

## Article

# New Dimension to Green Buildings: Turning Green into Occupant Well-Being

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**Abstract:** A series of international conferences and initiatives, such as the Habitat III New Urban Agenda and UN Sustainable Development Goals, have urged industry, scholars, and policymakers to create an inclusive and sustainable built environment for all in the coming era of cities. Green building schemes, which have been gaining momentum over recent decades, are one of the most influential measures that have been taken to promote urban sustainability. However, due to disciplinary characteristics, most current studies share a techno-engineering focus. Seldom do they answer the question: will green buildings make a difference to the occupants? This paper explains how, and to what extent, green features and design contribute to different dimensions of occupant well-being by conducting a systematic and comprehensive review of current journal articles and industrial reports. It provides an alternative, occupant-oriented perspective to the conventional discourse. A conceptual framework is developed, revealing that green building aspects are linked to six dimensions (three subjective and three objective) of occupant well-being. It further shows how different green features are linked with these dimensions through a detailed examination of the literature. Finally, suggestions are provided based on the research findings for the direction of future green building development and empirical research.

**Keywords:** green buildings; occupant well-being; healthy buildings; occupant-orientation; indoor environment conditions



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## 1. Introduction

Urban sustainability on multiple frontiers has been promoted in recent years, with the human-centered perspective receiving unprecedented attention and more stress on the utility, performance, and effectiveness of sustainable measures. These themes occur regularly, most recently in a series of international conferences and initiatives. The Habitat III New Urban Agenda is probably the most important, as it constitutes a more specific and feasible agenda for urban sustainability and highlights the importance of building an urban environment that contributes to the well-being of all residents. Occupant well-being has always been one of the issues in built environment sustainability, yet it has never become the focus of academic debate. However, in a new urban epoch where the built environment is playing an unprecedented crucial role in people's lives, this question needs to be examined more thoroughly and systematically.

Nevertheless, attempting to maximize the utility of the environment and contribute to the well-being of human beings is not a contemporary theme. Its seeds are buried in our civilization even at the earliest stage, thousands of years ago. The pursuit has never halted. For example, dating back to the warring state period (around the beginning of Anno

Domini) in China, the integration of human behaviors and spirit with the environment was considered the top priority of human well-being, which is the cornerstone of the popular Confucius and Taoist doctrines [1,2]. This view has not diminished in the process of rapid urbanization. Rather, it has mutated and adapted itself to the era of cities, arguing that the built environment now surpasses the natural environment and exerts an ever-increasing influence on the well-being of city dwellers [3,4].

This trend echoes with multiple global development consensuses and initiatives. For instance, the 11th Sustainable Development Goals (SDG) of the UN 2030 Agenda for Sustainable Development clearly states that city residents need to be provided with an “inclusive, safe, resilient and sustainable” built environment and to improve the well-being of the general citizens [5]. The Gallup poll in 2016 also indicates that the built environment is highly relevant to the overall well-being of occupants worldwide [6]. In effect, efforts have been maneuvered globally to enhance the well-being of occupants by encouraging more sustainable/greener design and construction technologies, leading to the flourishing of various green building schemes with little difference in regional characteristics. Green building certification, as one of the most universally adopted approaches to promote the sustainability of the built environment, therefore, needs to be revisited to see how, and to what extent, green buildings have contributed to the well-being of occupants. As a result, a group of academic researchers and professional practitioners at the cusp of the interface of social, environmental, and engineering studies has begun to investigate the influences of the built environment on people [7].

However, it should be noted that current research is still scattered, and there is remains a gap to fill. First, current research is mostly from a techno-engineering perspective and seldom from an occupant-oriented perspective. Second, occupant well-being is a very broad concept, with many different dimensions, covering a wide range of disciplines from engineering to sociobiology. Thus, current studies are mostly fragmented and isolated. Often, they simply deal with only one or some dimensions of occupant well-being and fail to evaluate the issue in a comprehensive and systematic manner. Most relevant research targets cases in a certain region or country, so the results may be less representative on a global scale. Third, as a multi-faceted concept, some dimensions of well-being are more subjective. To date, current research on such aspects is still lacking. Moreover, the benefits involved change over time, which is also an often-neglected area of study.

