Enhancing Tenant Well-Being: Financial Feasibility of Implementing Healthy Building Concepts in New Multi-Family Housing

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Enhancing Tenant Well-Being: Financial Feasibility of Implementing Healthy Building Concepts in New Multi-Family Housing

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Abstract

The average person spends 90% of their entire life indoors and therefore, the quality of the indoor environment in dwellings is a key contributing factor to occupants' health and well-being (MacNaughton, 2016). Strategies aimed at improving indoor environments, such as 'healthy building concepts' are of critical importance (Frey et al., 2015; Galvin, 2010; Paradis, 2016). However, it is not clear which strategies are the most effective and cost-efficient (America, 2020). A clear and reliable model is needed for applying large amounts of data on healthy building concepts to new multi-family buildings to improve the health and well-being of tenants.

The primary objective of my thesis was to investigate the financial feasibility of applying WELL building standards to new multi-family buildings to enhance indoor environmental quality. My research involved investigating the Return on Investment (ROI) of various healthy building features for a hypothetical multi-family building of 50 units, over a 10-year period (2023-2033). My approach was to 1) calculate the costs of incorporating diffuse and dynamic lighting, providing views, improving indoor air quality, and increasing thermal comfort, and 2) gauge the potential premium tenants would be willing to pay for improved well-being and comfort. I developed a cost-benefit model to measure the economic gains from these interventions at the building level. I also conducted a nationwide willingness-to-pay survey using Amazon MTurk to contribute to the overall economic assessment. The study aimed to determine if the benefits of adopting healthy building principles outweighed the implementation costs.

The research demonstrated that it makes financial sense to include health-focused features in multi-family properties, such as dynamic lighting, enhanced views, improved indoor air quality (IAQ), and increased thermal comfort. Lighting had a 412% return on investment (ROI) over a ten-year period equivalent to a 1.95-year payback period, while thermal comfort, the top preference among respondents with the highest-ranking average of 2.49, would take longer to pay back at 4.35 years. Tenants are willing to pay higher rents for apartments with health-centric amenities, averaging between $214 and $225 per month. These findings support the idea that the investment in such features is justified by the value they bring.

In conclusion, this research confirms the economic advantages of adopting healthy building standards, resulting in an overall ROI of 129% and a comprehensive payback period of 4.36 years for all features combined. These results challenge previous beliefs about the costs of such enhancements while highlighting their potential to generate higher rents and improve net operating income and indicate to residential developers that health centric building features generate a positive ROI.

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Definition of Terms

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CBA	Cost-Benefit Analysis
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
MERV	Minimum Performance Reporting Value
NPV	Net Present Value
PM	Particulate Matter
ROI	Return on Investment
SBS	Sick Building Syndrome
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
WHO	World Health Organization
YLL	Years of Life Lost due to premature mortality
YLD	Years of Healthy Life Lost due to disability

Chapter I

Introduction

The impact of the built environment on health and well-being is not a new concept, but it has emerged recently as an increasingly significant priority in the design and construction industry (Wimalasena et al., 2022). The quality of the indoor environment in dwellings is a key contributing factor to occupants' health (D’Amico et al., 2020; Engelen et al., 2022; Navaratnam et al., 2022). Several existing studies have largely focused on establishing frameworks for designing healthy offices or incorporating green features into hospital settings (Carmichael et al., 2020; D’Amico et al., 2020; Loftness et al., 2007; Ulrich, 1984). However, there is limited research concerning the development of new multi-family projects with healthy building features and the estimation of costs associated with them (Stantec, 2020; United States Environmental Protection Agency, 2014e).

By integrating healthy building features from the outset, new multifamily buildings have the potential to enhance the well-being of occupants and contribute positively to the environment, creating a win-win scenario for both people and the planet (Frey et al., 2015; Galvin, 2010; Paradis, 2016). For instance, a portfolio of green buildings using energy-efficient strategies attained $7.5 billion in reduced energy costs, with associated health and climate benefits of $5.8 billion for a total of $13.3 billion saved between 2000-2016 in the United States (MacNaughton et al., 2018). The health benefits were derived from reduced air pollution, which reduced healthcare costs, lost work/school days, and premature deaths amounting to $4.4 billion (MacNaughton et al., 2018). The climate benefits were realized through the avoidance of negative effects of climate change, reducing costs by $1.4 billion (MacNaughton et al., 2018). But which strategies are the most optimal to achieve health benefits considering cost-efficiency? Equally important is understanding tenants' motivation to pay rent premium for enhanced living conditions.

Currently, in the realm of new multifamily buildings, developers have mainly prioritized financial gains alone. However, by emphasizing healthy building concepts, they can create spaces that are both financially beneficial and improve occupants' well-being. This shift fosters a more sustainable living environment. If these benefits are substantial, government policies could establish clear guidelines and incentives for improving indoor environments in new multi-family buildings.

Research Significance & Objectives

My research assessed the cost-effectiveness of home features in providing enhanced health benefits and addressed misconceptions about the returns from integrating healthy building features into new multifamily buildings. It evaluated the possibility of recouping costs, considering the positive impact on occupants' health and well-being, and tenants' willingness to pay more for such advantages.

This analysis addressed data gaps in the fields of architecture and public health by conducting a cost-benefit analysis on healthy building features like dynamic and diffuse lighting, views, improved air quality, and thermal comfort.

I aimed to develop a scalable and globally applicable model that is responsive, inclusive, and adaptable for any new multi-family building, ultimately enhancing human health and promoting well-being. The results of this research should be valuable to apartment seekers, investors, global thought leaders, public health professionals, business executives, and the United States Green Building Council (USGBC). It may also assist developers in decision-making about the costs of healthy building features. Additionally, this research contributes to the specificity and specialty of the WELL building standard version two (WELL v2).

The objectives of my research were therefore:

- To study the feasibility of implementing various healthy building features in new large multi-family buildings to improve occupant health
- To determine the costs and benefits associated with the incorporation of healthy building features
- To provide a framework applying preferred cost-effective healthy building features based on Cost-Benefit Analysis (CBA), offering a baseline to support developers' decision-making in multi-family projects
- To inform policymakers, advocacy groups, industry professionals, and the public about robust techniques to improve the overall indoor environment cost-effectively in new multi-family buildings

Background

The average person spends 90% of their entire life indoors (offices, homes, restaurants) and it is safe to say that, in the era of a pandemic like Covid-19, that number is even higher (MacNaughton, 2016; Roberts, 2020; US EPA, 2017b). Specifically, the time spent inside homes for an average person is 65% of their entire life (School of Public Health, 2022). However, the relationship between indoor building conditions and the well-being (health and comfort) of occupants is complex (Rolfe et al., 2020; Senitkova, 2019). Strategies aimed at improving indoor environments, such as ‘healthy building concepts’ are of critical importance (Frey et al., 2015; Galvin, 2010; Paradis, 2016).

Healthy Buildings

The World Health Organization (WHO) defines a healthy building as a space that supports the physical, psychological, and social health and well-being of the occupants (Sadikin et al., 2021). The nine foundations of a healthy building— ventilation, air quality, thermal health, moisture, dust & pests, safety and security, water quality, noise, and lighting & views— were developed as a summary of the underlying science and act as a guide to improve the indoor environmental quality of buildings (Allen et al., 2019).

To evaluate building design features there are several standards and certifications for healthy buildings, like the WELL building standard by the International WELL Building Institute (IWBI) (WELL, 2020). It is an above-code building standard that encourages building owners and designers to incorporate evidence-based design to promote the health and well-being of building occupants (Tarramai, 2018). WELL (2022) considers 10 aspects of space: air, water, nourishment, light, movement, thermal comfort, sound, materials, mind, community, and innovation. Each of these concepts are composed of multiple features that are either mandatory preconditions or optional optimizations to achieve a rating in the certification (Table 1) (WELL, 2020). The features across the WELL (2020) concepts comprehensively address not only the design and operations of buildings, but also how they impact, and influence human behaviors related to health and well-being (Table 1). I selected and review some of the healthy building concepts and their features in separate sections below.

Table 1. Framework for healthy building concepts and mitigating features: insights from Allen et al., (2019), and WELL (2022).

Scenario	Healthy Building Concepts	Relevant Housing Improvements required	Mitigating Features	Health Risks Lack of Mitigating Features
1	Dynamic and Diffuse Lighting	Incorporating Daylighting	Low-e windows Smart windows	Cognitive, psychological, physiological
		Incorporating Circadian lighting	Energy star rated LED Dimmer plus Motion sensor light bulbs	
2	Biophilic Design	Implementing Biophilic Design	Additional window area Balconies for views	Cognitive, stress, sick building syndrome, psychological
3	Improved Air Quality (IAQ)	Reducing Particulate Matter (PM)2.5	Air filtration-MERV13 Air quality sensors	Cardiopulmonary mortality: chronic bronchitis, respiratory
		Preventing Dampness and Mold (D/M) and other allergens	Reducing water infiltration Mold resistant painting and coatings	Respiratory illness, severe asthma, asthma exacerbation, allergic rhinitis
		Reducing Volatile Organic Compounds (VOC)	Choosing low-no formaldehyde products	Childhood asthma, cancer,
4	Thermal Comfort	Improving HVAC efficiency and individual comfort	VRF system UVGI lights Humidity controls Green insulation Economizers Smart thermostats	Respiratory illness, asthma, Sick building Syndrome

Dynamic and Diffuse Lighting

Dynamic and diffuse lighting, which combines varying light intensities and shadow, plays a crucial role in mimicking natural conditions, thereby impacting human circadian rhythms (Peters & Verderber, 2022; Taylor, 2019). This concept is vital in multi-family housing design, as disruptions to the circadian system can lead to health issues like poor sleep, hormonal imbalances, and mood disturbances. Prioritizing daylight through operable windows and façade optimization is essential in supporting circadian health in residential environments (Guzowski, 2020).

The health benefits of natural sunlight, well-documented in hospital settings, are equally applicable to multi-family housing where increased exposure to natural light has been linked to reduced stress and improved well-being (Heerwagen, 2000; Walch et al., 2005). Studies in healthcare settings, where patients in sunnier rooms experienced shorter stays and reduced medication use, provide compelling evidence for the benefits of natural light (Benedetti et al., 2001; Walch et al., 2005). Translating these benefits to multi-family housing could lead to improved quality of life for residents, highlighting the importance of incorporating dynamic and diffuse lighting in residential building design.

In addition to traditional daylighting methods, the use of smart windows is emerging as a transformative approach to enhance indoor environmental quality (Dabbagh & Krarti, 2021). Smart windows, equipped with advanced technologies, can dynamically adjust their properties in response to external conditions. This adaptability allows for optimal natural light penetration while minimizing glare and excessive heat gain (Carmody et al., 2004). By intelligently regulating the amount of natural light and solar radiation entering the building, smart windows significantly contribute to energy efficiency and occupant comfort (Dabbagh & Krarti, 2021). Incorporating smart windows alongside window treatments like low-e windows, can profoundly impact the building's lighting design (Dabbagh & Krarti, 2021; Heschong, 2002).

Furthermore, circadian lighting systems, using fixtures like LEDs for ambient lighting and task lighting with variable color temperatures, motion sensors and dimmers with varying brightness intensity levels, complement these natural lighting strategies (Alkhatatbeh & Asadi, 2021). These systems emulate the natural light cycle, aligning with the human circadian rhythm to support physiological and psychological well-being.

