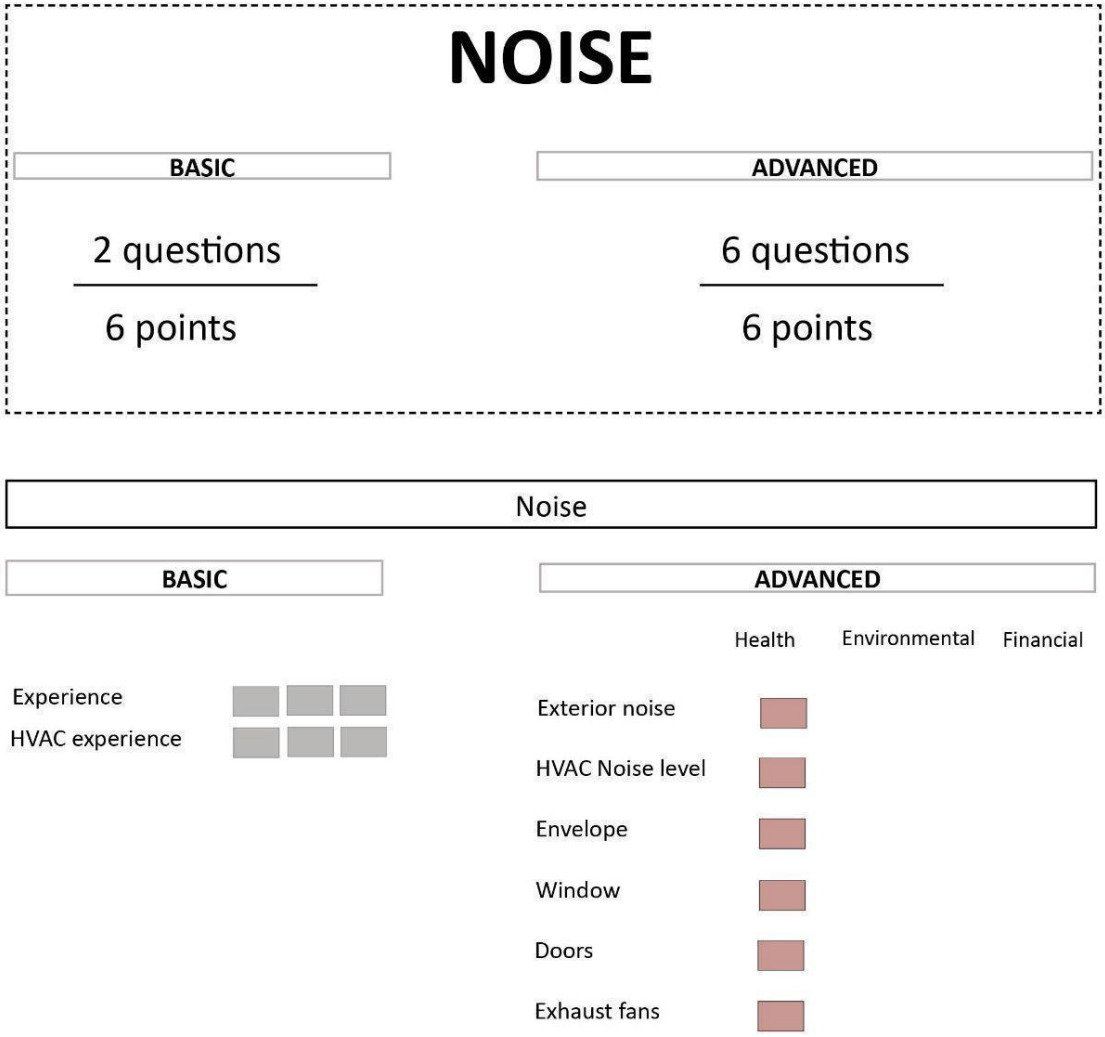


Figure 17. Noise : Basic and advanced metric and their scores

Catalog of questions from methodology

A compilation of all the three parts above is presented in the tables below. These tables present the questions under every category, their possible answers and the points allotted to those answers. It also indicates which impacts are valid for those questions, like the diagrams shown earlier. The tables also present the benefit-based definition which will be provided to the user of the application to enable them to understand the technical concepts. The source of the metric has also been mentioned in these tables. The information from these tables was used to develop the software application and the surveys in the next parts.

LIGHT

	Question	Answer options	Points	Health	Enviro	Financ	Benefit based explanation	Standards
	Daylight							
	Basic							
	Do all living spaces have windows	1)Yes 2)No	1)3 2)0					
3	What is the window to wall ratio between 30-60%?	1)Yes 2)No	1)3 2)0				Ratios up to 40% will provide enough daylight	Well
	Advanced							
2.a)	What is the depth of the room from the window ?	(A number)						
2.b)	What is the height of the window?	(A number)						
2	**Calculated Information for the renters:** Ratio of room depth to window	(A number)	If less than 2.5: 3 If more than 2.5: 0				Depth <= 2.5 * height of the window 75% of the area of all regularly occupied spaces is within 7.5 m [25 ft] of view windows.	Well v2 2022
4.a)	Does the window glass look clear or does it look tinted ?	1)Clear 2)Somehwat clear 3)Very tinted	1)3 2)1.5 3)0				If the glass is dark/tinted, enough daylight won't come in. It should be clear	
4.b)	What is the visible transmittance value of the windows(VT)?	(A number)	If equal to or more than limits: 3 If lesser: 0				This number indicates how much daylight is being allowed to come in, the more the better. Fixed window - 0.418 Operable window - 0.74	Ashrae 90.1
7	Are the illuminance levels through computer simulation or on site measuments above 50%, if available?	1)Yes 2)No 3)Not available	1)3 2)0 3)0				Daylight autonomy indicates whether a space is receiving enough daylight. Achieve illuminance levels between 300 lux and 3,000 lux for at least 50% of the regularly occupied floor area.	LEED_v4.1_O_M_Guide, LEED_v4.1_BD&C_Guide
9	**Calculated Information for the renters:** The LSG (VT/SHGC) ratio of the windows	(A number)	If equal to or more than 1.1: 3 If lesser: 0				Min LSG(VT/SHGC): 1.1 for all types	
	Are other buildings atleast 25 feet away	1)Yes 2)No	1)3 2)0					

Artificial lighting

	Basic							
12	How many total fixtures are there in the apartment?	(A number)						
13	Out of those fixtures, how many are LED? 1)led 2)CFL 3)incandescent	1)(A number) 2)(A number) 3)(A number)	1)3 2)0 3)0				LED fixtures are very efficient and save energy	
17	What is the wattage of the different type of fixtures ?	1)Type 1 : 2)Type 2 : 3)Type 3 : 4)Type 4 :	If the LPD is less than or equal to 0.46: 3 Else: 0					
	Advanced							
14	Can the fixtures in the major living s	1)Yes 2)No	1)3 2)0				Lighting power density is the maximum allowable lighting density whicha space requires. The formula is as follow : LPD = Wattage *quantity /area 0.46 W/sq.ft	IECC 21
15	What is the quantities of the different type of fixtures ?	1)Type 1 : 2)Type 2 : 3)Type 3 : 4)Type 4 :						
16	What is the color temperature of the light fixtures in the major living spaces?	1)Upto 3000k - Warm 2)3000 - 5000k - Bright 3)5000k above - Cool w	1)1 2)0 3)-1				To maintain circadian rhythm, 3000k in the evening and 3000k -5000k is important during the day "1)Upto 3000k - Warm 2)3000 - 5000k - Bright White 3)5000k above - Cool white"" 4)Some are white and some are warm "	
18	Are there dimmers in major living sp	1)Yes 2)No	1)3 2)0					
19	Is the Color rendering index of the light fixtures higher than one of the following : 1) 80 (CRI, average of R1 through R8) 2) 50 (Color Rendering Index R9)	1)Yes 2)No	1)1 2)0				To accurately portray colors in the space and enhance occupant comfort, all electric lights (except decorative fixtures, emergency lights and other special-purpose lighting) should meet the following conditions: a. Color Rendering Index Ra (CRI, average of R1 through R8) of 80 or higher. 80 b. Color Rendering Index R9 of 50 or higher	Well v1 2016

3 ENERGY

	Question	Answer options	Points	Health	Enviro	Finan	Benefit based explanation	Standards
Energy Use								
	Basic							
1	Are the electric bills paid by the tenant or the owner?	1)Owner 2)Tenant						
	Are the gas bills paid by the tenant or the owner?	1)Owner 2)Tenant						
2.a)	What is the average monthly Electricity cost for the apartment or building?	(A number)						
2.b)	What is the average monthly Gas cost for the apartment or building?	(A number)						
3.a)	What is the annual Electricity Energy Use for the building*?	(A number)					In most states, electricity uses non-renewable sources, hence lesser the use the better	
3.b)	What is the annual Gas Energy Use for the building*?	(A number)					Gas uses non-renewable sources, hence lesser the use the better	
	Are the following appliances energy star certified? hvac,hot water tank, refridgerator, dryer.	1)All 2)Atleast 2 3)None	1)3 2)1.5 3)0					
	Advanced							
4.a)	Is the electricity purchased all reneweable or not?	1)Yes 2)No	1)1 2)0					Ashrae 90.1
4.b)	If there is onsite renewable energy, is it meeting more than 10% of the load?(verify 10%) ?	1)Yes 2)No	1)1 2)0				Renewable energy helps produce clean energy that doesn't pollute	
	Calculated Information for the renters							
	Basic							
6	Annual Energy Use Intensity(Site) *Energy use from electricity and gas is used to calculate the EUI	xx kBtu/sq.ft/year	If atleast one building is below 48 kBtu/sq. ft/yr: 1)3, whichever building has a lower EUI 2)1.5, building with the higher EUI but below 48 kBtu/sq.ft/yr 3)0, building with the higher EUI but above 48 kBtu/sq.ft/yr If neither are below 48 kBtu/sq.ft/yr: 1)1.5, building with the lower EUI 2)0, building with the higher EUI				EUI helps compare the energy used on site of different buildings and an apartment building should be below 48 kBtu/sq.ft/yr	IECC 2021
	Advanced							
7	Annual Energy Use Intensity(Source)	xx kBtu/sq.ft/year	1)2, whichever building has a lower source EUI 2)0, whichever building has a higher source EUI				Source EUI helps compare the energy including wastages from the source plant	
8	Annual CO2 Emissions	xx Lbs./sf/yr	1)1, whichever building has lower carbon emissions 2)0, whichever building has higher carbon emissions				Carbon emissions help compare how much each building is polluting the planet and an apartment building should be below 21Lbs./sf/yr	Ashrae 90.1

System type and efficiency

	Basic							
19	Which HVAC equipment is in use ?						Different equipments have different efficiencies and energy usage	IECC 2021
20	Which DHW equipment is in use?						Different equipments have different efficiencies and energy usage	IECC 2021
21	What is the efficiency of the HVAC equipment?	(A number)	If equal to or better than the limits: 3 If lesser than the limits: 0				The more efficient means it uses lesser energy and can have financial plus environmental benefits	IECC 2021
23	What is its efficiency of the DHW equipment?	(A number)	If equal to or better than the limits: 3 If lesser than the limits: 0				The more efficient means it uses lesser energy and can have financial plus environmental benefits	IECC 2021
	Advanced							
	What is its efficiency of the VENTILATION equipment?	(A number)	If equal to or better than the limits: 2 If lesser than the limits: 0					
24	Does the hvac have energy recovery?	1)Yes 2)No	1)2 2)0					IECC 2021
24	Does the cooling unit have an economizer?	1)Yes 2)No	1)2 2)0				An economizier increases efficiency of the cooling unit by precooling the air, hence reducing energy use.	IECC 2021