This paper provides a panoramic view of how green buildings contribute to different dimensions of occupant well-being by reviewing current journal papers and interdisciplinary industry reports. As shown in Figure 1, the renowned tripartite structure of sustainability is one of the most popular concepts in research into sustainable urbanization. Nonetheless, previous research into green buildings, although also addressing issues in these three aspects, is mostly drawn from impersonal perspectives. This paper aims to summarize the current research from a human-oriented perspective to investigate how and to what extent green buildings will contribute to occupant well-being. It is, therefore, meaningful to evaluate whether the steps taken to promote urban sustainability have really made a difference to the public in general. The second part introduces the method of this paper, explaining how the current literature is reviewed and reorganized in a more comprehensive and systematic manner. Section 3 examines the dimensions of well-being and reveals how different green building aspects are connected to the dimensions of well-being. Section 4 illuminates the way forward for green building development in the future by offering some practical suggestions. It also discusses possible prospects for future research into green buildings. Conclusions are made in the final section.

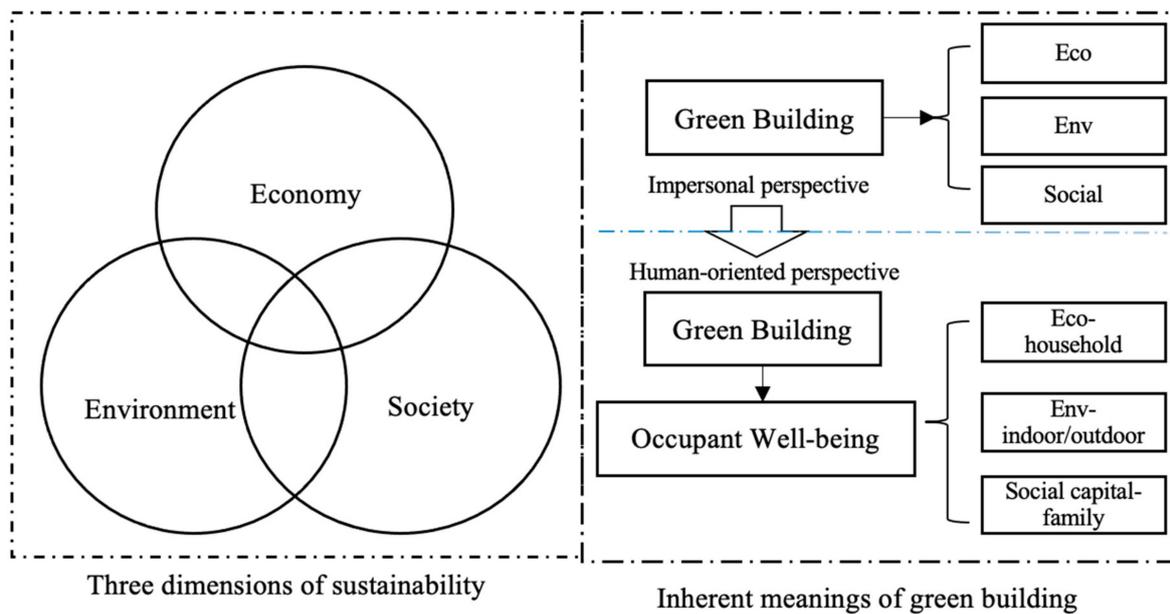


Figure 1. Inherent meanings shift from “Turning green into gold” to “Enabling green for well-being”.

## 2. Methods

The arguments in this paper are based on a systematic review of the current literature concerning green buildings and occupant well-being, including both academic journals and industrial reports. It needs to be highlighted that occupant well-being is a broad concept that covers various dimensions. However, green buildings are relevant to aspects of occupant well-being. Figure 2 reveals the roadmap of the research. To specify the conjunction of these two concepts, we need first to review the literature relating to the dimensions of well-being and see how they are connected to green buildings. In Section 3, a summary of the definitions and dimensions of well-being is followed by a review of general well-being relating to green buildings. The Web of Science™ is the primary source of the review. However, as articles on the overall impact of occupant well-being are rare (around a dozen in number), complementary reports from industry are also included to define the dimensions of well-being most relevant to green design and features. As a result, it is concluded that the conjunction of green buildings and overall occupant well-being (i.e., green features and design) will directly or indirectly affect the dimensions of well-being. These comprise reducing household expenditure (bill saving) on energy and water, physical health, indoor environment, mental health, occupant comfort, satisfaction, and way of life. It should be noted that the former three are objective dimensions while the latter three are more subjective.