The integration of smart windows and circadian lighting represents a holistic approach to building design. This combination not only prioritizes energy efficiency but also addresses the well-being of occupants, ensuring buildings are both environmentally sustainable and conducive to healthy living.

Biophilic Design: Views of Nature

Biophilic design is a concept that focuses on integrating natural elements into the built environment emphasizing human adaptations to the natural world, and depends on repeated and sustained engagement with nature (Ryan et al., 2014). Biophilic design enhances occupant well-being through three overarching health responses: cognitive, physiological, and psychological (Ryan et al., 2014). One of the 14 patterns of biophilic design is visual connection to nature, or living elements which is a strategic and mindful design that (re)connects humans with nature and improves the habitability of spaces along with various health benefits (Ryan et al., 2014; Ulrich, 1984). Biophilic design in university settings with green (plant) walls were found to increase participants' creativity and problem solving by 50% (Peters & D'Penna, 2020). School students in interior spaces full of greenery, enhanced their skill testing scores by 27% (Almusaed et al., 2022). Further, this biophilic effect reduces sick-leave absenteeism by more than 60% (Salem, 2019). Architectural features such as access to views of nature through windows and balconies, indoor plants, and green walls can be integrated into building design to create a more conducive indoor environment that fosters comfort and productivity while also promoting better mental health.

Biophilic design is increasingly relevant in the context of multi-family housing, particularly through features like balconies that offer views of nature (Ryan et al., 2014; Ulrich, 1984). When focusing on views, interventions must address quality, clarity, and quantity. Quality refers to visual richness, clarity to unobstructed sightlines facilitated by window materials, and quantity to the variety and accessibility of views. Optimizing these aspects enhances biophilic experiences, fostering well-being through deeper connections to nature (Ryan et al., 2014; Ulrich, 1984). Balconies become a critical element in offering residents a visual connection to the outside world, fostering a sense of openness and connection to nature even in dense urban settings. They create environments that are not only comfortable and productive but also support better mental health.

Indoor Air Quality (IAQ)

Several air pollutants are recognized by the United States Environmental Protection Agency (US EPA) to exist indoors, including nitrogen dioxide (nox), lead (pb), ozone (o3), carbon monoxide (co), volatile and semi-volatile organic compounds (vocs) like formaldehyde, particulate matter (pm), radon (rn), and microorganisms such as mold spores (US EPA, 2014a, 2015). The levels of indoor air pollutants are often two to five times higher than outdoor levels (US EPA, 2014a). Human exposure to indoor air pollutants has enormous health effects (Thongplang, 2017). Chronic exposure, which is continuous or repeated contact with a toxic substance over a long period of time, can also occur at home (NYS, 2022; Solutions, 2022). India experienced approximately 1.2 million premature deaths attributed to ambient and household air pollution (TERI, 2021).

The air exchange rate with the outdoors is an important factor in determining IAQ (US EPA, 2017b). People often think that they get sick with cold and flu more frequently in the winter because it is colder outside, but the fact that people spend more time indoors and are exposed to higher concentrations of airborne pollutants is often overlooked (US EPA, 2017b). These indoor pollutants include particulate matter (PM), dampness and mold (D/M), and volatile organic compounds (VOC's).

Particulate matter (PM). PM is a key indicator of air pollution and a major determinant of IAQ (US EPA, 2017b). The US EPA (2017b) has categorized PM into three categories, depending on particle size: coarse particles, PM10 (PM<10 μm (micron) in diameter); fine particles, PM2.5 (PM<2.5 μm in diameter) and ultrafine particles, PM10 (PM<0.1μm in diameter). PM size is directly proportional to penetration power into the lungs' bloodstreams and leads to cardiovascular and respiratory diseases (Dubey et al., 2021). Fine PM is positively associated with respiratory symptoms and with rescue medication use (Breysse et al., 2010). PM2.5 originating from indoor sources was found to be more potent in decreasing lung function than outdoor-derived (Breysse et al., 2010).

The air quality guidelines recommend by the WHO aims for annual mean concentrations of PM2.5 not exceeding 5 μg/m3 (Hoffmann et al., 2021). The US EPA

(2023) is also proposing to revise its current standards for PM2.5 from 12 µg/m3 to 9-10µg/m3. In a population of 150 inner Baltimore city preschool children, Breysse et al. (2010) found that for every 10µg/m3 increase in PM2.5 measured indoors, there was a 7% increase in days of wheezing severe enough to limit speech and a 4% increase in rescue medication days related to respiratory illness. Furthermore, the WHO estimated that long-term exposure to PM2.5 is associated with an increase in the risk of cardiopulmonary mortality by 6%–13% per 10 µg/m3 of PM2.5 (Thongplang, 2017). In India, 98% of the 1.2 million deaths of children below five years old were attributed to PM2.5 exposure indoors (Dubey et al., 2021).

PM concentrations inside a home, immediately outside the home, and at a central monitoring site were measured simultaneously using a light scattering nephelometer (Breysse et al., 2010). The PM inside the home was higher and more variable than outside or at the central monitoring site (Figure 1). This demonstrates the importance and complexity of addressing the health effects of indoor airborne particles.

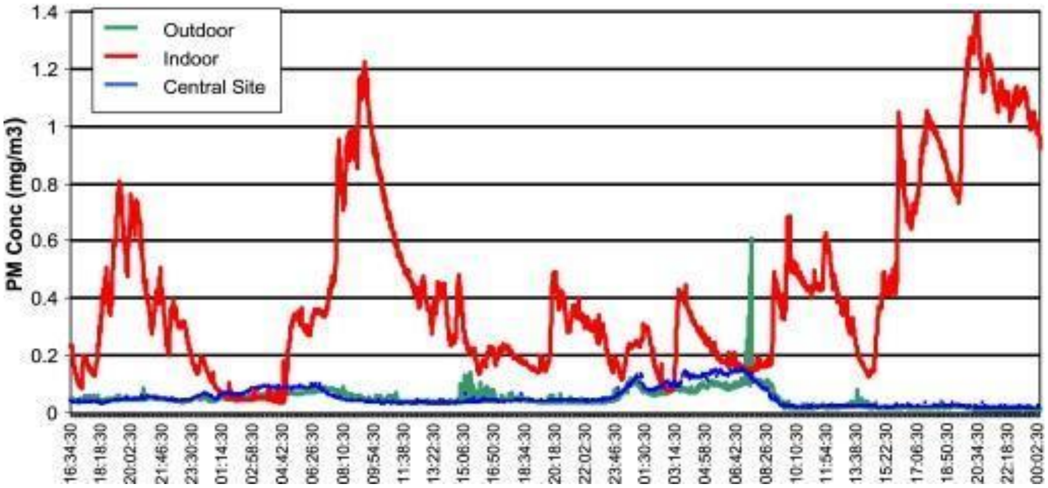


Figure 1. Indoor PM concentrations compared to different sites (Breysse et al., 2010).

Air filter effectiveness is rated using the Minimum Efficiency Reporting Value (MERV) (Bard et al., 2019). MERV 17 and 19 are found to have a minimum efficiency between 99.97% and 99.99% in removing 0.3mm particles (Bard et al., 2019). A minimum of MERV 8-13 is recommended for household HVAC systems (Bard et al., 2019). Although source control and proper ventilation are the first mitigating strategies in improving IAQ, it is crucial to adopt air filtration with MERV 13 or above in buildings to filter PM2.5 levels.

In addition to these measures, the integration of air quality sensors in multi-family housing can play a pivotal role. These sensors provide real-time monitoring of air pollutants, offering crucial data that can inform the need for air purification and ventilation adjustments (Wang et al., 2023). This approach ensures a more proactive and responsive system to maintain optimal indoor air quality, significantly contributing to the health and well-being of residents in multi-family housing.

Dampness and mold (D/M). Dampness, moisture, and mold problems in buildings are major factors affecting the IAQ, worldwide (Loftness et al., 2007). When dampness and moisture are uncontrolled, fungi grow and develop into visible mold (Loftness et al., 2007). Mold reproduces by means of tiny spores that are invisible to the naked eye which may grow indoors when mold spores land on wet surfaces (US EPA, 2014c). No quantitative health-based guideline values or thresholds are recommended for acceptable levels of contamination with microorganisms (Heseltine et al., 2009).

These are complex problems both from the point of view of building construction and human health (Bornehag et al., 2001; Loftness et al., 2007). Dampness in buildings has adverse health effects, including asthma development, asthma exacerbation, allergic rhinitis, and respiratory infections (Bornehag et al., 2004). In recent samples, D/M was found in 47% of US homes; visible mold in 35% of New Zealand homes, and in 40% of Japanese homes (Mendell & Kumagai, 2017).

The widespread occurrence of indoor D/M demonstrates that current public policies for preventing or controlling D/M are not adequate (Mendell & Kumagai, 2017). Therefore, improving policies for the primary prevention of building dampness (and subsequent microbial growth) through improved strategies of design, and preventive maintenance would be the ideal way to reduce this problem (Kercsmar et al., 2006). In addition to policy improvements, practical mitigating strategies are crucial. These include reducing water infiltration in buildings, particularly in moisture-prone areas like toilets, and using water-resistant sheets (Kercsmar et al., 2006). Furthermore, applying mold-resistant paints and coatings can effectively prevent mold growth (DeBella, 2024).

Maintenance strategies for D/M involve reducing water infiltration, removal of water-damaged building materials, alterations to HVAC, and environmental cleaning; post professional inspection (Kercsmar et al., 2006). Post-professional inspections, coupled with environmental cleaning, form an integral part of these mitigation strategies, ensuring a comprehensive approach to addressing D/M and other allergens in indoor environments (Mendell & Kumagai, 2017).

Volatile organic compounds (VOC). Organic chemicals that vaporize and become gases at normal room temperature are collectively known as VOCs (Bower, 2019). Some of the VOCs such as benzene, toluene, styrene, xylenes, and trichloroethylene may be emitted from aerosol products, paints, varnishes, glues, cleaners, spot removers, floor waxes, and polishes are harmful (Bower, 2019). High concentrations of benzene, toluene, and xylene were reported in 43 newly renovated homes in Guangzhou, China (Du et al., 2014). The extent and nature of the health effect will depend on many factors including level and time of exposure (US EPA, 2014d). The immediate symptoms experienced soon after exposure to some organics includes eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment (US EPA, 2014d).

It is essential to avoid the use of formaldehyde, a prominent VOC found in household products and construction products (Bower, 2019). The most significant source of formaldehyde in homes has been pressed wood products, especially medium-density fiberboard that contains a higher resin-to-wood ratio than any other pressed wood product (Bower, 2019). Above an air level of 0.1ppm, formaldehyde can cause various health problems skin irritations, nausea, and coughing (Nielsen et al., 2013).