AIR

	Question	Answer options	Points	Health	Envir.	Fin.	Benefit based explanation	Standard/ certificate
	Ventilation							
	Basic							
1	Does the apartment have operable windows?	1)Yes, all rooms 2)Some rooms 3)No rooms	1)3 2)1.5 3)0				Operable windows provide control of outside air to the occupant for natural ventilation. Natural ventilation can provide fresh air and reduce energy loads.	
3	Is there a local Exhaust system in Kitchen or bathroom	1)Yes, both have it 2)Only one has it 3)Neither have one	1)3 2)1.5 3)0				It clears the room of vapor, fume and other contaminants.	
	Advanced							
4	If there is a ventilation system, which of these three ventialtion systems is installed?	1)Balanced Whole-Dwelling Unit Ventilation - ERV or DOAS or HRV 2)Supply ventilation system 3)Exhaust ventilation system 4)No ventilation system	1)1 2)0.5 3)0.5 4)0				Fresh air is provided into the building when windows are not open, to maintain air quality	
5	What is the ventilation rate?		**If above or equal to 15 cfm/person :** 1 points				Amount of fresh air being provided. It is calculated as follows: 15 cfm/person (2 persons per 1bhk+1person every additional bedroom)	IMC 2021
6	If the outdoor conditions of PM levels, temperature, and humidity is above threshold, does the management inform the occupants?	1)Yes 2)No	1)1 2)0				If the outdoor air is not clean enough to keep windows open, the management should inform its occupants. If the outdoor air measurement system indicates that outdoor air either (i) exceeds ozone levels of 51 ppb or PM	LEED_v4.1_O_M_Guide,

Air quality

	Basic							
7	Is smoking prohibited inside the apartments?	1)Yes 2)No	1)3 2)0				Smoking produces toxins in the air that are carcinogenic	LEED_v4.1_O_M_Guide
8	Is there regular maintenance for the MERV filter?	1)Yes 2)No	1)3 2)0				MERV filters filter the outdoor air of harmful pollutant particles	
	Advanced							
9	At the primary entryway from the outdoors, is there a permanent walk-off mat like a carpet or metal grating?	1)Yes 2)No	1)1 2)0				Walk-off Mats can prevent pollutants from entering that occupants bring inside. There should ideally be a permanent walk-off mat that is at least 4 feet (1.2 meters) long and allows access for cleaning (e.g., grating with catch	LEED_v4.1_O_M_Guide
10	Which MERV filter is installed within the ventilation system, if any?	1) MERV 13 or higher 2) MERV 6 or higher 3)None	1)1 2)0.5 3)0				MERV filters help filter out small contaminants from outside air. The higher the rating of the filter, the better	
12	If there are CO mointors on every floor, are the CO levels in the building below 9 ppm?	1)Yes 2)No 3)There are no	1)1 2)0				Carbon dioxide and monoxide are major air pollutants that harm human health "Carbon dioxide : <= 1,000 ppm. Carbon monoxide : 9 ppm; no more than 2 ppm	LEED_v4.1_O_M_Guide
14	Is the level of TVOC in the building below 500 µg/m3 in the past one year?	1)Yes 2)No 3)Not measured	1)1 2)0 3)0				TVOC particles are known to trigger respiratory irritation	LEED_v4.1_O_M_Guide,
16	Is the particulate(PM2.5 and PM10) level in the building below 15 µg/m3 and 50 µg/m3 respectively in the past one year?	1)Yes 2)No 3)Not measured	1)1 2)0 3)0				Fine particles can be absorbed by breathing and trigger respiratory irritation	LEED_v4.1_O_M_Guide,
18	Are the Formaldehyde levels in the building below 27 ppb in the past one year?	1)Yes 2)No 3)Not measured	1)1 2)0 3)0				Exposure causes irritation and can be carcinogenic	LEED_v4.1_O_M_Guide,
19	Are the levels of the following additional inorganic and organic contaminants within the mentioned limit? **Inorganic Contaminants:** 1. Ozone (O3) (0.075 ppm) **Volatile Organic Compounds:** 1.Acetaldehyde (75-07-0) (140 µg/m3) 2.Benzene (71-43-2) (3 µg/m) 3.Styrene (100-42-5) (900 µg/m3) 4.Toluene (108-88-3) (40 µg/m3) 5.Naphthalene (91-20-3) (9 µg/m3) 6.Dichlorobenzene (1,4-) (106-46-7) (800µg/m3) 7.Xylenes-total (108-38-3, 95-47-6, and 106-42-3) (700 µg/m3)	1)Yes, all are within limit 2)Some are within limit 3)No, none are within limit 4)Not measured	1)1 2)0.5 3)0 4)0				Contaminants are known to trigger variety of health issues	LEED_v4.1_O_M_Guide,/Ashrae62.2
20	Are Space- and water-heating equipment that involves combustion outdside the building or are their supply air and exhaust ducts sealed?	1)Yes 2)No	1)1 2)0				Combustion by-products prevent oxygen from reaching cells in the body	LEED_v4.1_O_M_Guide
21	Is the building construction Radon-Resistant?	1)Yes 2)No	1)1 2)0				Prolonged exposure can harm the DNA and lead to cancer	IECC 2021

HUMIDITY CONTROL

	Advanced							
23	Are there water vapour barriers as part of the building envelope?	1)Yes 2)No	1)3 2)0				It restrict moisture from entering the facade and prevent growth of bacteria	
25	If there is a humidity monitor or on site measurement, is the relative humidity in the building between 30% to 50% ?	1)Yes 2)No	1)1 2)0				Low levels can cause irritation in the body and if higher, it promotes bacterial growth	Well v2 2022
26	Is there an moisture inspection plan to check for leaks, water damage or mold growth ?	1)Yes 2)No	13 2)0				Periodic inspections should be carried out to check for any signs of moisture damage which could harm the health of the occupants with mold growth and the building	Well v2 2022 LEED_v4.1_BD

WATER

Question	Answer option	Points	Health	Enviro	Financ	Benefit based explanation	Standards
Water usage							
Basic							
If paid by owner:							
What is the average monthly water cost for the building?	(A number)						
What is the measured water use of the building?	(A number)					A sustainable building should be within 42 gallons/sq. ft/yr.	EPA Energy Star Data trends
If paid by tenant:							
What is the average monthly water cost for the apartment ?	(A number)						
What is the measured water use of the apartment?	(A number)					A sustainable apartment should be within 2900 galons	https://www.epcor.com/learn/efficiency-conservation/Pages/water-calculator-multiresidential.aspx
Are there low flow fixtures in the kitchen/bathrooms ?	1)Yes 2)No	1)3 2)0				Low flow fixtures help save water	EPA Watersense AIA COTE-version_1.5.3 LEED_v4.1_BD_C
Are there any Water sense certified appliances (Ex: dishwasher, clothes washer) ?	1)Yes 2)No	1)3 2)0				Certified appliances use way lesser water than others	EPA Watersense AIA COTE-version_1.5.3
Advanced							
What is the fixture flow rate in the bathroom and kitchen? Toilet -1.1 Sink-1 Shower - 2 Kitchen sink - 1.8	Toilet -xx Sink-xx Shower - xx Kitchen sink - xx	If equal or below the mentioned rates: 1)2 if all have it 2)1.5 if 3 fixtures have it				Fixtures with a Water Sense Certificate use low flow rates, saving water	EPA Watersense AIA COTE-version_1.5.3 LEED_v4.1_BD_C
If the building has a cooling tower, does the cooling tower use any of the following water conservation strategies? 1) Using alternative sources of water 2) Optimizing the cycles of concentration 3) Minimizing bleed volume 4) Minimizing drift 5) Preventing overflows and leaks.	1)Yes 2)No 3)Doesn't have a cooling tower	1)2 2)0 3)2				Cooling towers use 7 gallons more (per sf/year).Water conservation strategies can help the cooling tower save water	AIA COTE-version_1.5.3
"Does the building measure and record its water use monthly and annually for the following? 1) Indoor plumbing fixtures and fittings. 2) Irrigation 3) Domestic hot water. 4) Reclaimed water. 5) Cooling tower	1)Yes 2)No	1)1 2)0				Record water use can help identify if excess water is being used and action can be taken accordingly.	AIA COTE-version_1.5.3

Question	Answer option	Points	Health	Enviro	Financ	Benefit based explanation	Standards
Water quality							
Basic							
Does the water look clear?	1)Yes 2)No	1)3 2)0				If unclear, it can be indicative of contamination	
Is the water quality tested on site or is there a municipal report ?	1)Yes 2)No	1)3 2)0				Water should be tested for various germs, pathogens, including bacteria, viruses and protozoa	Well v2 2022
Advanced							
Is the level of turbidity less than or equal to 1.0 NTU, FTU or FNU?	1)Yes 2)No	1)1 2)0				High turbidity levels can be indicative that germs are present adn the filteration system fo the building is not working well.	Well v2 2022
Is a 100 ml sample of water free of coliforms?	1)Yes 2)No	1)1 2)0				Presence of coliforms can be indicative of more dangerous pathogens, including bacteria, viruses and protozoa.	Well v2 2022
Are the levels of the following pesticides detected within the following range? Aldrin and Dieldrin (combined): 0.00003 mg/L or less. Atrazine: 0.1 mg/L or less. Carbofuran: 0.007 mg/L or less. Chlordane: 0.0002 mg/L or less. 2,4-Dichlorophenoxyacetic acid (2,4-D): 0.03 mg/L or less. Dichlorodiphenyltrichloroethane (DDT) and metabolites: 0.001 mg/L or less. Lindane: 0.002 mg/L or less. Pentachlorophenol (PCP): 0.009 mg/L or less.	1)All are within limits 2)Some or none are within limits	1)1 2)0				Pesticides can enter the water stream though agricultural practices and cause harm to the kidney, thyroid, gastrointestinal and reproductive systems.	Well v2 2022
Are the levels of the following organic contamiants detected within the following range? Benzene: 0.01 mg/L. Benzo[a]pyrene: 0.0007 mg/L. Carbon tetrachloride: 0.004 mg/L. 1,2-Dichloroethane: 0.03 mg/L. Tetrachloroethene (Tetrachloroethylene): 0.04 mg/L. Toluene: 0.7 mg/L. Trichloroethene: 0.02 mg/L. 2,4,6-Trichlorophenol: 0.2 mg/L. Vinyl Chloride: 0.0003 mg/L. Xylenes (o-, m- and p-): 0.5 mg/L"	1)All are within limits 2)Some or none are within limits	1)1 2)0				Organic contaminants pose a serious threat to human health that can enter the water through industrial activities. Hence, water should be cheked for these contaminants	Well v2 2022

Rainwater management/Potable water use

	Advanced							
	Is rainfall run-off retained on site for usage?	1)Yes 2)No	1)2 2)0				Amount of water being collected on site for usage	AIA COTE-version_1.5.3 LEED_v4.1_BD_C
	Is there a green roof?	1)Yes 2)No	1)2 2)0				Green roof can help reduce pollutants, cool the roof , promote biodiversity	AIA COTE-version_1.5.3
	Does the building use grey water for irrigation ?	1)Yes 2)No	1)2 2)0				Used water from the apartments is being recycled to used for other purposes on site	AIA COTE-version_1.5.3
	Are there any infiltration or collection feature in the landscape (e.g., vegetated swale, rain garden, rainwater cistern)?	(Name of feature)	1)2, if the building has any 2)0				These strategies reduce runoff from rainfall and help collect water or recharge groundwater	AIA COTE-version_1.5.3