Upon defining the six dimensions, journal articles in the Web of Science™ were searched using the keywords (and synonyms) of each dimension together with “green building”. Figure 3 shows the number of publications between 2005 and 2016 relating to each dimension. Publications prior to 2005 are not illustrated, as such themes are very limited. Some articles also simultaneously measure the mental and physical health of green building occupants, so the two types are combined together as “health”, yet as they belong separately to objective and subjective realms, a detailed discussion of the two dimensions is still made in two groups in the upcoming sections. However, research into how green buildings have changed the way of life and enhanced the social capital of the community is lacking. Though they are not illustrated in the figure, they are discussed as a distinct category in the following sections. It is clear that bill saving, which includes energy saving and water saving, attracts the most attention, but peaked in 2013. Although still the leading research topic in these dimensions, it is quickly being overtaken by research into other dimensions.

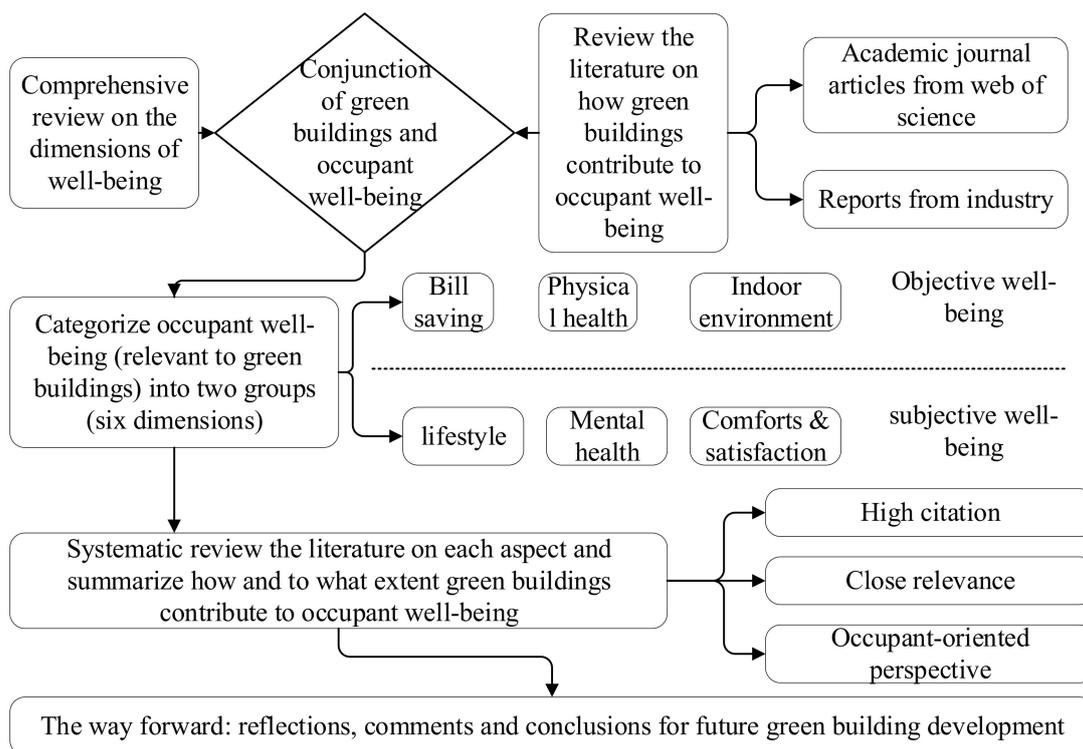


Figure 2. Process of the research design.