Formaldehyde has been classified as a human carcinogen by the International Agency for Research on Cancer (IARC) (Gilbert et al., 2008). The WHO guidelines recommend a value below 100µg/m3 (0.1 mg/m3) (0.8ppm) for any 30-min period of the day (Nielsen et al., 2013). The lowest concentration reported to cause sensory irritation of the eyes in humans is 0.38mg/m3 for four hours and an increase in eye blink frequency and conjunctival redness appear at 0.6 mg/m3 (Kaden et al., 2010). Further, a study carried out in 185 homes in Perth, Australia, observed indoor formaldehyde concentrations of between 2.5 and 133.7µg/m^3 (Kaden et al., 2010). In China, from 2011 to 2015, the median concentrations of indoor formaldehyde in newly renovated residences, schools, and offices were 153µg/m3, 163µg/m3, and 94µg/m3 respectively (Fang et al., 2022).

Restricting VOCs is a vital feature that requires avoiding the use of all wood products, paints and finishes that do not meet the American National Standards Institute criteria (ANSI) A208.1-1993 (Bower, 2019; Kaden et al., 2010).

Thermal Comfort

Thermal comfort depends on consumption, heating, ventilation, and air-conditioning (HVAC) (Niza et al., 2022; Wimalasena et al., 2022). Thermal comfort can reduce Sick Building Syndrome (SBS) symptoms, whereby building occupants experience acute health- or comfort-related effects that seem to be linked directly to the time spent in the building (Joshi, 2008). Peters and Verderber (2022) found that 100% fresh air and local filtration in each room significantly reduced the spread of illness, with 87% reduction in influenza in buildings compared to recirculated air and central filtration with only 30–70% reduction. The same benefits might be achieved by improving filter efficiency which can have a negligible impact on HVAC energy use (Fisk et al., 2002). Additionally, energy efficiency improvements to homes eliminate carbon monoxide leaks; and installation measures such as air sealing and insulation, reduces energy costs, as well as reduce asthma triggers in homes (Heschong, 2002; Loftness et al., 2007).

Integrating advanced HVAC technologies is crucial for ensuring optimal indoor air quality and occupant comfort in buildings. High-efficiency HVAC systems, characterized by lower energy consumption and higher operational efficiency, are essential for reducing health risks, especially when combined with built-in filtration systems (Heschong, 2002; Loftness et al., 2007). Regular maintenance, including filter replacement and annual system cleaning, further enhances their effectiveness.

Adding Ultraviolet Germicidal Irradiation (UVGI) lights to HVAC systems can inactivate airborne pathogens, improving air quality (Navaratnam et al., 2022). Humidity control within these systems maintains optimal indoor humidity levels, preventing mold growth and other humidity-related issues (Navaratnam et al., 2022). Economizers, which use outdoor air for cooling when conditions allow, have been shown to reduce sickness-related illnesses and respiratory problems (Fisk et al., 2011).

Additionally, smart thermostats offer precise temperature control, adjusting to occupancy patterns for energy efficiency (Stopps & Touchie, 2020). Variable Refrigerant Flow (VRF) rooftop units provide flexible heating and cooling solutions, adapting to different zones within the building, thereby enhancing system efficiency and occupant comfort (Parameshwaran & Karunakaran, 2023; Senarathna et al., 2024). Collectively, these technologies contribute to a healthier indoor environment and promote the well-being of building occupants.

Multi-family Housing

In multi-family housing, the cost considerations for healthy building features involve a balance between developers' financial objectives and tenants' demand for healthier living environments. Developers typically assess the potential for higher rental yields and property value enhancement against the initial investment costs. Studies suggest that although healthy building features incur upfront costs, they often lead to long-term profitability through increased demand and rent premiums (Zhang et al., 2018).

On the tenant side, there's a growing awareness of the health and comfort benefits associated with healthy living spaces. Research indicates that tenants prioritize apartments that offer improved environmental quality such as improved air quality, natural lighting, and reduced exposure to harmful substances (Zhang et al., 2018). This trend is driven by the recognition of the direct impact of living environments on personal health and well-being (Zhang et al., 2018).

The interaction between developer profitability and tenant preferences creates a complex decision-making landscape in multi-family housing. It's about striking a balance where investments in healthy building features satisfy both the developers' financial returns and the tenants' expectations for high-quality, health-promoting living spaces. This balance is crucial for the successful adoption and sustainability of healthy building practices in the multi-family housing sector.

Research Questions, Hypothesis and Specific Aims

The primary objective of this research was to identify the most cost-effective methods of incorporating healthy building features in new multi-family projects. The research explored the following questions and related hypotheses:

1. Which home improvement features offer the greatest Return on Investment (ROI) over a 10-year period (2024-2033)?

Hypothesis 1: Features such as views of nature, dynamic lighting, and thermal comfort, known for their visually engaging, psychologically stimulating, and sensory enhancements, were more likely to yield the highest ROI. This expectation was based on the perception that these aspects significantly impact well-being and living experience, potentially leading to greater financial returns compared to less tangible elements like PM2.5 reduction or D/M prevention.

2. Are the benefits of adopting features to meet healthy building standards worth the cost of implementation?

Hypothesis 2a: Tenants are willing to pay a premium for healthy building features, thereby justifying the costs of implementation.

Hypothesis 2b: Integrating healthy building features/concepts in new multi-family buildings justifies a lucrative rent premium and improved net operating income for developers, overcoming misconceptions about the overall costs involved.

Specific Aims

To address these research questions and hypotheses, I:

- Outlined features that contribute to a healthier living environment in new multi-family buildings.
- Conducted a survey to understand tenants' willingness to pay rent premium for these healthy features.
- Created an Excel-based Cost-Benefit Analysis template to evaluate the financial aspects of implementing these features over 10 years (2024-2034).
- Analyzed the costs and financial implications of incorporating healthy building features.
- Performed a comparative analysis to correlate tenants' willingness to pay with the Return on Investment (ROI) and Payback Period (PBP) for various features.

- Developed a foundational framework for healthier multi-family buildings and suggested policy changes for implementing cost-effective strategies.

Chapter II

Methods

The study comprised three distinct stages: first, an evaluation of relevant features; second, a willingness-to-pay survey; and third, the development of a cost-benefit model for a hypothetical multi-family housing project. The insights garnered from the willingness-to-pay survey were incorporated into a comprehensive cost-benefit analysis (CBA). This analysis aimed to evaluate the integration of healthy building concepts and features within multi-family housing projects, leveraging the findings to assess their potential implementation by developers.

Initial Assessment of Relevant Features

Referencing the principles of WELLv2 and the nine foundations of a healthy building (Allen et al., 2019), a detailed checklist was formulated specifically for a new multi-family building. This checklist emphasizes vital features crucial for establishing and maintaining a healthy indoor environment. The chosen concepts from the checklist were systematically categorized into sections that focus on dynamic and diffuse lighting, mind, improved air quality (IAQ), and thermal comfort (Table 1).

This process identified specific areas within a multi-family housing project with potential for improvements to enhance indoor environmental quality. These areas target fundamental features essential for creating a healthier living environment. The structured framework used for assessment also highlights the health effects resulting from the absence of these features (Table 1).

Willingness-to-Pay Survey

The study sought to investigate tenants' willingness-to-pay (WTP) for upgrades in new multi-family housing, aiming to assess their perception of cost justifiability through the utilization of Amazon Mechanical Turk (MTurk). The survey focused exclusively on residents of the United States who are either current apartment renters or those who plan to rent an apartment in the foreseeable future. Participants were randomly selected tenants from diverse socio-economic backgrounds nationwide, received questionnaires to assess their preferences regarding costs and healthy features. The WTP Survey ran from Sep 25th, 2023, to Oct 26th, 2023, and received 608 responses.

In the study, various simulated scenarios were created to assess the willingness to pay (WTP) of tenants to pay rent premiums for healthier indoor environments. The survey encompassed several inquiries regarding individual demographic information, covering aspects such as age, gender, race, annual household income, zip code, current place of residence, and the number of residents (Appendix). Additionally, two questions delved into their current rent payments and their willingness to pay rent premiums. These queries were succeeded by questions regarding their intentions to move into an apartment within the next six months. .

The latter portion of the survey concentrated on rent premiums respondents were willing to pay for each feature detailed in the framework (Appendix). The final two questions specifically addressed the ranking of the four categories and the willingness to pay rent premiums for a WELL-certified building, an apartment marketing its healthy features, or an apartment perceived as healthy based on a leasing tour.

Data Analysis

After careful review of the screening process, a total of 119 responses were rejected. Rejection was based on criteria aimed at enhancing data integrity, such as eliminating redundant responses, those with all zeros or invalid inputs like repeated values (e.g., consistently answering the same values for all questions). A filter was also applied by examining responses to a specific question designed to gauge respondent focus, and only those who strongly agreed were retained. Furthermore, responses originating from IP addresses outside of the United States were excluded.

Before screening, the total number of responses was 608, with 193 female and 415 male respondents. After the screening process, removed 119 responses, the remaining total was 489, comprising 173 female and 316 male respondents. This reduction of 20 female responses and 99 male responses indicated that the screening process did not disproportionately exclude respondents of a particular gender. Additionally, the demographic analysis after the screening process showed that the proportion of 'White' respondents remains significantly higher, although the ethnic composition of the survey maintained a consistent distribution, with no apparent bias introduced towards or against any ethnic group. The careful consideration in the design of the screening criteria aimed to preserve the representativeness of the survey while enhancing the accuracy and relevance of the data collected.

The analysis of the WTP results involved examining the proportion of respondents currently renting apartments, condos, or single-family homes, along with gender, income, current rent and household size. Additionally, the analysis involved computing the average additional rent respondents were willing to pay for each feature.

The highest-ranked preference among the four categories was identified by averaging the ranks provided by respondents. Furthermore, the average willingness to pay a premium for a WELL certified apartment, an apartment marketing its healthy features, or an apartment perceived as healthy based on a leasing tour was also calculated to understand respondent preferences.

The study categorized respondents' willingness-to-pay for various enhancements in four key areas: lighting, views, indoor air quality, and thermal comfort. Within each category, average responses were grouped and calculated to determine the premium rent individuals were willing to pay. For instance, in the lighting category, responses for window-related upgrades and improved electrical lighting were averaged separately and then combined for an overall premium rent value. Similar methodologies were applied to views, indoor air quality upgrades, and thermal comfort enhancements. These averaged values for premium rent were subsequently utilized in the cost-benefit analysis (CBA) to calculate the Return on Investment (ROI) for each category.

Cost-Benefit Analysis Model

A CBA spanning ten years was performed to assess the ROI of key healthy building features. The analysis calculated the Net Present Value (NPV) as the difference between cash inflow and outflow. The ROI was then determined using the formula:

$$ROI = (\text{Net Profit} \div \text{Initial Investment}) \times 100.$$

A discount rate of 3% was applied in the cost-benefit analysis, consistent with standard practice in high-income countries like the United States. This rate adjusts for the time value of money, ensuring that future costs and benefits are accurately represented in present-day terms. For instance, this rate implies that receiving $1.03 in a year's time holds the same value as having $1 today. This approach is crucial for realistic ROI calculations, aligning the study with industry standards and providing a comprehensive view of the financial viability of healthy building enhancements in new multi-family housing projects.

Overall, the study's ROI analysis, incorporating these cost estimations and the discount rate, delivers critical insights into the economic feasibility of adopting healthy building standards in new multi-family housing projects. It evaluates both the immediate and long-term financial implications, ultimately aiming to demonstrate the tangible benefits for tenants and developers in fostering healthier living environments.