THERMAL COMFORT

	Question	Answer opt	Points	Health	Environ	Financi	Benefit based explanatio	Standards
	Temperature control & survey							
	Basic							
	If there is a thermostat in the apartment:						Occupants should be able to adjust temperature for their comfort	
1.a)	Is it a smart thermostat?	1)Yes 2)No	1)3 2)0				Smart thermostats help customize to occupant schedules, saving energy and money	
	If there is no thermostat in the apartment:							
1.b)	What is the operative temperature maintanied by the building facility over the seasons?	Heating : xx Cooling : xx	If 72°F for heating (+-3): 3, else 0 If 75°F for cooling (+-3): 3, else 0				Comfort temperatures as specified by the codes is 72°F for heating and 75°F for cooling	IECC 2021
2	Is there a fan in your apartment?	1)Yes 2)No	1)3 2)0				Fans are lesser energy intensive way of cooling and can help increase HVAC temperatures, saving energy.	
	Advanced							
1	Is the orientation of the major rooms in the apartment facing south or east? 1)Living room 2)Master bedroom 3)Second bedroom, if any 4)Dining area 5)Kitchen 6)Additional rooms, if any	1) 3 or more 2) 2 or more 3)1 or more 4)None	1)3 2)2 3)1 4)0					
3	Has occupant survey been conducted to evaluate thermal comfort in the past year?	1)Yes 2)No	1)1 2)0				Occupant surveys can help improve the thermal comfort	ASHRAE Standard 55
4	Has building measurement been conducted to evaluate thermal comfort in existing building in the past year? The following should be measured in the survey: 1)Air temperature 2)Air speed 3)Humidity 4)Radiant temp	1)Yes 2)No	1)1 2)0				Building measurement can help identify the issues with less thermal comfort. The results should be within the following range : Radiant temp: Air speed : less than 0.25 m/second during the cooling mode and less than 0.15 m/second (30 fpm) during the heating mode.	ASHRAE Standard 55

Envelope								
	Basic							
5	Does the apartment feel airtight?	1)Feels airtight 2)Feels somewhat airtight 3)Feels drafty	1)3 2)1.5 3)0				If the apartment is more airtight and allows less exchange of air with the outside, it will stay warm or cool with lesser use of energy, providing more comfort	
6	Do the windows have a single, double or triple glass?	1)Triple 2)Double 3)Single	1)3 2)1.5 3)0				More panes means lesser heat transfer. Double or triple panes are preffered	

	Advanced							
7	Is the measured infilteration rate less than 0.4 cfm/sq.ft (@75 pascals)?	1)Yes 2)No	1)3 2)0					
22	Are there air barriers installed continuously across all surfaces of the building envelope?	1)Yes 2)No	1)3 2)0				Air barrier restricts air entering/leaving the building, thus saving energy. The barrier should be made of materials with an air permeability not greater than 0.0040 cfm/ft²	Ashrae 90.1
8	What is the R value of the walls?	(A number)	If equal to or better than the limits: 3 If lesser than the limits: 0				The more the R value means the wall helps the apartment to remain cool or warm easily without any transfer of heat. Mass : R-15.2 (continuous) Metal building - R-0 + R-19(c.i.) Steel framed - R13 +R12.5(c.i.) Wood framed and other - R19 +R-5(c.i.) or R-13+R 7.5(c.i.)	
9	What is the R value of the roof?	(A number)	If equal to or better than the limits: 3 If lesser than the limits: 0				The more the R value means the roof helps the apartment to remain cool or warm easily without any transfer of heat. Metal buildingR-30 +R-11 Ls Attic and other - R49 Insulation above deck R-30 c.i.	
10	What is the R value of the grade slab?	(A number)	If equal to or better than the limits: 3 If lesser than the limits: 0				The more the R value means the slab helps the apartment to remain cool or warm easily without any transfer of heat. Heated : R-25 for 48inch Unheated : R-20 for 48 inch	
11	What is the areas of the windows (sq.ft)	(A number)						
12	What is the assembly U value of the windows?	(A number)	If equal to or better than the limits: 3 If lesser than the limits: 0				U Value means how much heat is allowed to leave/gain from the window, the lesser the better. Maximum U value : Fixed : 0.34 Operable : 0.42 Entrance door : 0.63 Skylight : 0.5	
13	What is the SHGC value of the windows?	(A number)	If equal to or better than the limits: 3 If lesser than the limits: 0				Solar heat gain coefficient means how much solar heat is being allowed through the window Maximum SHGC value : Fixed : 0.38 Operable : 0.34 Entrance door : 0.34 Skylight : 0.4 In cold climates, west should be low SHGC but east and south can be higher and high VT In hot climates, SHGC should be very low but high VT	
14	Do the windows have a low-E coating?	1)Yes 2)No	1)3 2)0				Low emmissivity coating allows natural light to enter while preventing heat loss/gain	
15	Do the windows have an argon gas fill in the cavity?	1)Yes 2)No	1)3 2)0				Argon gas improves thermal insulaiton in windows	IECC 2021, PNNL Home energy scoring tool
16	Are there any solar screens	1)Yes 2)No	1)3 2)0				Solar screens reduce the solar radiation entering the apartment	
17	Is there a Window overhang/shade on the East/South /West	1)Yes, on all orientations that are possible 2)On half the number of possible orientations 3)On one out of three orientations 4)None	1)3 2)2 3)1 4)0				Window shades on these orientation prevent harsh sunlight from coming in.	
18	How deep is the overhang?	1)East : 2)West: 3)South :					Depending on the location and window orientation, different overhang depths are need to block harsh sunlight.	PNNL Home energy scoring tool

MATERIALS

	Question	Answer o	Points	Health	Environm	Financi	Benefit based explanation	Standards
Toxic materials								
	Basic							
1	Have the flooring, ceiling, wall, insultaion, interior adhesives and sealants, furniture and furnishings, paint finshes been tested for the following? 1)VOC emissions 2)Formaldehyde Emissions Evaluation 3)VOC content evaluation	1)Yes 2)No	1)3 2)0				VOCs, formaldehyde promote sick buildings and reduces air quality. Long term exposures have proven to lead to serious health issues.	LEED BD+C
3	Is the apartment free of all the listed materials in the construction and furniture?	1)Yes 2)No	1)3 2)0				Long term exposure to the following is known cause various health issues : Antimicrobials (marketed with a health claim) • Alkylphenols and related compounds	Living building challenge 4.0
	Advanced							
2	Is the furniture BIFMA Compliant?	1)Yes 2)No	1)2 2)0				BIFMA ensures the comfort, safety, and durability of furniture. They also verify if any harmful materials have been used.	https://www.bifma.org/page/standardsoverview
4	Is the floor and ceiling tiles, plasters, insulations, adhesives, wallboard, roofing materials, fireproofing materials, and cement products free of asbestos?	1)Yes 2)No	1)2 2)0				Asbestos is a known carcinogen, and inhalation of asbestos fibers is known to cause respiratory problems and lung diseases such as Asbestosis, Mesothelioma, or lung cancer. All three of these diseases experience delayed	National centre for healthy housing
5	Is the wood used in the building free of any CCA treatment?	1)Yes 2)No	1)2 2)0				Chromated Copper Arsenic (CCA)-treated wood can be hazardous to human health because arsenic is a known carcinogen.	National centre for healthy housing
6	Are the wood products free of any adhesives that contain urea-formaldehyde (UF) resins?	1)Yes 2)No	1)2 2)0				Formaldehyde, a colorless, pungent-smelling gas, is a known respiratory irritant and carcinogen	National centre for healthy housing
7	Is the carpet, furniture free of Perfluorinated Compounds?	1)Yes 2)No	1)2 2)0				PFOA is a likely human carcinogen; it causes liver, pancreatic, testicular, and mammary gland tumors in laboratory animals.	National centre for healthy housing
8	Is the carpet backing, resilient flooring, wall coverings, acoustical ceiling surfaces, upholstery textiles, roof membranes, waterproofing membranes, and electrical cord insulationfree of PVC?	1)Yes 2)No	1)2 2)0				Certain phthalates are known or suspected endocrine disruptors, meaning they impact and alter the human hormone system. Phthalates are also suspected to be potent reproductive toxins, especially in boys.	National centre for healthy housing
9	Are any palastic product, insulation , cushions used in the building free of Polybrominated Diphenyl Ethers ?	1)Yes 2)No	1)2 2)0				PBDEs have been associated in animal studies with liver toxicity, thyroid toxicity, developmental and reproductive toxicity, and developmental neurotoxicity.	National centre for healthy housing
Life cycle assessment								
	Advanced							
10	Are there any materials with an EPD	1)Yes 2)No	1)2 2)0				"An Environmental Product Declaration (EPD) is a document that communicates verified, transparent and comparable information about the life-cycle environmental impact of products." - International EPD System	AIA
11	Were any of the materials used to make the building recycled or reused?	1)Yes 2)No	1)2 2)0				Generally, the more resused, recycled, and/or local materials, the better.	AIA
12	Were any of the materials used to make the building sourced locally?	1)Yes 2)No	1)2 2)0				Generally, the more resused, recycled, and/or local materials, the better.	AIA

ECOLOGY

	Question	Answer options	Points	Health	Environmental	Financial	Benefit based explanation	Standards
Site Area	What is the total site area?	(A number)						AIA COTE-version_1.5.3
Vegeted Area	Area of the total site that is green / vegetated	(A number)	The building with more than 50% green area: 3 The building with more green area: 1.5 The building with lesser green area: 0				Green / Vegetated Area is good for human wellbeing and for the environment	AIA COTE-version_1.5.3
Turfs	Area of the total site covered by turf grass	(A number)	The building with no turf: 3 The building with turf: 0				Turfs can require a lot of water and maintenance which can be resource intensive as compared to native plants	AIA COTE-version_1.5.3
	Advanced							
Native Plants	Area of the total site covered by native plants	(A number)	The building with native plants more than 50% of site: 2 The building with more native plants: 1 The building with more native plants: 0.5 The building with no native plants: 0				Native plants use less water and promote biodiversity. . A greater percentage of native plants and a smaller percentage of turf grass is usually preferable.	AIA COTE-version_1.5.3
	What is the percentage of impervious materials out of total site(like concrete, asphalt, pavers)	(A number)	1)1, whichever building has more than 50% 2)0.5, whichever building has lesser 2)0, for the building which has more				These materials help recharge ground water	AIA COTE-version_1.5.3

ACCESS TO NATURE

	Question	Answer options		Points			Benefit based explanation	Standards
				Health	Environmental	Financial		
Outdoor Biophilia	Are landscaped grounds or rooftop gardens accessible to building occupants?	1)Yes 2)No	1)3 2)0				Green areas are import for wellbeing an connection with nature	Well
Plantation	How much percent of the lanscape are have plantation including trees?	(A number)	The building with more plantation: 3 The building with lesser plantation: 0				Which one is better? 75%	Well
	Advanced							
Indoor Biophilia	Are there potted plants or plant beds inside the building - lobby, corridor?	1)Yes 2)No	1)1 2)0				cover at least 1% of floor area per floor	Well
Quality VIews								
	Basic							
10	Do you see greenery or an active community when you look out of the window?	1)Yes 2)No	1)3 2)0				For mental wellbeing, at least 50% of the regularly occupied spaces in each residential unit, should have one window that has a view of one of the following: (1) flora, fauna, or sky	Well v2 2022 IECC
11	Are windows with a clear view and free from any patterns on the glass or permanent shading devices?	1)Yes 2)No	1)3 2)0				Qualifying windows must provide a clear image of the exterior, not obstructed by frits, fibers, patterned glazing, or added tints that distort color balance.	Well v2 2022 IECC