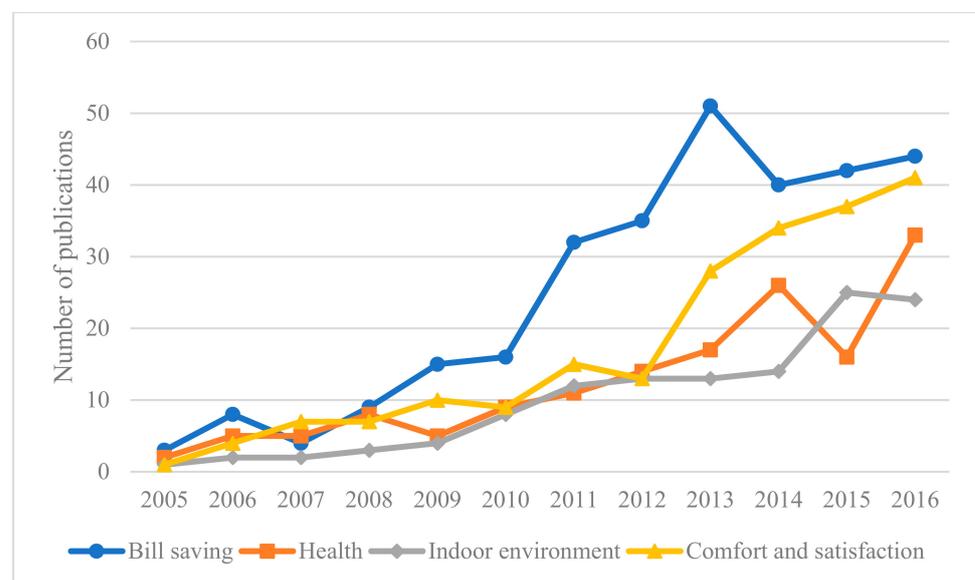


Figure 3. Annual publications of four dimensions of occupant well-being (Web of Science).

It also reveals that the focus has been shifting to more subjective and human-oriented issues, such as how green buildings increase occupant comfort, satisfaction, and health conditions. Publications concerning occupant comfort and satisfaction have constantly grown in recent years and may potentially surpass those of the conventional topics of energy and water saving in the near future. Occupant health has also been spotlighted, and related publications have dramatically increased in recent years, quickly catching up with the leading two groups. In addition, the study of indoor environmental quality has been growing steadily over the past decade. As Figure 3 indicates, current research resonates with the change in professional and political discourses most recently, gradually changing from an impersonal perspective to a human/occupant-oriented perspective.

Current research is, and will likely continue to be, more focused on such “soft” aspects as occupant health, comfort, and satisfaction. These retrieved journal articles, together with industry reports, are examined in more detail in Sections 3 and 4 following.

We created three criteria for the detailed review of all the literature collected (shown in Figure 2). First, highly cited journal articles were reviewed with priority, as they had the potential to be of higher quality. This standard did not apply to the industry reports. Second, several articles retrieved by keywords were not closely related to our analysis. Therefore, we selected those most closely connected to green buildings and well-being dimensions. Third, as we were trying to identify the overlaps between green design/features and occupant well-being, we highlighted the articles and reports with a human-oriented perspective. However, this is not an exclusive standard. We also include many articles with a technical/impersonal focus, which is particularly true for those concerned with energy and water saving. Detailed reflections on how and to what extent green buildings will improve occupant well-being are then provided as a result of the analysis, specifying how green features and designs exert an influence on different well-being dimensions. A conceptual framework is developed to facilitate the illustration in Section 3. Based on these reflections and the summary of the review, advice is provided for future green building development strategies.

### 3. Dimensions of Well-Being and Green Buildings

It is clear that the general well-being of occupants is a broad concept of which the aspects related to green buildings form only a subset. Well-being is a multi-faceted concept that can be understood from different perspectives. It can also be interpreted from various disciplinary backgrounds such as economics, philosophy, sociology, and psychology [8–12]. Therefore, although there are many different approaches to examining the concept of well-being, it is difficult to judge which is the best. Since the late 1980s, many attempts have been made from different disciplines to define the variables and indices constituting well-being [13–15]. Others tried to establish a well-being index with these variables and indices, but have not been generally accepted, as it is hard to create a system that merges these variables on the one hand, and meets the requirements of the wide range of well-being measures on the other [16]. However, a common practice is to categorize well-being into two subsets of objective and subjective, with the former covering such issues as physical health, social relationships, and environment conditions, and the latter encompassing mental health, satisfaction, etc. [17]. Neither of these two categories adequately serve the purpose to explain well-being alone and, as a result, a combination of the two is usually adopted to increase the reliability, validity, and consistency of the system [18].