The analysis encompassed various factors: capital costs, involving product procurement, installation, professional fees, and permits; operating expenses, covering maintenance, utility charges, inspections, and insurance; and financing expenses, encompassing loan interest and associated bank charges. Interest on loan amount was considered to be 3% incremental. In calculating NPV, future cash flows are discounted to their present value using a rate that accounts for inflation, ensuring the cash flows are valued accurately in today's money. This adjustment in ROI calculations prevents an inflated portrayal of profits by recognizing the diminishing purchasing power of money over time. Thus, incremental interest enhances the accuracy of the financial assessment. Operating revenue was derived from rental income, as determined by WTP survey findings, with additional financial benefits factored in from incentives, rebates, and cost savings.

I conducted detailed cost estimates for healthy building features in multi-family housing, drawing on a variety of sources for a well-rounded market perspective. Quotations were sourced from architects, contractors, and manufacturers, including specialized providers like VIEW Inc. for daylight-enhancing windows. For routine maintenance aspects, such as balcony upkeep, quotes were obtained from professional contractors. Market prices for building materials and services were benchmarked using public resources like Home Depot, Green Building Supply, and Building Green, allowing for the calculation of average costs, and accommodating market and regional price variations. These cost estimates were drawn from San Antonio, TX area.

Baseline Model and Healthy Building Scenarios

I selected a hypothetical multi-family building and assumed it lacked all the health-focused features outlined in Table 2, aimed at mitigating potential health risks. This building was conceptualized as a new multi-family project, accommodating 50 units of 1-bedroom and 1-bathroom apartments measuring 750 square feet each. I focused on 1-bedroom apartments that constitute 44% of the total rental market (Hill, 2023). Table 2 details the building's current conditions as baseline and the addition of new health-promoting features. A side-by-side comparison of the baseline and enhanced features in the multi-family apartment building, covering Lighting, Mind, Indoor Air Quality (IAQ), and Thermal Comfort categories are presented (Table 2).

Table 2. Baseline multi-family building conditions alongside the integration of healthy building features.

Category	Relevant Housing Improvements	Baseline Building Conditions	Incorporated Healthy Building Features
Diffuse and Dynamic Lighting	Daylighting	4 Standard double pane 3'x6'	Smart View inc Windows
		Low-e glass	Low-e glass
	Electrical Lighting	Compact fluorescent lamp (CFL) bulbs	Energy star rated LED bulbs 10 watts each dimmable
		N/A	Dimmer Light Switch, Plus Motion and Ambient Light Sensor
		N/A	No of bulbs remains same
Biophilic Design	Views	No balcony	Addition of 4'x10' composite balcony
		Size 72 sq ft of window area	Size 110 sq ft of window Smart windows.
Indoor air quality (IAQ)	Reducing PM2.5	MERV 8 filter	Merv 13 filter
		N/A	Air quality sensors
	Preventing Mold and dampness	Standard drywall sheets	Mold and mildew resistant sheets
		N/A	mold resistant painting and coatings
	Reducing volatile organic compounds (VOC's)	Standard interior Paint	Low-VOC interior paint
		Standard Kitchen Cabinetry	Low-VOC Kitchen cabinets
		Standard Flooring	Low-VOC flooring

Category	Relevant Housing Improvements	Baseline Building Conditions	Incorporated Healthy Building Features
		Standard Adhesives and Sealants	Low-VOC Adhesives and Sealants
Thermal Comfort	Improving HVAC efficiency and individual comfort	Standard HVAC design with Air- or water-cooled chilled water system	VRF rooftop unit (RTU)
		N/A	UVGI light systems
		N/A	Smart thermostats
		N/A	Humidity controls
		Standard-Fiberglass insulation	Green insulation-Mineral wool
		N/A	Economizers-enthalpy

I conducted a study of four different scenarios to assess the potential expenses involved in adding a variety of health-oriented features to a building, from the viewpoint of a developer. These evaluations, projected over a 10-year period, factored in the costs linked to the implementation of these features.

In scenario 1 (S1), under the category of Dynamic and Diffuse Lighting, the focus was on enhancing natural light through the addition of standard and smart windows. The cost analysis for standard Low-E double-pane windows, each measuring 3'x6' (18 sq ft), covering a total of 72 sq ft at $100 per sq ft, came to $7,200. The additional expense for Low-E glass was $20 per sq ft, leading to a total of $1,440 for 72 sq ft, summing up to $8,640.

For the Smart Windows by View Inc., expenses covered framing and installation across 72 sq ft at $150 per sq ft ($10,800), wiring and control systems at $60 per sq ft ($4,320), and additional glazing and electrical labor at $10 per sq ft ($720). A federal tax credit of $52.50 per sq ft under the Inflation Reduction Act (IRA) reduced the total cost to $12,060. The incremental cost for upgrading one unit with smart windows, additional glazing and labor, covering 72 sq ft was thus $3,420.

In terms of electrical lighting, upgrades to energy-efficient bulbs, dimmer switches, and motion and ambient light sensors incurred incremental costs of $101.05 per unit. The analysis also included professional fees of $93.75 in the initial year's cash outflow, accounting for the interest on the loan amount. Additionally, I estimated the ongoing expenses for maintenance, inspections, and loan interest over a decade, which are essential for a detailed financial analysis.

The calculation of cash inflow was based on the additional rent tenants were willing to pay for improved features, as well as various financial benefits like incentives, rebates, and energy savings. This approach included considering the Section 45L New Energy Efficient Home Credit, which offers a $500 incentive for spaces upgraded with energy-efficient appliances and infrastructure (Energy Star, 2024). Additionally, savings were anticipated from daylight harvesting and the use of LED bulbs. For daylight harvesting, savings were calculated based on an energy savings rate of 0.84 kWh/ft^2 in a 750 sq ft apartment, at an electricity cost of $0.131 per kWh. The formula used to determine the overall savings contributed by these energy-efficient measures was:

Total Monthly Savings=Energy Savings per Square Foot × Apartment Area × Electricity Rate.

For scenario 2 (S2), I evaluated design elements for improved views, balconies were added, specifically focusing on their types, costs, and associated expenses. Two balcony types were assessed: bolt-on and composite.

For composite balconies (4'x10'), the cost analysis included labor, materials, and installation ranging from $45 to $80 per sq ft, resulting in a cost of $2,500 per unit. Additional railing costs were estimated at $270 per balcony, bringing the total incremental cost for adding a composite balcony to $2,770 per unit.

In contrast, the Vestis bolt-on balconies (4'x9'6") entailed a broader cost range of $220,000 to $240,000 for 50 units, averaging $4,400 per unit. This included engineering costs of $46 per unit, delivery expenses of $290 per unit, and installation and labor costs between $90,000 and $140,000, totaling approximately $1,800 per unit. Consequently, the total cost for installing bolt-on balconies came to $6,536 per unit.

Given the focus of this study from a developer's perspective, and after a thorough evaluation of the costs involved, I selected composite balconies for this project. This decision was influenced by the comparative affordability of composite balconies, which, at $2,770 per unit presented a more cost-effective option than the Vestis bolt-on balconies, priced at $6,536 per unit. This choice aligns with the objective of balancing improved views with financial feasibility.

In addition to the direct costs of the balconies, the analysis also considered other significant expenses for composite balconies. Maintenance considerations included labor costs at $30 per hour and waterproof paint at $109.98 per 0.66 gallon. Inspection costs for Exterior Elevated Elements were calculated at $75 per hour. Furthermore, permit costs were factored in at $100 per unit, ensuring compliance with regulatory requirements and contributing to the overall financial assessment of the balcony installation.

Additionally, enhancing apartment views by upgrading from the standard 72 sq ft low-e double-pane windows to 110 sq ft of the same type results in an incremental cost increase of $4,560. When combined with the addition of composite balconies and the associated costs for maintenance, inspections, and permits, the total investment for view enhancements totals $7,652.90 per apartment for views.

In the third scenario (S3), enhancing Indoor Air Quality (IAQ) for multi-family housing, my methodology involved a comprehensive estimation of incremental capital costs in areas such as PM2.5 level reduction, dampness and mold prevention, and VOC minimization. For PM2.5 level reduction, the upgrade from MERV 8 to MERV 13 filters in HVAC systems was analyzed. The installation of MERV 13 filters was estimated at $34.28 each, compared to $16.47 for MERV 8 filters, with identical costs for bi-annual replacements. Additionally, air quality sensors were considered at $204 each, bringing the total cost for reducing PM2.5 per unit to $238.28, with incremental costs of $221.81.

In the realm of dampness and mold prevention, I estimated the costs for using mold and mildew-resistant materials. This included a change from standard drywall sheets ($10.45 each) to mold and mildew-resistant sheets ($14.01 each), resulting in an incremental cost of $56.96. With mold-resistant paints and coatings, plus labor costs for application, the total incremental cost for preventing dampness and mold per unit was $839.41.

In the assessment of VOC (volatile organic compounds) reduction, the incremental costs for opting for low-VOC materials were calculated. For interior paints, the standard cost was $25 per gallon, requiring 8 gallons for 2 coats over a 2,700 sq ft area, amounting to $400. The low-VOC paint option, priced at $28.22 per gallon, resulted in a total of $451.52, leading to an incremental cost of $51.52. Similarly, for interior primers, the standard option cost $596.96, while the low-VOC variant was priced at $715.84, resulting in an incremental cost of $118.88.

For kitchen cabinetry, the standard 10'x10' installation was priced at $13,250, while opting for formaldehyde-free materials incurred an additional cost of $1,205, representing a 9.1% increase. The standard flooring cost was $1,170 (at $1.56 per sq ft), and the shift to a low VOC sustainable hardwood floor at $2.99 per sq ft led to a total of $2,242.50, amounting to an incremental cost of $1,072.50. In adhesives and sealants, the standard wet glue at 9 cents per sq ft cost $67.50, whereas the low VOC Lok-Lift Dry adhesive at 33 cents per sq ft amounted to $247.50, resulting in an incremental cost of $180.00.

Thus, the total incremental cost for reducing VOCs in a single unit, excluding maintenance costs, was calculated to be $2,627.90. These cost estimations, based on current market rates and manufacturer quotes, ensure a realistic reflection of the market.

The yearly maintenance costs in the analysis were calculated, amounting to a total of $904.66. This includes an incremental cost of $17.81 for filter replacements, $475.45 for regular inspections and repairs to address mold issues, and $411.40 for the upkeep of low-VOC paints.

For scenario 4 (S4), the thermal comfort enhancement analysis for multi-family housing, I focused on several components, each with their specific costs and energy efficiency benefits. The installation of a Variable Refrigerant Flow (VRF) system, a more efficient alternative to standard HVAC systems, incurred a cost of $18,562.50, significantly higher than the $16,242.19 for a standard air or water-cooled chilled water system. Additionally, Ultraviolet Germicidal Irradiation (UVGI) light systems were considered, with the total cost including installation coming to $700.00.

Smart thermostats were priced at $185.55, and humidity controls, essential for maintaining comfortable indoor environments, were installed at a total cost of $800.00. Economizers, which help in reducing energy consumption, were incorporated at a total cost of $2,070.00. A significant aspect of the analysis was the inclusion of green insulation (Mineral wool) at $1,620.00, which, with a 30% rebate, effectively reduced the cost. The total incremental cost for improving HVAC efficiency for one unit was determined to be $6,145.86.