	HYGIENE							
	Question	Answer options		Points			Benefit based explanation	Standards
				Health	Environmental	Financial		
Green cleaning policy	Is there a cleaning policy for the green cleaning procedures, materials, and services in the building?	1)Yes 2)No	1)3 2)0				Policy is important to regularise green cleaning that can reduce levels of contaminants and maintain hygiene	LEED O+M
Pest management	Is there an integrated pest management (IPM) plan for the building and grounds within the project boundary.	1)Yes 2)No	1)3 2)0				Pest control is necessary to maintain hygiene levels	LEED O+M
	Advanced							
Green cleaning equipments	Are all cleaning products and materials of any of the specified standard - Green Seal, UL EcoLogo, EPA Safer Choice Standard, California Code of Regulations?	1)Yes 2)No	1)1 2)0				To reduce levels of chemical, biological, and particulate contaminants, which can compromise human health, building finishes and systems, and the environment, by implementing effective cleaning procedures	LEED O+M

4.6.2 Testing and prototype

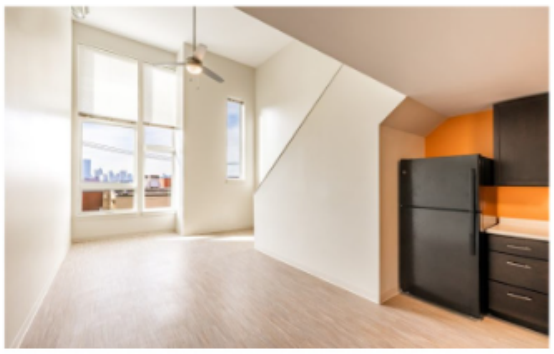
The second phase of the methodology includes testing the hypothesis via the renter-based surveys and developing a prototype. The surveys serve as a means to understand if the hypothesis holds true. If renters choose an apartment after learning about the building performance of it, it will prove our hypothesis and the validity of the need for a solution that could inform the renters about it.
During visit to the apartment, for inspection and enquiry; a mobile application prototype would serve best since the renter might need to refer to the metrics to ask relevant questions. Moreover, developing a new platform is more practical since integrating the building information in the existing model of the real estate platform would require lot of investment and change in the mental models of their customers. Hence, looking into all the above factors, we decided to create a new mobile platform where renters can go and get information about the apartment buildings and their sustainability metrics.

Part 04: Surveys

Based on the data collected from a developer for two apartments in Pittsburgh, a survey was developed to be sent out to potential renters or people who have rented in the past. A score was provided to the two apartments and that, along with the performance information was presented in the survey. The survey was structured in a way that the renter first picks one of the two apartments based on the factors that are considered today in the market, i.e., rent, utilities, proximity to office, area and aesthetics. A screenshot of this can be seen from

Figure 18 below. After this the survey presented information about the performance of the apartments under all the categories. An example of the thermal comfort category is presented below in Figure 19. Based on this information, the survey presented the final scores (Figure 20) under all categories and asked the renter to pick one of the two apartments again. The aim of the survey was to get an insight into if the renter changes their decision based on the performance-based information. The responses to the survey can be found in the results section below.

Apartment 01



Apartment 02

	Apartment 01	Apartment 02
Year Built	2016	2021
Area of apartment	820 sq.ft	850 sq.ft
No. of bedrooms	2bhk	2bhk
Area of outdoor balcony, if any?	Yes, 100 sq.ft	No
Rent per month	Your budget	30% more than budget
Proximity to your office	10 minutes drive	20 minutes drive

Figure 18. Survey screenshot: Basic information about the two apartments

THERMAL COMFORT: *

After reading the information below, **select which all features are important to you**?

	Category: Thermal Comfort	Apartment 01	Apartment 02
1	Access to thermostat in the apartment Occupants should be able to adjust temperature for comfort	No	Yes
2	Smart thermostat Smart thermostats help customize to occupant schedules, saving energy	No	Yes
3	R values: It is the ability of the following to keep the apartment warm or cool. The higher the value, the better Roof Walls	 20 29	 26.1 41.3
4	U-value of the windows U value measures how quickly the apartment becomes hot or cold. The lesser the value, the better.	0.31	0.19

Figure 19. Survey screenshot: Performance information under thermal comfort

Apartment Performance Scores

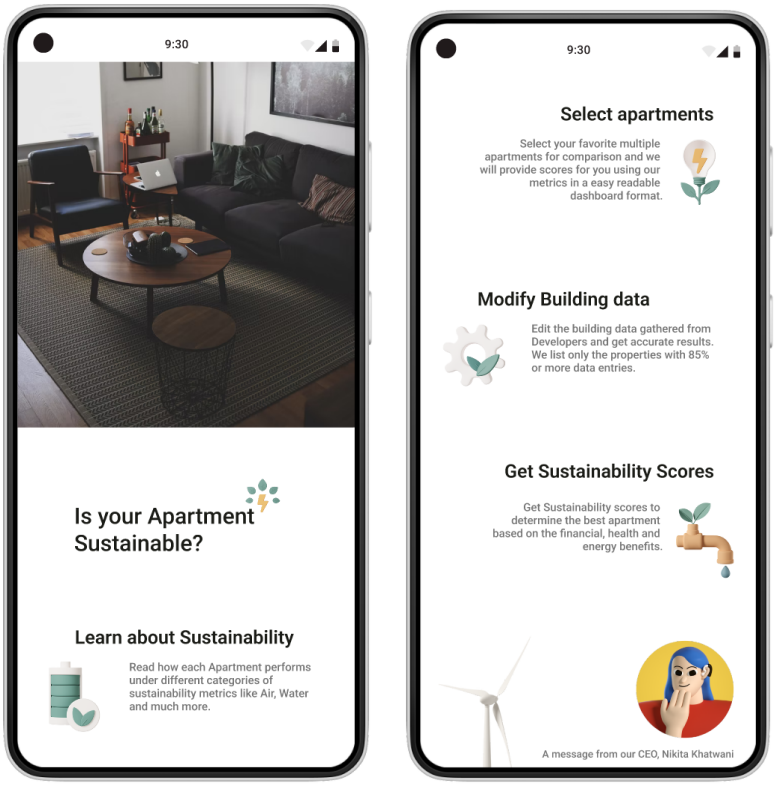
Note the performance comparison score of 2 Apartments under all categories	Apartment 01	Apartment 02
Air	60%	100%
Water	40%	80%
Light	60%	80%
Light	40%	80%
Energy	40%	95%
Thermal Comfort	40%	100%
Ecology	10%	60%
Hygiene	66%	100%
Materials	40%	80%
Noise	50%	100%
Total (Weighted Average)	**43%**	**85%**

Figure 20. Survey screenshot: Total scores under all categories

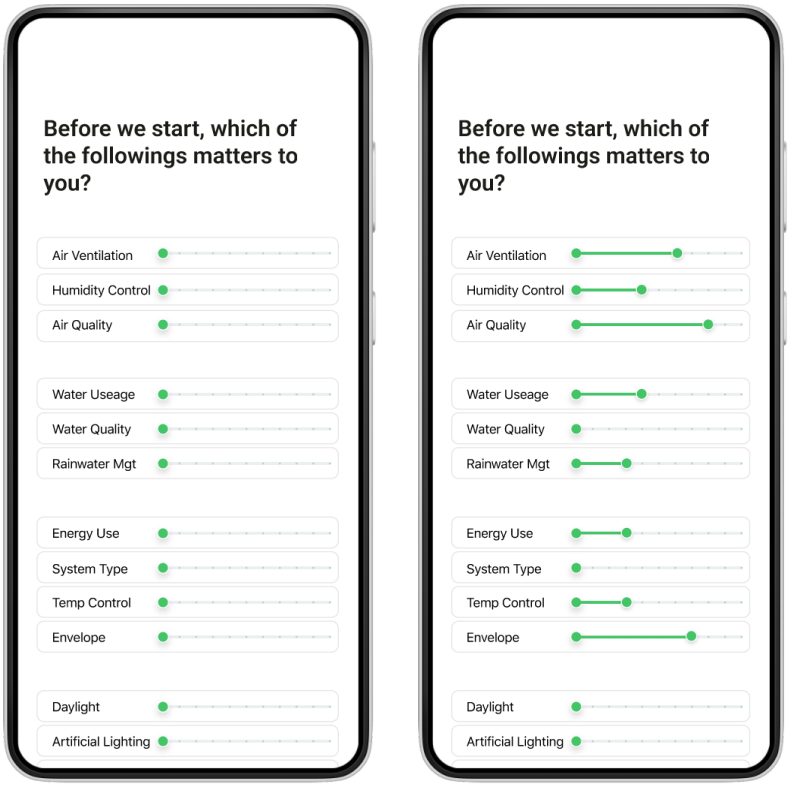
Part 05: Prototype: Software Application

The prototype for the solution is a software application (App), that would be accessible to renters at all the stages of renting an apartment, making it easy to access building metrics, resulting in being more informed and ask the right questions to the developer. The design of the prototype is divided into following:

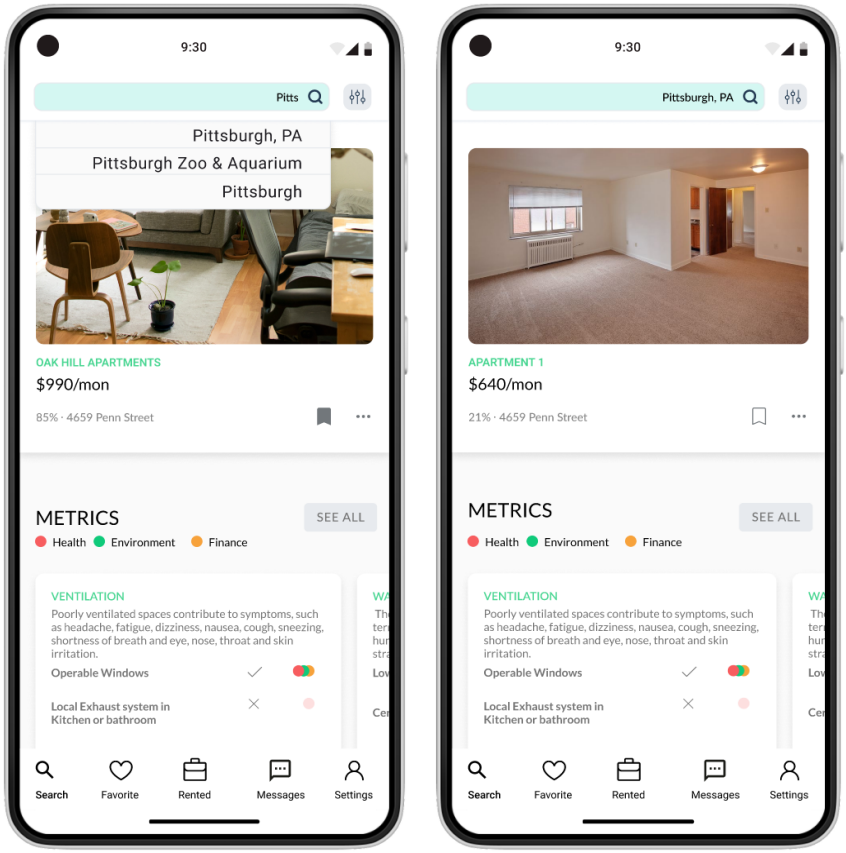
1. **Onboarding**: Once the stakeholders have downloaded the application, the app starts with an easy onboarding process to inform them about how it works -
    a. Learn about Sustainability,
    b. Select Apartments,
    c. Modify Building Data,
    d. Get Sustainability Scores.