The stress on occupant well-being is becoming more prominent as the sustainability discourse evolves into a new era, questioning how the newly emerged new towns, retrofitted areas, and innovative planning methods affect the well-being of people in cities [19,20]. Updated technologies, management approaches, and policy instruments have been constantly employed in the industry to improve people’s quality of life [21]. It seems that the built environment has an ever-bonding connection to occupant well-being. To date, green building schemes are perhaps the most universally adopted and accepted approach to promoting urban sustainability worldwide. As the built environment is so crucial to occupant well-being, green buildings can potentially make a significant difference from this perspective. There are many regional, national, and international standards practiced worldwide, including famous certifying schemes such as LEED, BREAM, and HK-BEAM (plus) [22,23]. Accordingly, decades of practice in the industry and intensive academic research provide both theoretical and empirical evidence of how green features, design, and technologies have improved occupant well-being.

After the review of several industrial reports and journal articles, we find that green buildings are closely related to many dimensions of occupant well-being. Although it may not be the most decisive factor in all aspects, it is certainly crucial. As is indicated by many studies, the employment of green features will create, on the one hand, cost premiums, but

on the other, extra benefits to many stakeholders [24]. This is a popular recurring theme in green building studies in recent years and resonates with many scholars [25,26]. However, the research is highlighted from the occupants' perspective and a review of the journals and reports of each specific dimension of the occupants' lives (shown in Figure 3). For instance, empirical evidence has shown that exterior and interior design, together with the adoption of other green features, are positively connected with the emotional and intellectual dimensions of well-being [27]. Hence, it is reasonable to argue that the built environment is supportive of the mental, psychological, and emotional functions of people. Many studies have revealed that green buildings tend to be better at saving energy and water, bill saving, and improving quality of life [28,29].

Many other minor aspects of occupant life might also be improved by green buildings. For example, that the green features will possibly enhance overall indoor environmental conditions, including air quality, lighting, and ventilation [30]. Consequently, the changes in these conditions will affect many other subjective dimensions of occupant well-being. Empirical studies have shown that green features are effective in improving the level of occupant comfort and satisfaction and boost productivity accordingly [31,32]. There is research revealing that green buildings will even enhance the social capital of the community and have a positive influence on the performance of schoolchildren [33,34]. They are also directly linked to the retired life of the elderly people in the community [35]. Despite these studies being rare, they provide meaningful reflections on how green buildings have changed the occupant-building relationship. It is commonly recognized that green design, technology, and features contribute positively to different subjective and objective dimensions of occupant well-being. The benefits of green features in the academic journals and industrial reports are directed at the aspects of occupant health, bill saving, better indoor environmental conditions, more comfort, and higher levels of satisfaction in general [8,14,27]. To understand this further, a more detailed discussion of green buildings and the dimensions of occupant well-being is required.

### 3.1. Green Buildings and Objective Well-Being

Many green features and techniques are highly relevant to the various dimensions of well-being. For instance, the indoor environment, including apartment conditions, daylighting, ventilation, microbial contamination, thermal comfort, and glare control as well as annual savings in energy and water bills are factors influencing objective well-being dimensions [36]. Figure 4 provides a conceptual representation of how the aspects of green buildings contribute to the different dimensions of occupant well-being, which outlines the structure of Section 3. Some of the connections are more direct and obvious (solid lines), while others are more indirect and subtle (dotted lines). Section 4 provides more discussion on how each aspect is related to the different dimensions of well-being.