In the financial analysis for enhancing thermal comfort in multi-family housing, the initial costs included the purchase and installation of various systems, combined with a one-time permit fee of $80.00 in the first year. For the subsequent ten years, the ongoing expenses included maintenance, estimated at $150.00 annually, and inspection costs at $140.00 each year.

A significant aspect of the analysis was the energy savings projected from these enhancements. The installation of Variable Refrigerant Flow (VRF) systems was expected to offer a 14% reduction in energy costs. This percentage translates to a considerable saving, especially when considering the typical energy expenditure in multi-family housing. Economizers, which improve HVAC efficiency, were projected to save about 29% in energy costs, further contributing to overall savings. However, it's important to note that the inclusion of MERV 13 filters was anticipated to increase energy consumption by approximately 5%, slightly offsetting these savings. Additionally, financial incentives such as rebates from the CPS Energy under residential energy efficiency rebate Program and benefits from installing Wi-Fi-enabled smart thermostats were factored into the analysis.

Table 3 presents an initial and ongoing cost-benefit analysis of introducing healthy building features in multi-family housing for the first year and subsequent years up to year 10. This analysis encompasses Dynamic and Diffuse Lighting, Biophilic Design-Views, Improved Air Quality, and Thermal comfort enhancements. The table includes the initial capital costs (including product procurement, installation, professional services, and permits), operational expenditures (maintenance, utility charges, inspections, insurance), and financial charges (loan interest, banking fees).

Table 3. Cost analysis for implementing healthy building features in multi-family housing.

Details	Dynamic and Diffuse Lighting (net) ($)	Biophilic Design-Views (net) ($)	Improved air quality (net) PM2.5, Low VOC, Mold prevention ($)	Improving Thermal Comfort (net) ($)
A. Cost: Cash Outflow: ($)				
A1. Capital costs				
Product purchase and installation	3521.05	7330.00	3689.12	6145.86
Professional fees	93.75	NA	NA	NA
Permits	NA	100.00	NA	80.00
A2. Operating costs (Recurrent expenses)				
Maintenance costs (per yr)	40.00	109.98	904.66	150.00

Details	Dynamic and Diffuse Lighting (net) ($)	Biophilic Design-Views (net) ($)	Improved air quality (net) PM2.5, Low VOC, Mold prevention ($)	Improving Thermal Comfort (net) ($)
Cost of utility (power. Water fuel. any)	NA	NA	NA	NA
Inspection cost	25.00	75.00	200.00	140.00
Insurance	NA	NA	NA	NA
A3. Financing cost (Recurrent expenses)				
Interest on loans Incremental Interest 3%	108.44	222.90	110.67	186.78
Bank charges/fees	0.00	0.00	0.00	0.00
A. Total Cash outflow: (A=A1+A2+A3) with interest				
B. Benefit: Cash Inflow: ($)				
B1. Operating Income				
Revenue from user pay (WTP rent/yr)	2616	2568	2652	2700
Incentives/rebates/savings ($/one time or yearly)	602.00	NA	NA	890.47
Total Annual Cash In Flow B=B1				
Financial Analysis				
Discount rate				
NPV (present value of cash flow)				
ROI = (Net Profit / Initial Investment) * 100%.				
Payback period (ROI)				

Key assumptions in this financial analysis included the reliability of average market prices from these public resources and the representativeness of quotes from industry professionals. Tenants' willingness to pay a premium for healthier environments was considered indicative of broader tenant preferences, and the durability of materials and systems was factored into long-term costs.

Chapter III

Results

Among the respondents of the national survey targeting new apartment seekers, a total of 489 individuals participated after eliminating 119 redundant responses. From the respondents across the United States (Figure 2), 173 were female, and 316 were male. The demographic breakdown revealed that 97.96% (479) identified as white, 0.20% (1) as Hispanic, 1.43% (7) as Black or African, and 0.41% (2) as Asian (Table 4).

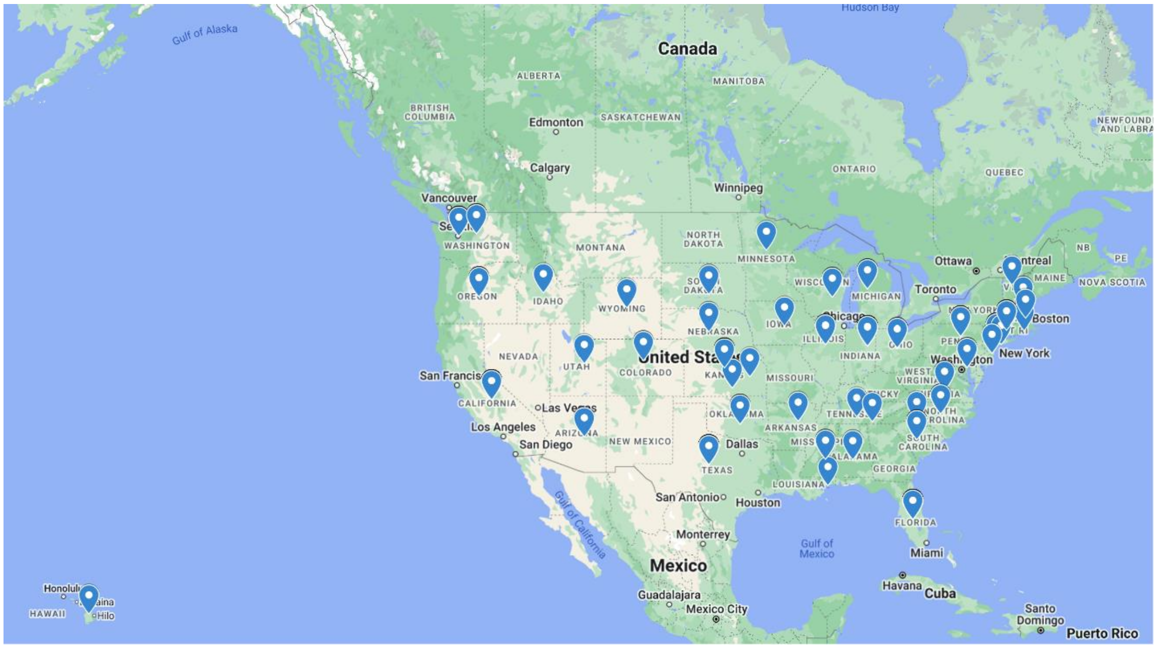


Figure 2. Geographical distribution of survey respondents.

Of the 489 respondents, 302 (approximately 61.76%) currently reside in rented apartments, 52 in owned condos (10.63%), and 135 in owned single-family homes (27.61%) (Table 4) with an average current rent of $2,793.

Table 4. Demographic distribution of willingness to pay (WTP) survey respondents by gender, ethnicity, and housing status.

Category	Asian	Black or African American	Hispanic, Latino or Spanish origin	White	Grand Total
Apartment (Rented)	1	5	1	295	302
Female	1	2	1	116	120
Male		3		179	182
Condo (Owned)				52	52
Female				10	10
Male				42	42
Single family home (Owned)	1	2		132	135
Female	1			42	43
Male		2		90	92
Grand Total	2	7	1	479	489

The demographic sampling revealed that a notable segment of the survey participants, specifically 197 out of 489 respondents, reported annual household incomes ranging between $50,000 and $74,999. On average, households consisted of approximately 4.5 individuals. The data also indicated a trend where younger respondents were more likely to currently rent rather than own a house (Figure 3).

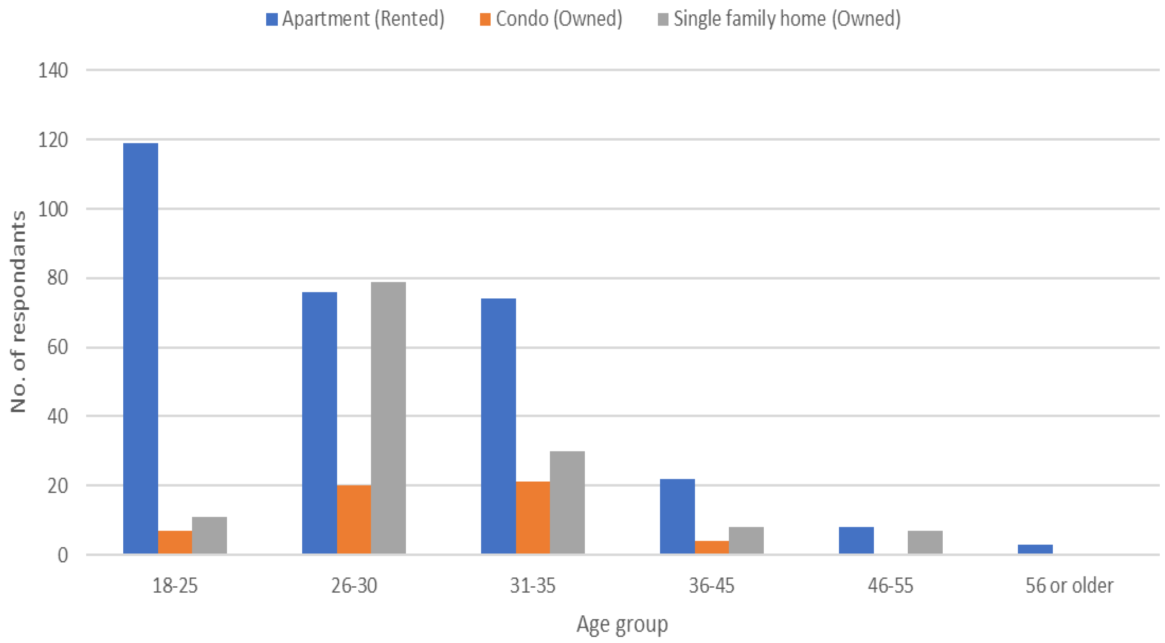


Figure 3. Demographic breakdown by age group and residence type of participants.

Willing-to-Pay Premium Rents

The average rent premiums that respondents were willing to pay for distinct features was analyzed within four main categories of a multi-family building: lighting, views of nature, indoor air quality and thermal comfort. Among the assessed four concepts for ranking, thermal comfort emerged as the top preference among respondents with the highest-ranking average of 2.49, demonstrating a strong inclination towards this aspect. Views and Indoor Air Quality (IAQ) were also important, receiving similar rankings of 2.39 and 2.38, respectively. Lighting, while still a significant consideration, ranked slightly lower at 2.27. These rankings offer insights into the prioritization and preferences of respondents regarding the various features evaluated in the study.

For the CBA, the features are systematically grouped (Table 5). Similar subcategories were clustered together and averaged, with the resulting averages summed together to determine a total rent premium for the healthy building features (Table 5).

Table 5. Mean rent premiums respondents were willing to pay for each feature.