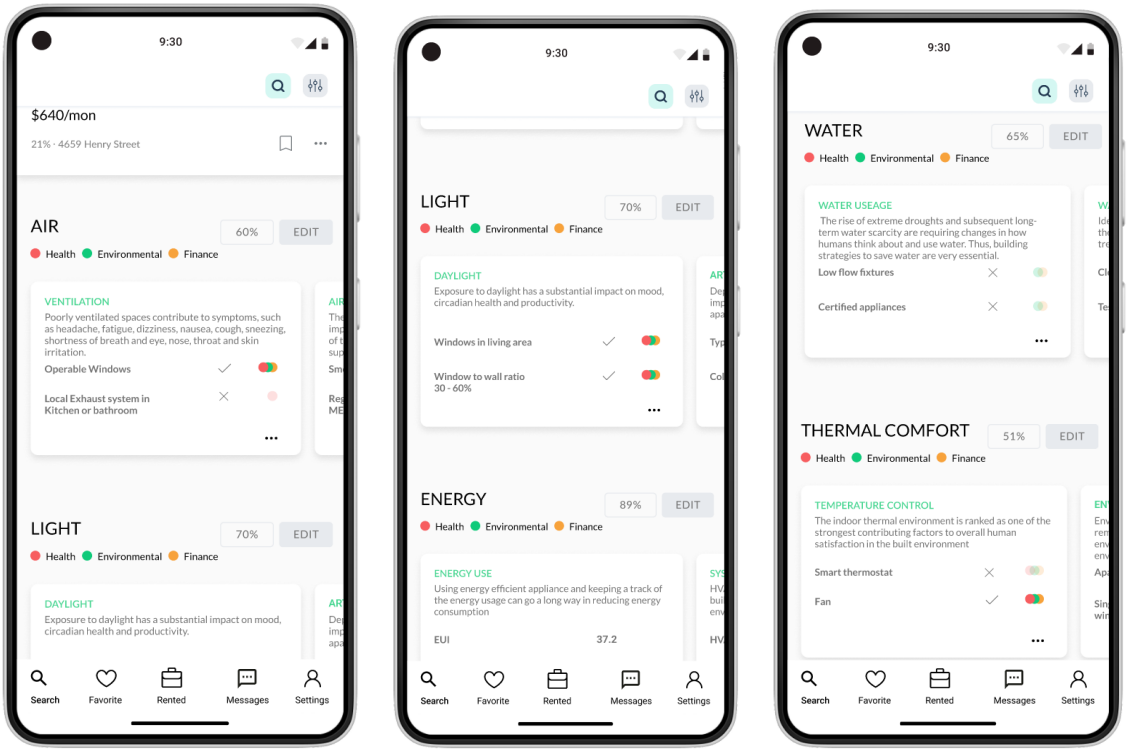
2. **Renter's Preferences**: The App asks the renters about their sustainability preferences for the Apartment, which they can relate with the building metrics as well as modify later if required. This would help them to understand which metrics are important to them.



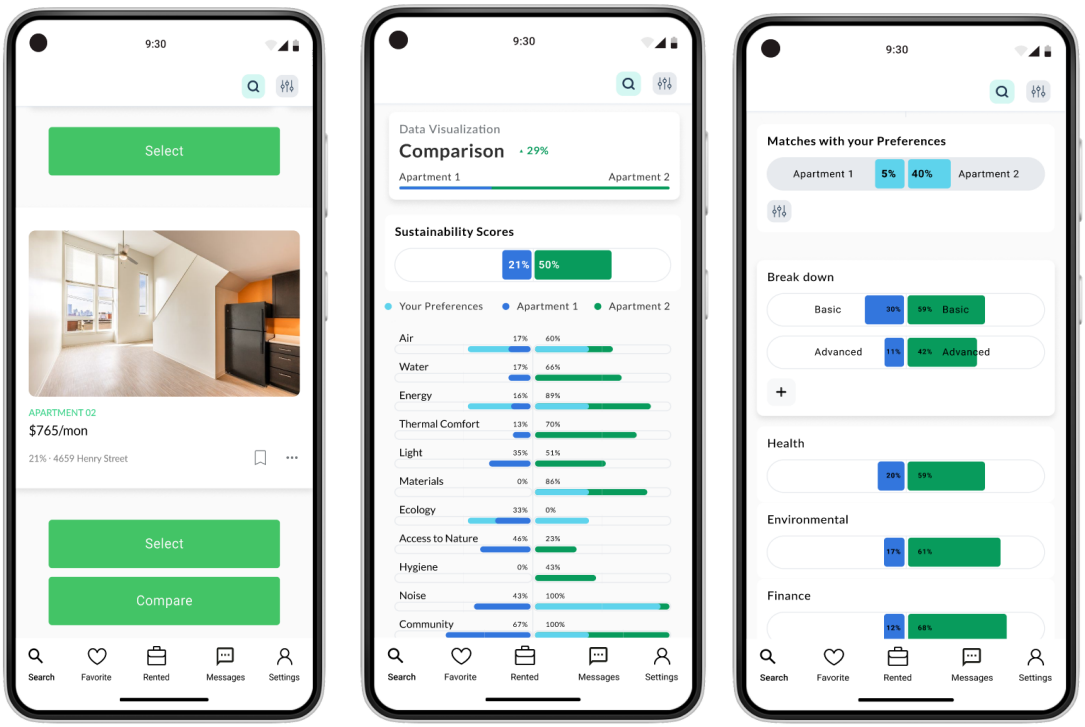
3. **Selecting Location and Time:** The Renter can put the location and time for which they are looking to rent the apartment. This would allow the app to give precise results based on the needs of the renter.



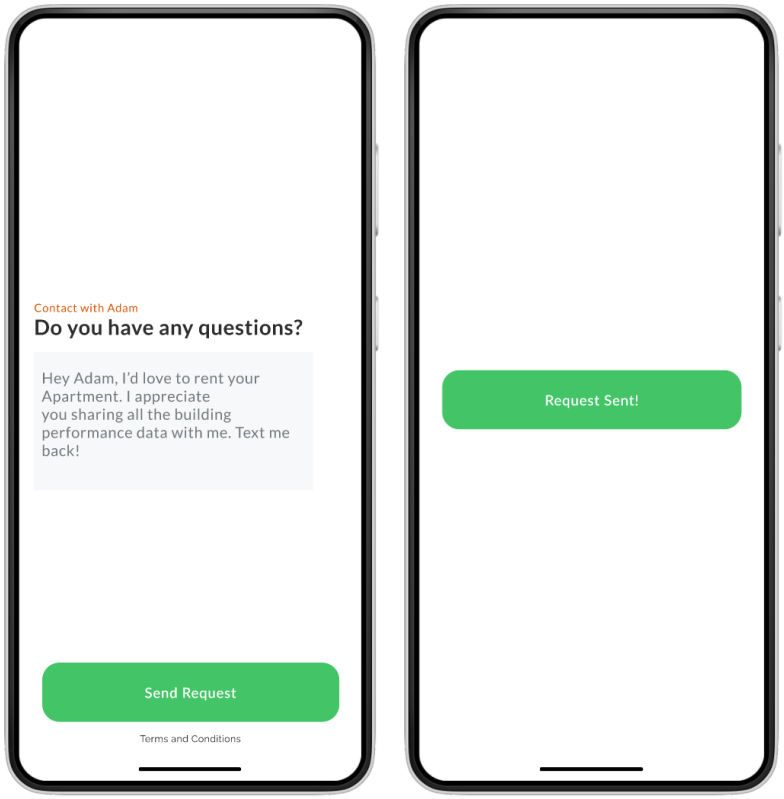
4. **Metrics**: The App prompts the user with the key metrics to overview the key categories that are important to them and learn more about the apartment. By clicking on ‘See All’, the Renter can look into all the Categories and the associated benefits.



5. **Shortlist the Apartment and Compare**: After selecting the Apartments, the renters can compare the metrics of different apartments in the dashboard. The dashboard shows the Overall sustainability scores of each apartment and maps them with Renter preferences and shows the comparative analysis. We believe this is an important step, to show the consolidated results to the renters and inform them about the benefits on health and productivity.



6. **Send information to developer**: In the last stage the renter can send this information to the Developer to request a visit or ask for more information.



7. **Document Building data**: Similarly, the app would also help the real estate developers to list the data collected from the architect, building manager, etc. By doing so, their listings can gain more popularity because of more data and list additional benefits that would give them an edge over other real estate developers, earning them more profits.

This prototype targets renters in the Pittsburgh region between the ages of 26 to 40 who are interested in renting the place and are interested in health, productivity benefits, on top of sustainability benefits. In the future, the same app can also be developed to include benefits for developers like correct listing of properties, comparison with other properties etc.

Movie: https://vimeo.com/823725005

4.7: Results
4.7.1: Case study

The application was used to compare two apartments based on the data received from the developer. Both buildings are in Pittsburgh and have similar areas and price ranges. Their basic information can be seen from Figure 21 below.

Case study

	Apartment 01	Apartment 02
		
Rent	$640	$765 (20% more)
Utilities	$90	$52 (31% less)
Walk score	92%	90%
Transit score	83%	61%

Figure 21. Survey results

Using the obtained information, the apartments were evaluated based on the aforementioned scoring system. Here are a few examples of the questions and their corresponding answers:

1) **Question:**
   Are the following appliances energy star certified?
   Refrigerator, hvac, hot water equipment and dryer.
   Answer:
   Apartment 01: None **(***0 point)*
   Apartment 02: All (*3 points)*

2) **Question:**
   Do the windows have triple, double or single glazing?
   Answer:
   Apartment 01: Single **(***0 point)*
   Apartment 02: Double *(1.5 points)*

3) **Question:**
   What is the fixture flow rate in the bathroom and kitchen?

   Answer:
   Apartment 01: None **(***0 point)*
   Apartment 02: 3 fixtures are low flow *(1.5 points)*

After answering additional questions about the apartments, the scoring system produced the following results. Figure 22 shows a breakup of the basic and advanced scores for both the buildings under all the categories. The advanced score also shows a breakup of the health

financial and environmental impact. Building 02 does well in many of the categories but loses points in ecology, access to nature and hygiene whereas building 01 is not doing so well across all the categories. Figure 23. shows a total summary score under all categories. Figure 24. shows the total score, total basic and advanced score and the percentage of impact under health, environmental and financial. Building 02 has higher benefits under all three of them as compared to building 01. The results conclude that building 02 performs better than building 01 in all categories.