	Window Technology		Electrical Lighting Technology				
Dynamic and Diffuse Lighting	Windows with low e-films/glass	Smart windows	Task lighting	Ambient lighting	Lighting color temperature control	Average Lighting	
Rent Premiums ($)	$106	$110	$109	$109	$112		
Average ($)	$108		$110			$218	

	Enhanced View Area		Any Views				
Views	More number of windows	Floor to ceiling windows	Views of adjacent buildings	Views of nature	Views of natural settings like trees	Balcony with any view	Average Views
Rent Premiums ($)	$100	$106	$109	$110	$113	$114	
Average ($)	$103		$112				$214

	Air Monitor/Purifiers			Materials			
IAQ	Air quality monitor/sensors	Stand-alone HEPA filters	MERV 13 filter in HVAC	Mold prevention	No-Low Volatile Organic Compounds materials	Average IAQ	

Rent Premiums ($)	$111	$109	$109	$111	$113	
Average ($)	$110			$112		$221

	HVAC System		HVAC Additions			
Thermal Comfort	Individual unit Indoor air circulation (rather than combined circulation)	Economizer : Used for energy efficiency	UVGI (Ultraviolet Germicidal Irradiation) light in HVAC systems	Humidity control	Monitoring Thermal Comfort/ Smart thermostats	Average Thermal Comfort
Rent Premiums ($)	$110	$113	$112	$113	$115	
Average ($)	$111		$113			$225

Features are grouped together in each category based on their relevance; color coded to blue and green. The average rent premium for each category is color coded to orange.

The determined average rent premiums per month for dynamic and diffuse lighting, views, IAQ, and thermal comfort being $218 (7.77%), $214.00 (7.71%), $221.00(7.91%), and $225.00 (8.07%), respectively.

On average, respondents were willing to pay a rent premium of $404.20 for a WELL Certified, $420.05 for an apartment that markets its healthy features on its leasing materials, and $448.51 for an apartment that they perceive to be healthy based on their leasing tour (Figure 4).

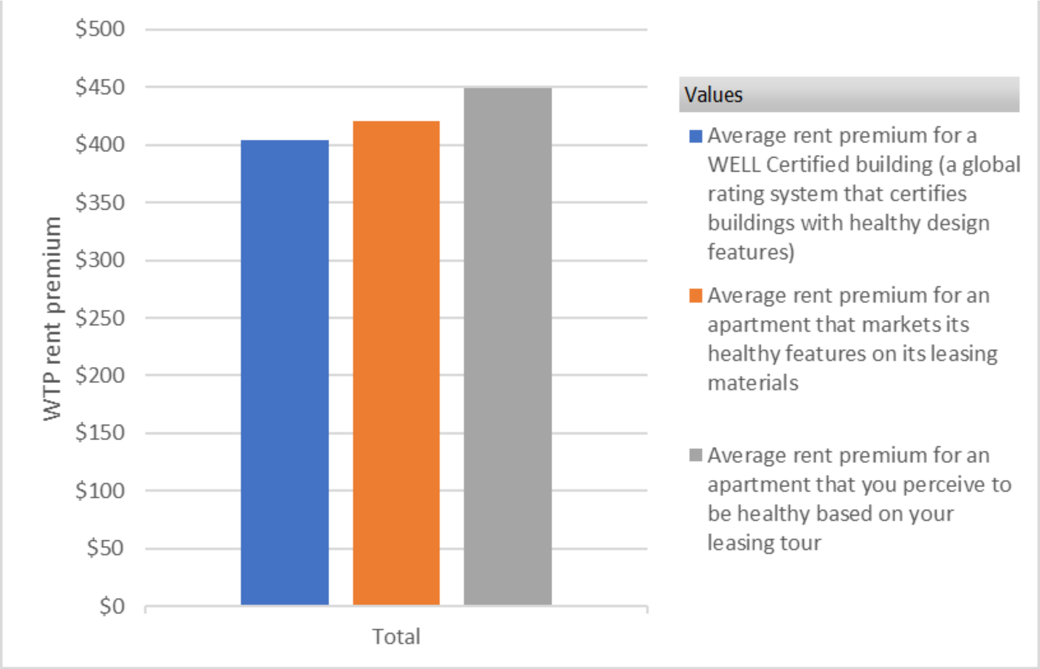


Figure 4. Willingness to pay for health certified, marketed, and perceived.

Cost-Benefit Analysis

The comprehensive ten-year Cost-Benefit Analysis (CBA) assessed the estimated costs in four key areas: dynamic and diffuse lighting, views of nature, indoor air quality and thermal comfort, revealing significant findings.

Dynamic and Diffuse Lighting

In the lighting category, the ten-year CBA indicated considerable economic and energy savings. The collective initial investment for lighting improvements was $3,521.05 covering enhancements such as, smart window integration, low emissivity (e-films/glass) application, task, and ambient lighting, as well as advanced lighting color temperature control. This led to a comprehensive first-year cash outflow of $3,723.249 per apartment, which includes professional service fees ($93.75) and interest on loans

($108.44). From the second year through to the tenth, the cumulative maintenance, inspections, and interest expenses were $173.44 per apartment.

Moreover, the Section 45L energy-efficient home credit contributed a $500.00 reduction, with an additional $102.00 in energy savings accrued monthly from LED bulb fixtures and daylight harvesting techniques. These lighting improvements were projected to yield a monthly rent premium of $218.00. Along with total incentives amounting to $602.00, the estimated cash inflow per apartment was projected to be approximately $3,218.00 over the course of a decade.

Views of Nature

The financial analysis for enhancing views of nature with the addition of 4'x10' balconies and more windows or increased size of windows indicated an initial investment of $7,652.90 per apartment. This cost includes the installation of a balcony with railings, one hour of labor at $30.00, waterproof paint at $109.98, and one hour of Exterior Elevated Elements services at $75.00 and expanded window area from 72 sq ft to 110 sq ft. Included in the initial cost were a permit fee of $100.00 and a $222.90 interest payment on the loan. For the decade following, maintenance and additional expenses were expected to total about $407.88 per apartment. While there were no immediate incentives for balcony installation, the projected rental uplift of $214.00 per month due to the improved views produced an additional revenue of $2,568.00 per apartment over the ten-year period.

Indoor Air Quality (IAQ)

The initial investment for IAQ enhancements was calculated to be \$3,689.12, which included \$221.81 for PM 2.5 reduction, \$839.41 for dampness and mold prevention, and \$2,627.90 for VOC reduction. When the loan interest of \$110.67 was added, the total initial cost for IAQ improvements increased to \$3,799.79. Additionally, over the next ten years, the projected total expenditure, encompassing maintenance, inspections, and loan interest, was estimated at \$1,215.33.

Despite the absence of immediate incentives for IAQ improvements, the rent premium derived from the willingness-to-pay (WTP) survey was estimated at \$221.00 per month. This was projected to result in a cumulative cash inflow of \$2,652.00 for each apartment over a span of ten years.

Thermal Comfort

The initial cost for thermal comfort enhancements was \$6,145.86, including the installation of VRF HVAC systems, UVGI light systems, smart thermostats, humidity controls, insulation, and enthalpy economizers. Additional expenses like permit fees and loan interest raised the first-year total to \$6,412.64. Over the next decade, the expected total outflow, comprising maintenance, inspections, and interest, was estimated at \$476.78. This included \$150.00 for maintenance, \$140.00 for inspections, and \$186.78 for loan interest.

The thermal comfort enhancements yielded cash inflow from two key sources: energy savings and rent premiums. The Variable Refrigerant Flow (VRF) systems delivered annual savings between 11% and 17%, economizers offered a 29% reduction, and View Smart windows resulted in 18% energy savings. Conversely, incorporating

MERV 13 filters led to a 5% yearly increase in energy use. The total annual energy savings reached $1,073.60, averaging $89.47 per month. Additionally, the first year saw a significant inflow from one-time incentives: a green insulation rebate of $486.00, the Residential Energy Efficiency Rebate Program offering $200 per ton, and a $115 incentive for Wi-Fi-enabled CPS enrollment, summing to $801.00 in total. Together with the energy savings, this resulted in an initial cash inflow of $890.47. The monthly rent premium of $225.00 accumulated to $2,700.00 annually per apartment, bringing the first year's total cash inflow to $3,590.47.

Over the next ten years, the cash inflow was projected to be $2,819.47. This reduction is attributed mainly to the singular nature of the initial incentives. In the following years, the ongoing energy savings of $89.47, the $30.00 annual CPS incentive, and continued rent premiums contributed to a total annual inflow of $2,819.47.

Cost-Benefit Final Model

A comprehensive financial analysis of all healthy building concepts was performed including: dynamic and diffuse lighting, biophilic design (i.e., views of nature) improved air quality, and enhancements in HVAC efficiency (Table 6). Each concept was evaluated in terms of Net Present Value (NPV) Outflow and Inflow, Return on Investment (ROI), and the Payback Period, measured in years. Collectively, these initiatives yield a total NPV Outflow of $40,981 and an NPV Inflow of $93,958. This results in an aggregate ROI of 129%, with an average payback period of 4.36 years, highlighting the economic viability of investing in healthy building features.

The concept of time value of money is central in NPV calculations. By applying a 3% discount rate, the analysis acknowledges that future earnings from these healthy building features are not as valuable as immediate earnings. For example, when considering the lighting concept over a 10-year period, the gross NPV inflow amounts to $32,180. However, when this figure is adjusted using a 3% discount rate, the NPV inflow is reduced to $26,650 (Table 6).

Table 6. The net present value (NPV) and return on investment (ROI) for the four categories.

Healthy Building Concepts	Net Present Value (NPV) outflow (USD):	Net Present Value (NPV) Inflow (USD):	ROI= (net profit/initial investment) x100 (%)	Payback Period (yrs)
Dynamic and Diffuse Lighting (net) ($)	$5,202.76	$26,650.67	412.24	1.95
Biophilic Design- Views (net) ($)	$11,132.20	$21,267.53	91.05	5.23
Improved air quality (net) PM2.5, Low VOC, Mold prevention ($)	$14,166.84	$21,963.20	55.03	6.45
Thermal Comfort (net) ($)	$10,479.63	$24,076.89	129.75	4.35
NPV (Outflow, Inflow)	$40,981.42	$93,958.30	129.27	4.36

The ROI of 412% in the lighting category, as indicated by the analysis, means that for every dollar invested in this category, a return of approximately $4.12 is realized over the lifespan of the project. This figure represents the total return accumulated across the 10-year period considered in the analysis. It's important to note that this ROI is not an annual rate but a cumulative return over the entire 10 years. Therefore, the investment in the lighting category not only recoups its initial cost but also generates an additional $4.12 for every dollar spent over the decade. This is reflected in the short payback period of 1.95 years, after which all subsequent returns are net gains.

Chapter IV

Discussion

The cost-benefit analysis (CBA) incorporating the survey data substantiated the economic feasibility of healthy building strategies and supported key hypotheses about their financial impact. The study showed distinct financial performance differences among categories such as dynamic and diffuse lighting, biophilic design – nature views, improved air quality, and thermal comfort. Dynamic and diffuse lighting, with an ROI of 412% and a payback period of 1.95 years, emerged as the most profitable investment, aligning with hypothesis 1 which predicted high returns from visually engaging and psychologically stimulating features that are tangible. On the other hand, views of nature, and thermal comfort, with ROIs of 91% and 130% respectively, offer viable investment opportunities but with longer payback periods of 5.23 years and 4.35 years respectively, supporting the hypothesis that tangible well-being elements can lead to financial gains. In contrast, IAQ, which included less tangible elements like PM2.5 reduction, mold prevention, and VOC reduction, offers benefits but with a modest ROI of 55% and the longest payback period at 6.45 years. The differences between the strategies were driven primarily by cost to implement rather than differences in willingness to pay.