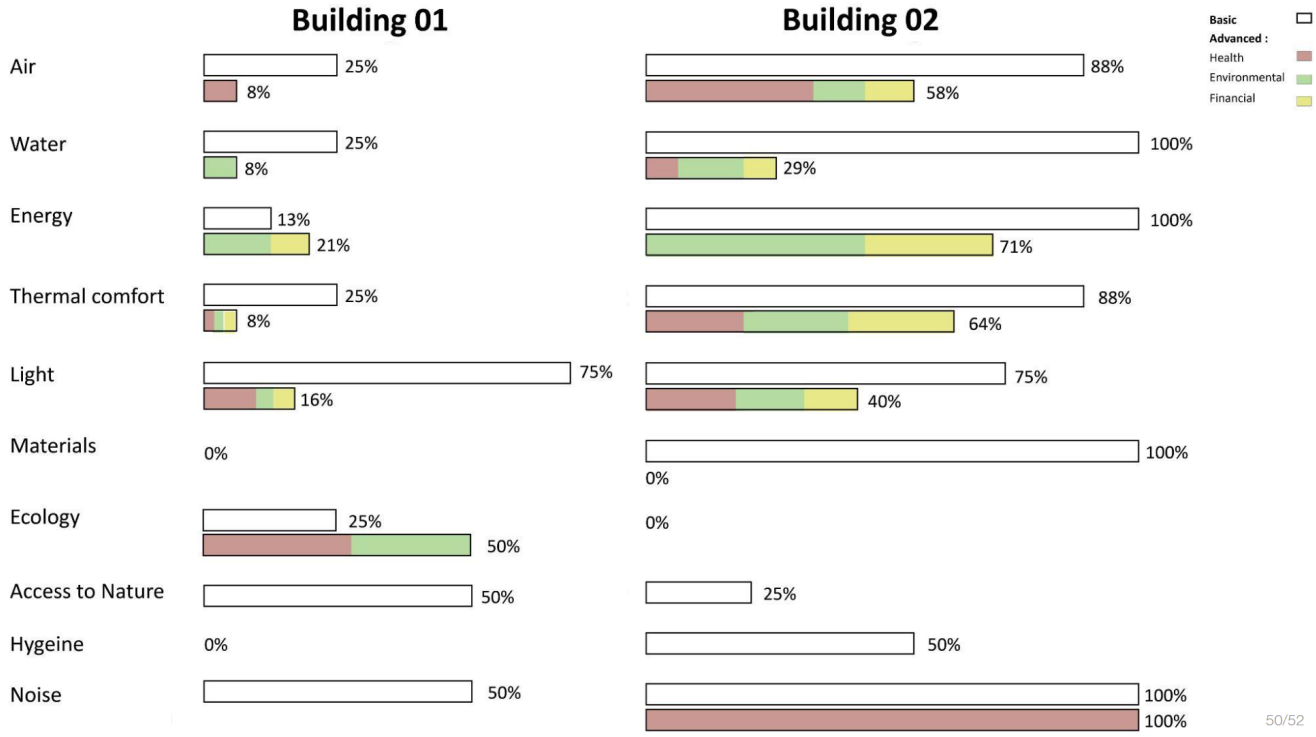


Figure 22. Comparison detailed scores under basic and advanced questions

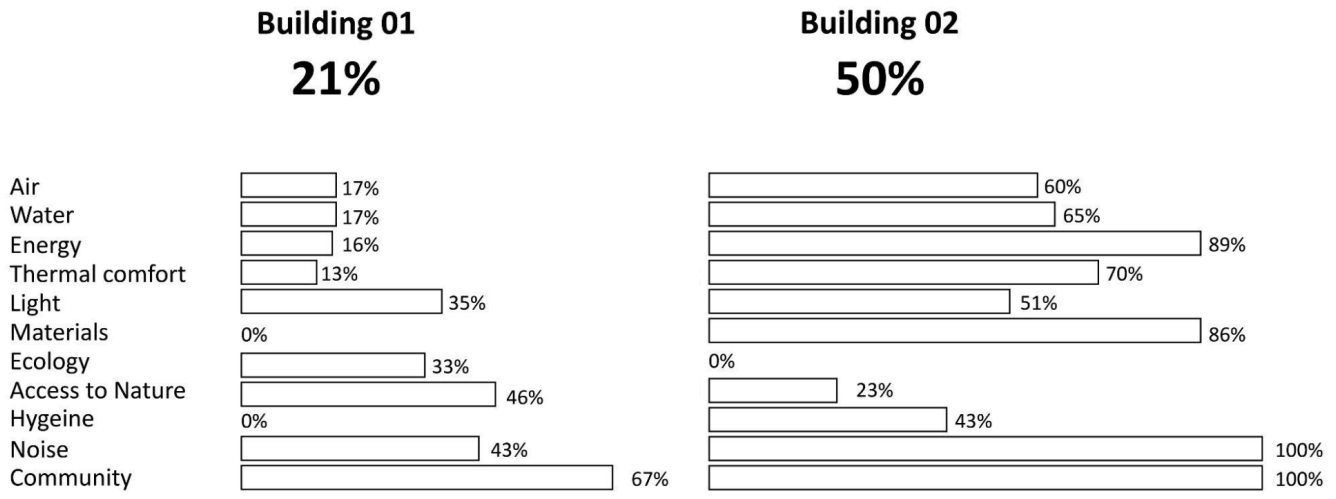


Figure 23. Summary scores under all category

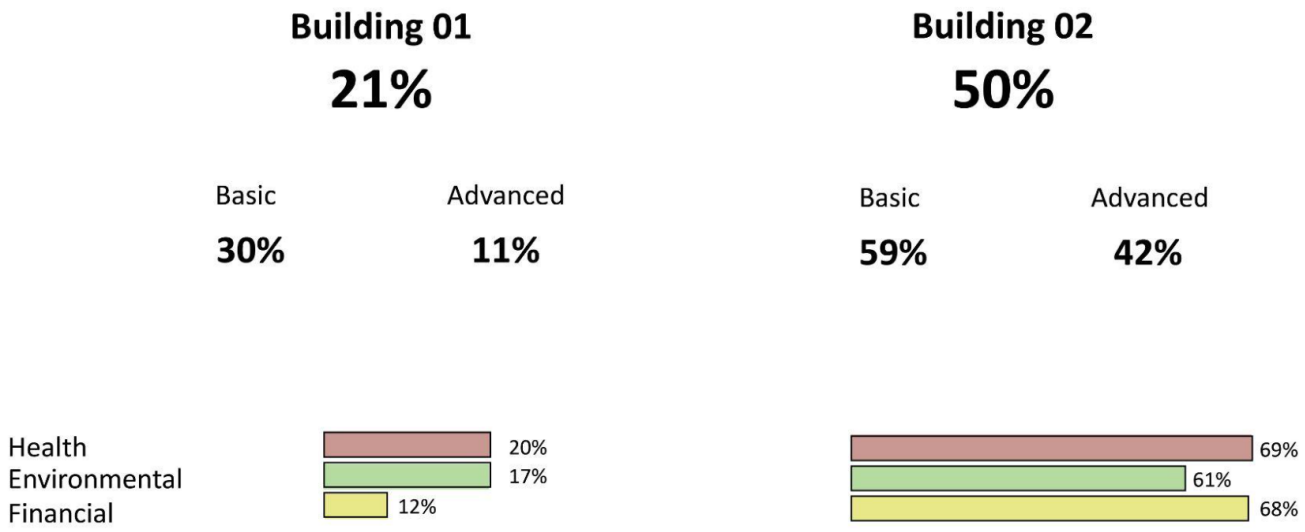


Figure 24. Total scores and impact scores

4.7.2: Survey

The survey received a total of 33 responses, which is a small sample number and can be increased in the future scope of this research. As per Figure 25, the results from the survey showed that before reading the performance-based information, only 8% of the renters picked Apartment 02 and the majority picked apartment 01 because of lesser rent and proximity to the office. However, after reading the performance-based information, 68% of the renters picked apartment 02 because of its better performance. This means 60% of the renters changed their mind and picked based on the performance, even though the rent for this apartment was higher. This is an insightful result from the survey that supports the hypothesis and provides positive feedback for the use of the application.

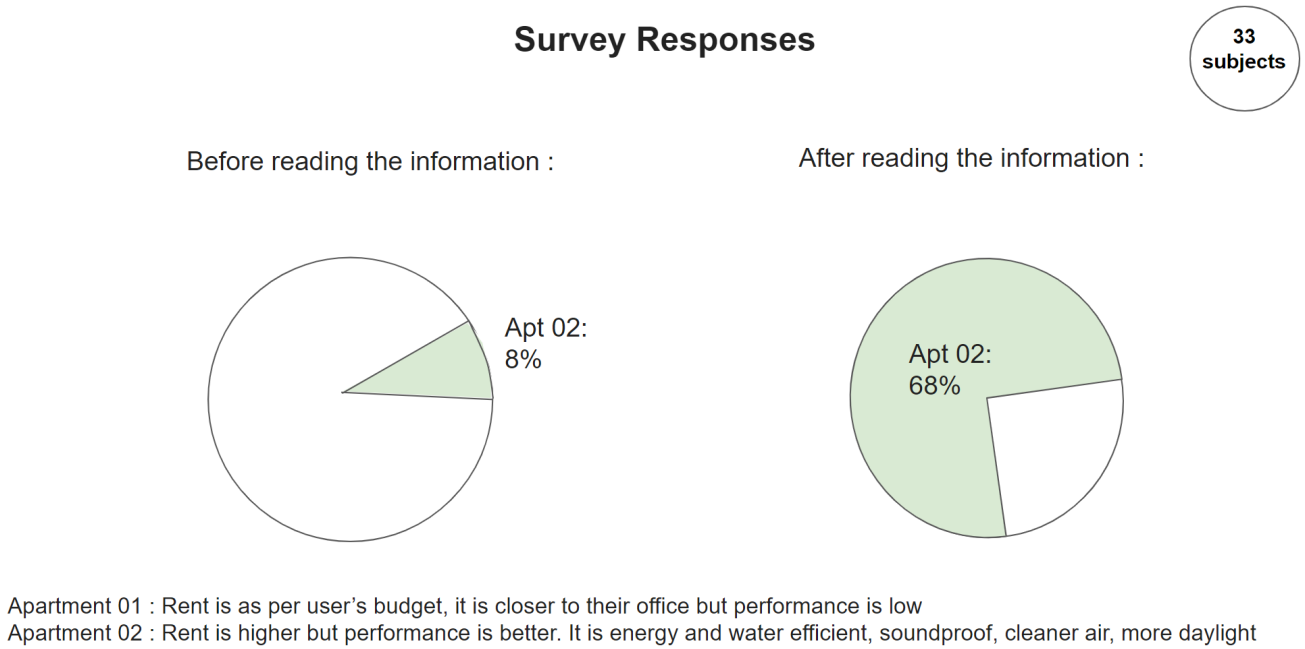


Figure 25. Survey results

The renters were also asked to rate the different categories based on their preference and perceived importance on a scale of 1 to 5, 5 being the highest. Based on their preference rating, every category received a weightage for the scoring. This changed the scoring results as seen in Figure 26. The original scores based on performance were 44% and 85%, however after applying the weightage to each category based on a single renter preference from the survey response, the scores changed to 33% and 66%. In this case as well, building 02 scored better. This method provides a customized score for every renter which is a part of the application. This allows the renter to pick which scoring method they prefer, the one that came from the application or the one based on their preferences.