The study also confirmed Hypotheses 2a and 2b, showing that tenants are willing to pay rent premiums ranging from $214 to $225 for apartments with these healthy features, thus justifying the costs of implementation. The overall positive ROI of 129% and an average payback period of 4.36 years across all four features point to the economic viability of adopting healthy building standards. This supports the anticipated benefits of rent premiums and improved net operating income for developers, addressing misconceptions about the costs of such initiatives. Therefore, the study not only indicates the appeal of healthy building features to potential tenants but also provides developers with clear insights into the range of investment options, balancing immediate financial returns with long-term profitability, and catering to diverse financial goals and tenant preferences.

The survey data indicated no significant gender or demographic differences, in the valuation of healthy building features. Men were willing to pay premiums ranging from $216-$225 for features like Dynamic and Diffuse Lighting, Views, Indoor Air Quality (IAQ), and Thermal Comfort, while women's willingness to pay ranged from $211-$224 for the same features (Figure 5). This suggests that people of all genders and races are similarly motivated to invest in these healthy building features.

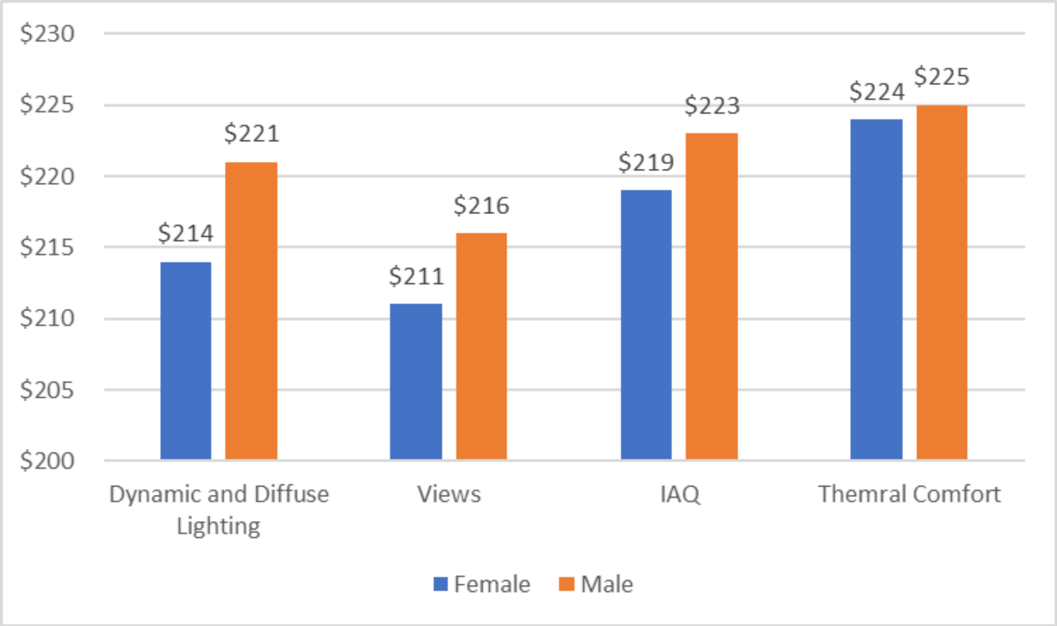


Figure 5. Willingness to pay- gender disparities in valuing healthy building features.

Moreover, this research revealed a nuanced tenant preference in the multi-family housing market, particularly when it comes to health-related features. While the study by Gabe et al. (2022) highlighted a rental premium of 10.2% to 14.7% for LEED-certified properties, the findings of my research showed an even stronger tenant inclination towards units they perceive as healthy. Respondents demonstrated a willingness to pay 16% ($448.51) for apartments perceived as healthy during a leasing tour, surpassing the 14% ($404.20) premium for WELL Certified units. The preference for perceived healthiness over formal certifications such as LEED or WELL, as indicated by the survey, suggests not only a shift in tenant priorities towards personal experience and perception but might also reflect a lack of awareness about the WELL Certification, combined with variations in the demographic and socio-economic backgrounds of the respondents.

Additionally, while previous studies like Rotondo et al. (2020) emphasized quantifying health benefits and their impact on energy efficiency, my research complements that U.S. Department of Energy's study by conducting a survey to understand tenant willingness to pay (WTP) for healthy building features like lighting, views, indoor air quality, and thermal comfort in multi-family housing. My research offers a market perspective, assessing the economic value tenants place on these health-enhancing features. This approach provides valuable insights for developers and policymakers, highlighting the financial incentives and market demand for incorporating these features in housing units.

Multifamily Rental Market

The 2024 national multifamily rental market in the United States is characterized by complexity, with differing outcomes across various metropolitan areas. Cities like Austin, Phoenix, and Jacksonville have experienced rent declines due to the influx of new rental properties, while others such as Kansas City, Cincinnati, and St. Louis have seen above-average rent growth (Kimosa & Betancourt, 2024). Nevertheless, a consistent national demand for rental properties persists, driven by factors like job growth, rising incomes, higher interest rates, and housing shortages (Kimosa & Betancourt, 2024). For example, in May 2023, there was a seasonally adjusted annual rate of 571,000 units, but elevated financing costs have made it challenging to underwrite new projects, resulting in a significant 30% decrease in starts to 402,000 units by October 2023 compared to 2022 (Kimosa & Betancourt, 2024).

Before the pandemic (2016-2019), the rental market experienced an influx of 1.3 million households earning over $75,000, while losing 1.0 million with incomes under $75,000 (Kimosa & Betancourt, 2024). However, during the pandemic (2019-2022), this trend reversed, with 1.1 million new renters earning under $75,000 and only 16,000 with higher incomes (Kimosa & Betancourt, 2024). This shift was propelled by higher-income renters buying homes due to low interest rates, some of whom formed smaller, lower-income households. Significant growth also occurred among single- and two-person households earning less than $75,000 (Kimosa & Betancourt, 2024). It's noteworthy that while lower-income households led growth during the pandemic, rental demand has increasingly been driven by higher-income households in the long term. The number of renter households with incomes of $75,000 or more has surged by 43% since 2010, reaching 13.5 million in 2022. Additionally, the share of renters earning at least $75,000 annually has grown by over 6 percentage points to 30% during the same period. These shifts in the renter demographic can impact the quality and demand for rental housing, with higher-income renters potentially influencing the market in different ways compared to lower-income renters.

The projected national vacancy rate for 2024 is estimated to reach 6.25%, primarily influenced by the introduction of new rental properties, reshaping the rental market landscape (Kimosa & Betancourt, 2024). Importantly, while the vacancy rate is expected to rise, it is likely to remain close to the long-term average, indicating a temporary adjustment in market dynamics.

Amid these market challenges and the subdued demand observed in 2023, Class A units, targeting higher-income tenants, experienced a rent decrease of 0.69%, while Class B units, appealing to a broader range of renters, saw a 1.11% decrease (Kimosa & Betancourt, 2024). In contrast, budget-friendly Class C units, catering to cost-conscious renters, saw a modest growth of 0.33% during the same period.

To address these dynamics, developers should prioritize the implementation of healthy building concepts (Kimosa & Betancourt, 2024). Notably, Class B units may face a higher vacancy rate due to increased availability from Class A units. Therefore, incorporating health-conscious features can serve as compelling incentives for tenants to choose Class B and C units, potentially reducing overall vacancy rates. Conversely, with Class A properties having greater competition, the flight to quality will reward those properties that have differentiated with healthy features.

My research findings also showed that individuals with incomes of $150,000 or more exhibited the highest WTP, with amounts ranging from $240 for Views to $250 for Thermal Comfort (Figure 6). Interestingly, those in the $75,000-$99,999 bracket similarly valued these features, only slightly less than the highest earners, suggesting that the perceived value of health-related home improvements does not increase linearly with income (Figure 6).

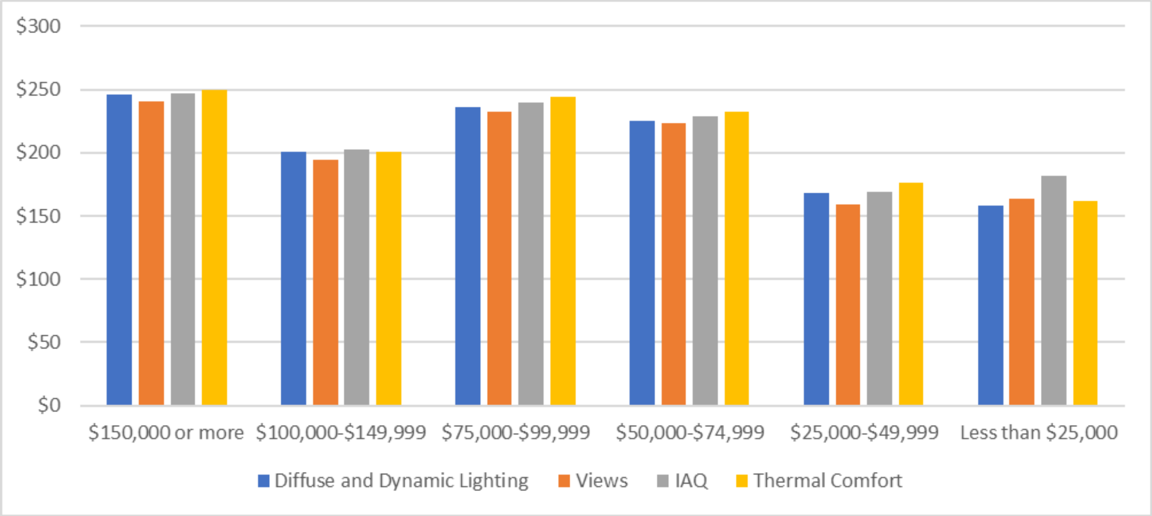


Figure 6. Income-Based willingness-to-pay (WTP) for healthy building features.

Conversely, those earning less than $25,000 annually had the lowest WTP, yet their willingness to pay substantial premiums, $158 for Lighting and up to $182 for IAQ, indicates a recognition of the importance of these features (Figure 5). This perspective is echoed in a study done in 2022 showing that a record 22.4 million renter households spent over 30% of their income on rent and utilities (JCHS, 2024). Within this group, 12.1 million households faced severe financial strain, with housing costs consuming more than half of their income (JCHS, 2024). This scenario indicates that despite financial constraints, lower-income renters may be more motivated than wealthier tenants to invest in healthy housing features.

My survey data revealed a consistent trend: as income decreases, the WTP diminishes, but not drastically, suggesting a broad recognition of the benefits of healthy housing features across economic strata. These data highlighted the income-dependent demand for healthy building features, emphasizing the need for policy action.

Highlighting housing disparities by income, recent 2021 American Housing Survey data reveals significant variations in rental housing quality (JCHS, 2024). Alarmingly, 12% of renters earning less than $15,000 annually lived in substandard conditions marked by structural problems, inadequate upkeep, and inconsistent basic amenities, particularly prevalent in older homes (JCHS, 2024). This disparity underscores the challenges faced by low-income renters in securing safe and healthy housing.

Historically discriminatory policies have disproportionately placed Black and Hispanic households in inadequate housing. In 2021, 10% of Black and Hispanic renter households lived in substandard conditions, exceeding the percentages for white (7%) and Asian households (6%). These disparities persist despite income differences (JCHS, 2024).