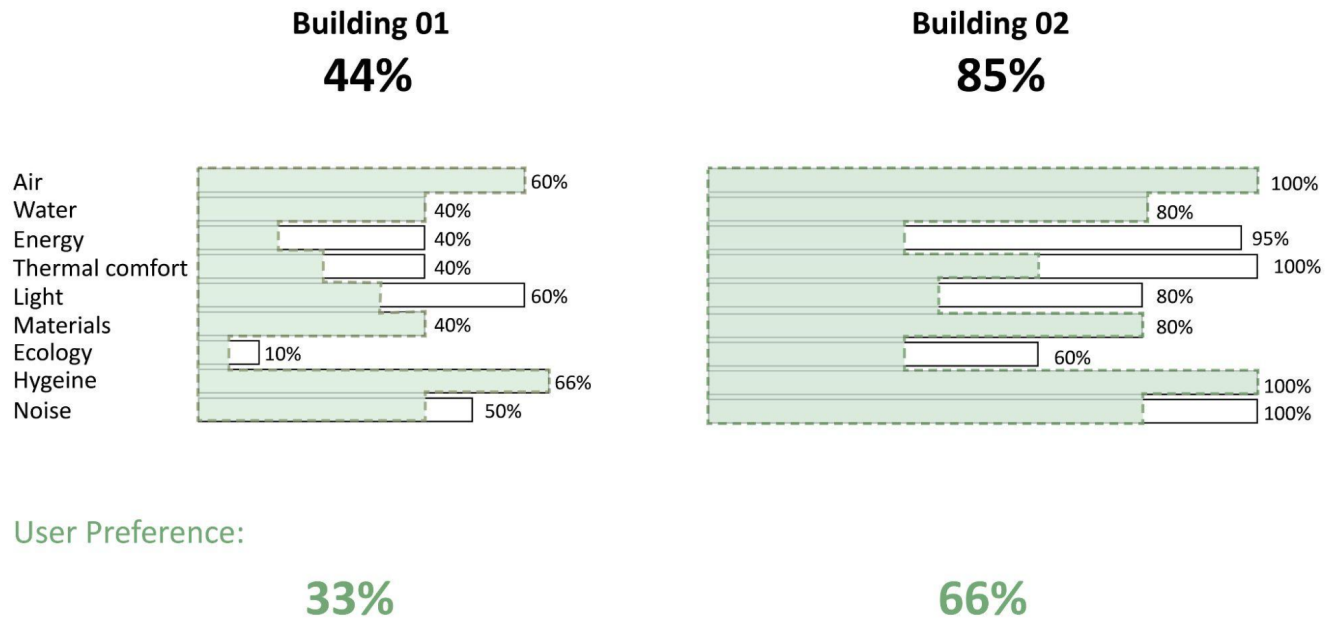


Figure 26. Survey results: Renter preference

The renters were also asked three other questions to gain an insight about the importance of sustainability for them. As seen in Figure 27 below, it can be seen that 70% of the respondents were willing to pay more for a sustainable apartment(if it cost more). 88% of them were also interested to know the performance of the apartment before they rent it. 60% of them would like to take the time to read the information while others simply wanted to see the results.

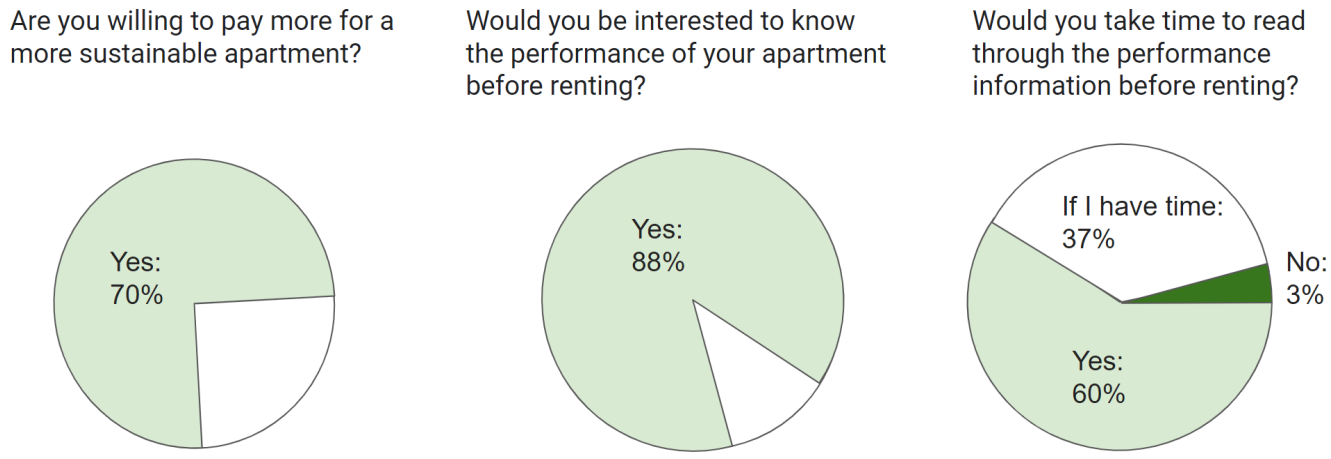


Figure 27. Survey results: Importance of sustainability for the renters

4.7: Conclusions

The proposed application's primary goal is to help a renter choose a better performing apartment amongst their other choices, by raising their awareness about building performance metrics. Survey results support this hypothesis, with 68% of renters choosing a better-performing building when provided with relevant performance information about their options. However, it is important to note that these results will need to be confirmed with a larger sample size in future iterations of this study.

This study makes notable contributions to the field of sustainability in four ways:

1. Introducing a novel prototype to guide renters in selecting sustainable choices, particularly in the rental market where such an application is not available.
2. Compiling a set of questions that enables non-experts to evaluate an apartment and ask pertinent questions to the developer
3. Creating an innovative scoring system to assess apartments based on three benefits that hold significance to renters (health, environmental, and financial)
4. Establishing a platform for raising awareness on building performance in society.

Not having the technical knowledge to make an informed decision before renting an apartment can also be due to a lack of information available to the renter. . However, providing comprehensive and understandable information to renters can be challenging. While this application does not claim to solve the problem entirely, it aims to develop a framework to start addressing it by empowering renters to understand the performance metrics of buildings and the benefits of their choices.

As per the hypothesis, the primary goal of this application is to increase the demand for better performing buildings in the real estate market, thus making it more sustainably built. In addition to assisting renters in making informed decisions, the application would also benefit developers by providing them with insights into renters' preferences for sustainable features in the market. It would also enable developers to learn from the best-performing buildings, gain knowledge about the performance of buildings in their neighborhood and offer a sustainability-specific marketing platform that is currently unavailable.

The application has the potential to create a valuable database of multi-family building performances over time, which can be utilized by various organizations to advance research in the field of sustainable built environments.

4.9: Future work

In the next phase of the study, the following three aspects will be targeted:

1. A larger sample size would have to be collected to make statistically significant statements about the results of the survey.
2. The current scoring system would need additional research into the quantitative aspects of the three impacts - health, environmental and financial. They currently have a flat one point if the impact exists, however, in reality one impact would be more than the other for a particular question and it would be important to provide the correct weightages for every question. This would require extensive research for every question which will be conducted in the next phase of the study.
3. The prototype would need multiple user testing studies to understand which parts of it work and which don't for further development. The benefit-based explanations provided against every metric would need to be tested with multiple renters to find the correct mode and method of explanation that a majority would understand.

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6: Appendix

Appendix A

	Well v1	LEED: Operations and Maintenance	LEED: BD&C	Ashrae	IECC 2021
AIR					
Ventilation	**VENTILATION EFFECTIVENESS**	Mechanical exhaust system, supply system or combination will provide the follwing V.R: Total req V.R(cfm) = 0.3 *Dwelling unit floor area(sq.ft) + 7.5 (number of bedrooms >=1 +1)	Local mechanical exhaust systems in each kitchen and bathroom (including half-baths) DC or continuous local exhaust in bathroom and kitchen	Total Ventilation Rate*	**15 cfm per person or 0.35 ACH**
	PART 1: VENTILATION DESIGN ASHRAE 62.1-2013 (Ventilation Rate			**1)Mechanical ventilation system** Shall consist of one or more supply or exhaust fans and associated ducts and control. Not only exhaust	
	INCREASED VENTILATION			**Local exhaust-kitchen ,bathroom**	
	/PART 1: INCREASED OUTDOOR AIR SUPPLY Exceed ASHRAE outdoor air supply rates met in the WELL Ventilation Effectiveness feature by 30%.				
	Demand control ventilation				
	OPERABLE WINDOWS PART 1: FULL CONTROL PART 2: OUTDOOR AIR MEASUREMENT PART 3: WINDOW OPERATION MANAGEMENT	An operable window in each bedroom with the total openable window area a **minimum of 4% of the room floor area**		All habitable space **4% ventilation opening**	
			CO levels in the building below **9 ppm**	**Particicle Filteration** Filteration factor* Merv and filteration efficiency *	
Air quality		**AIR QUALITY STANDARDS** PART 1: STANDARDS FOR VOLATILE SUBSTANCES The following conditions are met: -Formaldehyde levels less than 27 ppb. - Total volatile organic compounds less than 500 µg/m³. PART 2: STANDARDS FOR PARTICULATE MATTER AND INORGANIC GASES The following conditions are met: -Carbon monoxide less **than 9 ppm.** - $PM_{2.5}$ less than 15 µg/m³. b.2 PM_{10} less than 50 µg/m³. -Ozone less than 51 ppb. PART 3: RADON The following conditions are met in projects with regularly occupied spaces at or below grade: - Radon less than 4 pCi/L in the lowest occupied level of the project.	CO levels in the building below **9 ppm**	**Particicle Filteration** Filteration factor* Merv and filteration efficiency *	
	(Target LEED 4) Is CO2 measured? Maximum Measured CO2 levels Is VOC measured? Maximum Measured VOC levels	PART 1: INDOOR SMOKING BAN PART 2: OUTDOOR SMOKING BAN	TVOC in the building below **500 µg/m3** in the past one year		
		AIR QUALITY MONITORING AND FEEDBACK "PART 1: INDOOR AIR MONITORING PART 2: AIR DATA RECORD KEEPING AND RESPONSE PART 3: ENVIRONMENTAL MEASURES DISPLAY "	Particulate(PM2.5 and PM10) level in the building below 15 µg/m3 and 50 µg/m3 respectively in the past one year		
		ADVANCED AIR PURIFICATION	Formaldehyde levels in the building below 27 ppb in the past one year		
		AIR FILTRATION "PART 1: FILTER ACCOMMODATION PART 2: PARTICLE FILTRATION MERV 13 (or higher) media filters PART 3: AIR FILTRATION MAINTENANCE "	Levels of the following additional inorganic and organic contaminants within the mentioned limit **Inorganic Contaminants:** 1. Ozone (O3) (0.075 ppm) **Volatile Organic Compounds:** 1.Acetaldehyde (75-07-0) (140 µg/m3) 2.Benzene (71-43-2) (3 µg/m) 3.Styrene (100-42-5) (900 µg/m3) 4.Toluene (108-88-3) (40 µg/m3) 5.Naphthalene (91-20-3) (9 µg/m3) 6.Dichlorobenzene (1,4-) (106-46-7) (800µg/m3) 7.Xylenes-total (108-38-3, 95-47-6, and 106-42-3) (700 µg/m3)		

Humidity control		**"1: Operational moisture management** a moisture management plan for building operations The project implements a moisture management plan for building operations that contains the following: A schedule of periodic inspections for signs and potential sources of water damage or pooling, discoloration and mold on ceilings, walls, floors and HVAC equipment.3 A system or inspection protocol to periodically assess water pipe leaks. A system for occupants and tenants to notify building management about mold or water damage.		25-60%	
		PART 1: RELATIVE HUMIDITY 30% to 50% at all times At least one of the following is required: ventilation system with the capability to maintain relative humidity between 30% to 50% at all times by adding or removing moisture from the air. a. 8 Modeled humidity levels in the space are within 30% to 50% for at least 95% of all business hours of the year. Buildings in climates with narrow humidity ranges are encouraged to pursue this option.			

WATER					
Water usage	**WATER USE**				
	Indoor Potable water use gallons/month -- **Target : 42 gallons/sq.ft/yr**	**Water Use calculator - 12 months data** Have permanently installed water meters that measure the total potable water use for the project and associated grounds.			
	Rainwater gallons/month				
	Reclaimed grey/black1 gallons/month		Landscape water reduction. Are they using any of these strategies "Install smart scheduling technology. This strategy counts for a maximum reduction of 30% provided all landscape water use is controlled by a soil moisture sensor control system or a weather-based irrigation control system. ☑ Use captured rainwater. ☑ Use reclaimed water. ☑ Use water treated on site or conveyed by a public agency specifically for nonpotable uses (water from naturally occurring surface water bodies, such as streams and rivers, and groundwater, such as well water, does not count)." Landscape with plants that are native or adapted to the region		
	Irrigation Water Use				
	Cooling tower				
	Low fixture flow rate in the bathroom and kitchen Toilet -1.1 Sink-1 Shower - 2 Kitchen sink - 1.8				
	Water sense certified plumbing appliances				

Water quality		**FUNDAMENTAL WATER QUALITY** 1.Turbidity of the water sample is less than 1.0 NTU. a. 50 2.Total coliforms (including E. coli) are not detected in the sample.			
		INORGANIC AND ORGANIC CONTAMINANTS*			
		AGRICULTURAL CONTAMINANTS*			
		PUBLIC WATER ADDITIVES*			
		PERIODIC WATER QUALITY TESTING*			

Rainwater management					
	3 - Stormwater managed on-site **(Storm event factor" x area x runoff factor)**	**Rainwater usage** Use low-impact development (LID) practices to infiltrate, evapotranspirate, collect and reuse water onsite from 25% of the impervious surfaces for the 95th percentile storm event.	installing permanent infiltration or collection features (e.g., vegetated swale, rain garden, rainwater cistern) that can retain 100% of the runoff from at minimum, the 80th percentile of regional or local rainfall events.		
	Roof				
	Impervious				
	Turf				
	Native Plantings	**Eradicate Invasive and exotic plant species**	Lists of native plants are maintained by the Lady Bird Johnson Wildflower Center, the North American Native Plant Society, state agencies, and local cooperative extension service offices and local native plant conservation organizations.		
	Semi-Pervious				
	Sub Total				
	After Storage				
	Total Percent Managed Onsite				

ENERGY

Energy use	AIA Benchmarks are from CBECS		**Permanently installed energy meters**		Site EUI(Target - 47 kBtu/sf/yr)
	Site EUI (Target - 79 kBtu/sf/yr)		**GHG emissions score**	**Percentage improvement in energy performance**	
	Carbon Emissions (Target -21 lbs/sf/yr)		**Source Energy Score**		
	Source EUI				
	Energy star certified appliances hvac,hot water tank, refridgerator, dryer.				

System type & System efficiency	**Heating**		Ashrae 90.1 efficiency targets		IECC 2021 SECTION C403
	^Type of Heating 1 System: None / Central gas furnace / Room (through-the-wall) gas furnace / Gas boiler / Propane (LPG) central furnace / Propane (LPG) wall furnace / Propane (LPG) boiler / Oil furnace / Oil Boiler / Electric furnace / Electric heat pump / Electric baseboard heater / Ground coupled heat pump / Minisplit (ductless) heat pump / Electric boiler / Wood Stove / Pellet Stove			**Different equipments have different efficiencies and energy usage**	Different equipments have different efficiencies and energy usage
	^Efficiency Value (AFUE or HSPF):				
	Year Installed				
	Cooling				
	^Type of Cooling 1 System: None / Central air conditioner / Room air conditioner / Electric heat pump / Minisplit (ductless) heat pump / Ground coupled heat pump / Direct evaporative coolin				
	^Efficiency Value (SEER or EER):				
	Year Installed				
	Hot water				
	^Water Heater Type: Electric Storage / Natural Gas Storage / LPG Storage / Oil Storage / Electric Instantaneous / Gas Instantaneous / Propane Instantaneous / Electric Heat Pump				
	^Hot Water System Efficiency:				
	Energy Factor				
	Year Installed:				

Renewable energy	**^PV system**		On-Site Renewables		Onsite Renewable energy
	Year Installed:		Off-Site Renewables		Adjusted Offsite Renewable energy (Multiple options)
	Direction Panels Face: N / NE / E / SE / S / SW / W / NW		Green-e Certified: EACs & Carbon Offsets		
	# of Panels:		EACs & Carbon Offsets		
	DC Capacity:				

THERMAL COMFORT

Temperature control and survey	Accessible thermostats	**THERMAL COMFORT** PART 1: VENTILATED THERMAL ENVIRONMENT All spaces in mechanically-ventilated projects meet the design, operating and performance criteria: P P P ASHRAE Standard 55-2013 Section 5.3, Standard Comfort Zone Compliance. PART 2: NATURAL THERMAL ADAPTATION All spaces in naturally-ventilated projects meet the following criteria: P P P ASHRAE Standard 55-2013 Section 5.4, Adaptive Comfort Model.	ASHRAE Standard 55-2017	Assuming slow air movement (less than 40 feet per minute) and 50% indoor relative humidity, the operative temperatures recommended by ASHRAE range from 68.5oF to 75oF in the winter, and from 75oF to 80.5oF in the summer.	
			Option 1. Radiant Comfort **Meet all of the following for each dwelling unit:** **1) Heating and cooling controls are installed in every unit** **2) Walls, floor, and roof components meet the prescriptive insulation value requirements of 2009 IECC Commercial code, tables 502.1.2 or 502.2.** **3) Have no thermal bridges in the envelope, including at patios and concrete podiums** **a. Minimum R-3 continuous insulation installed for all non-mass walls (CZ 1-2 are exempted)** **4) Windows meet the maximum U-value and SHGC.**	Acceptable temperatures for naturally ventilated spaces * Example : 20 deg. Cel. outside = 21-27deg. C. confort range inside	
				Analytical Comfort Zone Method _Appendix B -0.5<PMV<0.5	
				Occupant Survey*	
				Building measurement* Limits below : Metabolic rate : 1.3 (assumed) Clo : 1.0 (assumed) Air speed : less than 0.25 m/second during the cooling mode and less than 0.15 m/second (30 fpm) during the heating mode. HUmidity : 25-60	

Envelope	/Air leakage rate(cfm50)		0.3 cfm / sq.ft@50 pascals	0.35 cfm / sq.ft@75 pascals	0.45 cfm / sq.ft@50 pascals
	Has the house been professionally air sealed?				
			Points for percentage area with shading or nonabsorptive material	**These are for 5A, It will be differen for other climate zones**	
	Roof Attic 1 Area (sq ft): "Roof Construction: Standard Roof / with Radiant Barrier / with Rigid Foam Sheathing" "Exterior Finish: Composition Shingles or Metal / Wood Shakes / Clay Tile / Concrete Tile / Tar & Gravel " *Rvalue (roof) Rvalue (attic floor) Attic or Ceiling Type: Unconditioned Attic / Conditioned Attic / Cathedral Ceiling	*Roof Color: White / Light / Medium / Medium Dark / Dark / Cool Color Reflectivity	Envelope as per ASHRAE 90.1–	**Roof** R-value Metal buildingR-30 +R-11 Ls Attic and other - R49 Insulation above deck R-30 c.i.	
	Orientation of façade elements		**Roof** High-Reflectance Roof Vegetated Roof		
	Walls **Wall Characteristics:** Front or All (circle one) ""**Construction:** Wood Frame / Wood Frame with rigid foam sheathing / Wood Frame with Optimum Value Engineering (OVE) / Structural Brick / Concrete Block or Stone / Straw Bale Exterior Finish: Wood Siding, Fiber Cement, Composite Shingle or Masonite Siding / Stucco / Vinyl Siding / Aluminum Siding / Brick Veneer / none " "**Wall Insulation:** R-0 / R-3 / R-6 / R-7 / R-11 / R-13 / R-15 / R-19 / R-21 / R-27 / R-33 / R-38			**Walls** R-value Mass : R-15.2 (continuous) Metal building - R-0 + R-19(c.i.) Steel framed - R13 +R12.5(c.i.) Wood framed and other - R19 +R-5(c.i.) or R-13+R 7.5(c.i.)	
	Foundation "Type: Slab-on-Grade / Unconditioned Basement / Conditioned Basement / Unvented Crawlspace / Vented Crawlspace" ""R value : Floor Insulation over Basement or Crawlspace: R-0 / R-11 / R-13 / R-15 / R-19 / R-21 / R-25 / R-30 / R-38" ""Foundation Wall Insulation: R-0 / R-5 (slab only) / R-11 (bsmt/crawl wall) / R-19 (bsmt/crawl wall) "			**Slab on grade** R-value "Heated : R-25 for 48inch Unheated : R-20 for 48 inch"	
	Windows *Front or Back or Right or Left Window area(sq.ft) Solar Screens: Yes / No Panes: Single-pane / Double-pane / Triple-pane Frame Type: Aluminum / Aluminum with Thermal Break / Wood or Viny "Glazing Type: Clear / Tinted / Solar-control low-E / Solar-control low-E, argon gas fill / Insulating low-E / Insulating low-E, argon gas fill" **Uvalue** **SHGC**			**Windows** **"Maximum U value :** Fixed : 0.34 Operable : 0.42 Entrance door : 0.63 Skylight : 0.5" **SHGC** "Maximum SHGC value : Fixed : 0.38 Operable : 0.34 Entrance door : 0.34 Skylight : 0.4 ""**Min LSG(VT/SHGC):** 1.1 for all types"	
				Air barrier Materials with an air permeability not greater than 0.0040 cfm/ft²	

LIGHT					
Daylight	WWR : 30-40% (CBECS)	a.Between 30% and 60% in living rooms. b.Between 20% and 40% in bedrooms -Source : Well Feature 63 :	all living spaces have windows	Upto 40%	Upto 30%
		75% of the area of all regularly occupied spaces is within 7.5 m [25 ft] of view windows.	**Illuminance levels** Achieve illuminance levels between 300 lux and 3,000 lux for at least 50% of the regularly occupied floor area.		
		LRV: Ceilings have an average LRV of 0.8 Walls have an average LRV of 0.7 Furniture systems have an average LRV of 0.5			
				Visible transmittance of windows Fixed window - 0.418 Operable window - 0.74	Visible transmittance of windows is atleast 1.1 times SHGC
Artificical lighting	LPD - 0.7 (Ashrae 90.1 2007)		As per ASHRAE 90.1–	LPD -0.46	LPD -0.45
		Color rendering index of the light fixtures higher than one of the following : 1) 80 (CRI, average of R1 through R8) 2) 50 (Color Rendering Index R9)			