Severe underfunding of project-based assistance programs leaves around one in 10 renters in public housing or HUD-assisted private multifamily housing with inadequate living conditions, emphasizing the need for increased investment in affordable housing initiatives (JCHS, 2024). Furthermore, despite inspection standards, 11% of renters with Housing Choice Vouchers experienced inadequate housing conditions in

2021, highlighting the ongoing need for substantial improvements in housing assistance programs to ensure high-quality housing for vulnerable populations (JCHS, 2024).

From a policy perspective, these results point to the necessity of crafting legislation that supports equitable access to quality housing, recognizing that the benefits of healthy living spaces should not be a luxury afforded only to the higher-income earners but a standard accessible to all.

Affordability concerns for lower-income tenants highlights the need for federal and state incentives in housing development. HUD's Healthy Homes Program (HHP) serves as a model for such policies. Despite this, rental assistance programs haven't expanded sufficiently, impacting millions of low-income households (JCHS, 2024). Programs like the Rental Assistance Demonstration (RAD) convert public housing units into stable Section 8 contracts, benefiting older adults, people with disabilities, and families with children (JCHS, 2024). In rural areas, USDA's Section 515 program provides low-interest mortgages for affordable housing, though it faces challenges due to depleting stock (JCHS, 2024). To increase affordability and options, addressing zoning barriers is crucial. Many major cities reserve around 75% of their land for single-family homes, limiting rental opportunities (JCHS, 2024). State and regional housing authorities should expand rent assistance programs to include health-focused features, stimulating a market for such apartments and improving overall housing standards. Educational initiatives can raise awareness, aligning with the growing demand for health-centric housing and benefiting individuals across income levels.

Policies promoting healthy building features in rental housing can improve living conditions and affordability for all income groups. These policies incentivize property owners to provide better indoor air quality, comfortable temperatures, and improved lighting, reducing utility costs for tenants. Additionally, they can help lower healthcare costs associated with inadequate living conditions, which strains other tax-funded programs such as Medicaid and Medicare. Generally, preventative health measures, such as those delivered through healthy building features, are significantly more cost effective than managing health conditions once they've developed through secondary and tertiary care. Overall, such policies benefit renters across all income levels while cutting health-related expenses.

Research Limitations

My research, focused on a specific demographic and region, may not fully translate to areas with different socio-economic and environmental conditions, potentially limiting the wider applicability of its findings. The focus was specifically on one-bedroom apartments, and as such, the findings may not be directly applicable or generalizable to other types of residential properties, such as single-family homes or apartments with different configurations, such as five bedrooms. Additionally, the financial analysis is based on current market rates, which are subject to change, possibly affecting the accuracy of cost and ROI calculations. The rapid advancement in building technologies also raises the possibility of some studied features becoming outdated soon. Assumptions made about tenant preferences based on the survey might not reflect broader or future trends. Moreover, cost estimations, while comprehensive, might not cover all variables and unforeseen expenses in implementing healthy building features.

Challenges in applying the findings more broadly arise from variations in baseline levels across regions. Cost data primarily sourced from South Texas could lead to pricing inaccuracies when applied to other locations, and the healthy building strategies could be pursued through other design techniques that could be more or less expensive than the ones used here. Variations in local climate, occupancy patterns, and willingness-to-pay could significantly impact the payback period for healthy building features in different multi-family housing projects. Most importantly, willingness to pay surveys deal with hypothetical scenarios, and respondents tend to overestimate how much they would contribute in reality. Despite these limitations, the study offers valuable insights into the feasibility and effectiveness of incorporating healthy building features in multi-family housing.

Conclusions

This study confirmed the financial viability of implementing healthy building features in multi-family buildings, focusing on dynamic and diffuse lighting, views of nature, IAQ, and thermal comfort. Key findings included a 412% ROI for lighting over 10 years, significantly surpassing initial expectations and affirming the hypothesis regarding the financial benefits of visually stimulating features. Lighting also demonstrates a rapid payback period of just 1.95 years. Meanwhile, thermal comfort, despite being highly favored by respondents, showed a longer payback period of 4.35 years.

The demonstrated willingness of tenants to pay premium rents for healthy features, averaging between $214-$225, along with higher premiums for those apartments emphasizing healthy attributes, highlighting a clear market trend towards valuing health and wellness in living spaces, thereby rationalizing the investment required for their implementation.

Overall, the study validated the economic advantages of adopting healthy building standards, with an overall ROI of 129% and a comprehensive payback period of 4.36 years for all features combined. These findings challenge previous misconceptions about the costs of such features and underscore their potential for generating lucrative premium rents and improved net operating income, aligning with the initial hypotheses, and shaping future development strategies in the building industry.

The findings of this study are instrumental in informing the development of evidence-based building codes, policies, and incentives, marking a significant step towards promoting healthy indoor environments on a global scale.

Appendix

Survey on Tenant Willingness to Pay for Healthy Building Features in Multi-Family Apartments

Q1 What is your age?

- 18-25
- 26-30
- 31-35
- 36-45
- 46-55
- 56 or older

Q2 What is your gender?

- Male
- Female
- Prefer not to say

Q3 Which category describes you?

- White
- Black or African American
- American Indian/Native American or Alaska Native
- Asian
- Native Hawaiian or Other Pacific Islander

- Hispanic, Latino or Spanish origin
- Prefer not to say

Q4 What is your total annual household income before taxes?

- Less than $25,000
- $25,000-$49,999
- $50,000-$74,999
- $75,000-$99,999
- $100,000-$149,999
- $150,000 or more
- Prefer not to say

Q5 What is your US Zip Code?

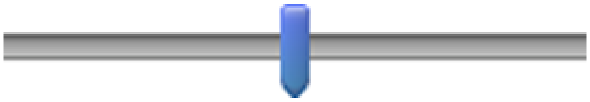
____

Q6 What best describes your current residence?

- Single family home (Owned)
- Condo (Owned)
- Apartment (Rented)
- Other ____________

Q7 How many people reside in your home?

0 1 2 3 4 5 6 7 8 9 10

No. of people	

Q8 How much do you currently pay per month in rent?

750 1175 1600 2025 2450 2875 3300 3725 4150 4575 5000

Current rent per month	

Q9 What is the most you would be willing to pay per month in rent if you were to move?

750 1175 1600 2025 2450 2875 3300 3725 4150 4575 5000

New rent per month	

Q10 Do you plan to move into an apartment in the next 6 months?

- Yes
- No

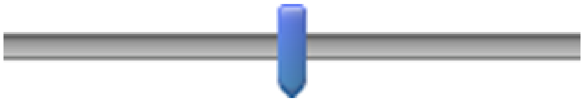
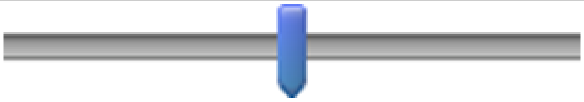
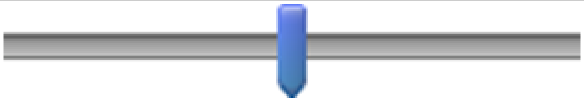
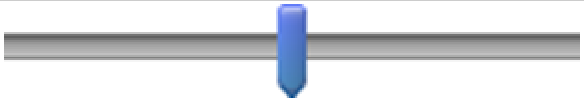
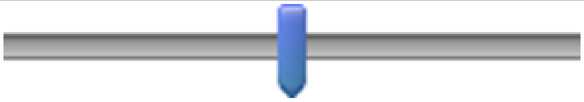
Q11 How much more are you willing to pay in rent each month to have the following lighting options in your apartment, within the range of $0 to $200?

0 40 80 120 160 200

More number of windows	
Floor to ceiling windows	
Windows with energy efficient low e-films/glass	
Smart windows that automatically adjust in response to the sun	
Task lighting (example: under cabinets lighting)	
Ambient lighting (provides overall illumination for a room)	
Lighting color temperature control (warm or light or dimmers)	
All of the above	

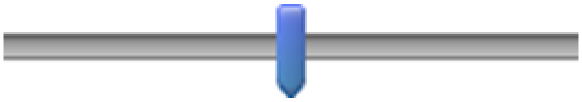
Q12 How much more are you willing to pay in rent every month to have the following view options in your apartment, within the range of $0 to $200?

0 40 80 120 160 200

View of adjacent buildings	
Partially obstructed views of nature	
Balcony with any view	
Scenic views of natural settings like trees	
Any of the above	

Q13 How much would you be willing to pay extra in rent every month to have the following air quality improvement features in your apartment, within the range of $0 to $200?

0 40 80 120 160 200

a) Stand-alone HEPA filters	

b) MERV 13 filter in HVAC	
c) Mold prevention measures such as mold resistant materials, painting and coatings	
d) Use of No-Low Volatile Organic Compounds materials	
e) Air quality monitor/sensors	
f) All the above	

Q14 How much more would you be willing to pay extra in rent every month to have the following HVAC features in your apartment, within the range of $0-$200?

0 40 80 120 160 200

Individual unit Indoor air circulation (rather than combined circulation)	
Humidity control	

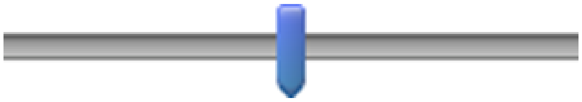
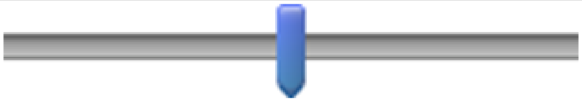
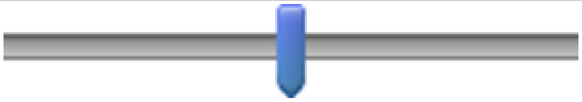
UVGI (Ultraviolet Germicidal Irradiation) light in HVAC systems	
Economizer : Used for energy efficiency	
Monitoring Thermal Comfort/ Smart thermostats	
All of the above	

Q15 Please select 'strongly agree' to show you that are paying attention to this question.

- Strongly disagree
- Agree
- Strongly agree
- Disagree

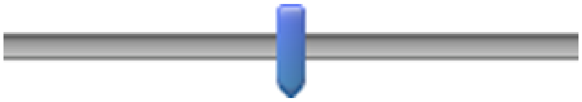
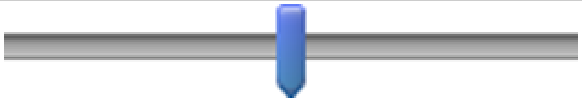
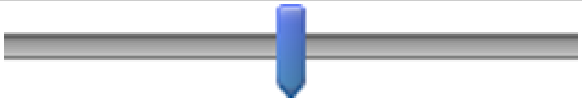
Q16 Please rank the following factors on a scale of 1 to 4, with 4 being the most important and 1 being the least important when selecting a healthier living environment:

	0 1 2 3 4
Lighting (day-lighting, electrical lighting)	

Views (nature settings, balconies, living walls)	
Indoor air quality (PM2.5, dampness and mold prevention, VOC reduction)	
Efficient thermal performance (temperature, humidity control)	

Q17 How much more in rent would you be willing to pay per month for one that incorporates healthy features/amenities, when considering to rent an apartment?

0 75 150 225 300 375 450 525 600 675 750

WELL Certified (a global rating system that certifies buildings with healthy design features)	
An apartment that markets its healthy features on its leasing materials	
An apartment that you perceive to be healthy based on your leasing tour	

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