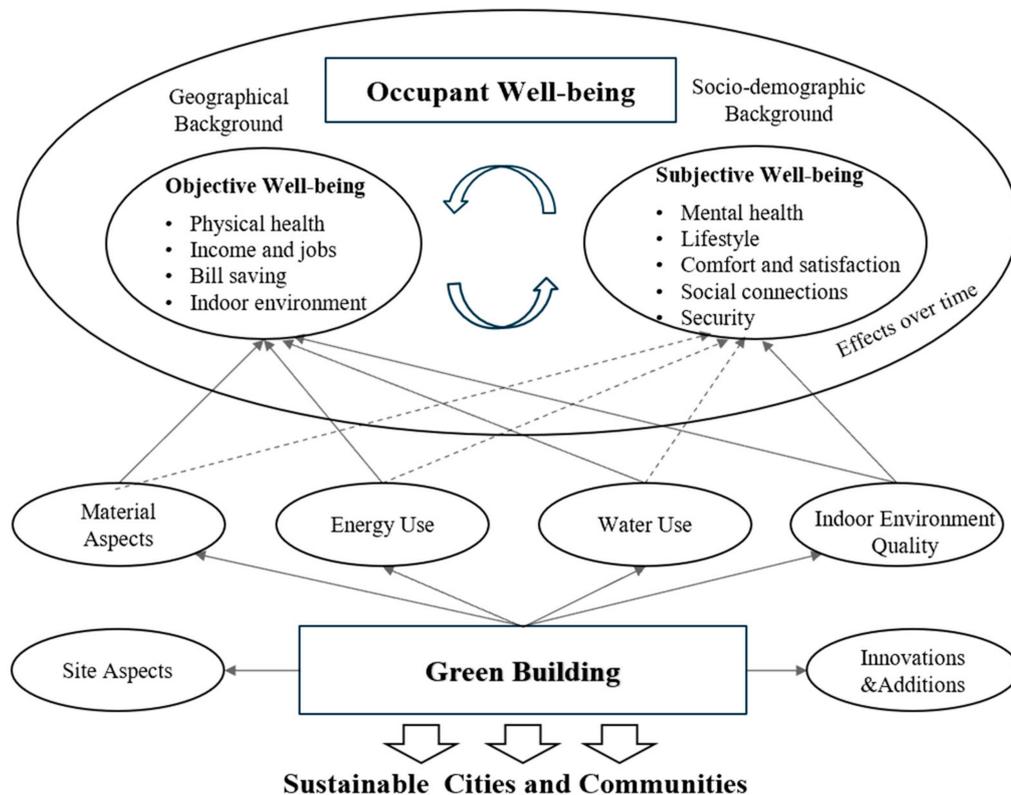
#### 3.1.1. Bill Saving Energy, Water, and Gas

Bill saving is most relevant to the studies of water and energy saving items and is the most intensively investigated dimension (over 300 articles shown in Figure 3). Green buildings also overtake conventional buildings in terms of energy/water efficiency and reduction in carbon emissions [37,38]. There is a total saving of around 30% of household consumption on such resources as water and energy throughout the building's life cycle [39]. Thus, green features provide financial benefits to households and directly improve their overall objective well-being.

#### 3.1.2. Physical Health

Health is a comprehensive issue that is affected by many other factors other than green buildings. However, empirical studies have investigated this in various ways. An example is a longitudinal study, tracing the health conditions of the same households before and immediately after they move into green buildings, with continuous follow up visits and surveys every 3 months/half a year for two or three rounds [40–42]. This found that the

overall health conditions improved after the move. Other studies have found a reduction in overall household spending on health services [42] and indoor environment-related diseases after green retrofitting residential buildings [43].



**Figure 4.** Conceptual framework for improvement in occupant well-being brought about by green housing.

### 3.1.3. Indoor Environment

Many green features and designs not only improve the physical health of occupants but also, with the stricter standards prescribed in green building schemes, provide an enhanced indoor living environment. Nevertheless, there are not as many studies on this topic as those involving financial improvements. Two separate studies have investigated indoor environment conditions, encompassing indoor environment quality, ventilation, lighting, and temperature as well as the facilities involved, concluding that the green buildings have better conditions than conventional ones [44,45]. Moreover, indoor environmental conditions have a significantly positive effect on the psychological and subjective well-being of occupants [46].

### 3.2. Green Buildings and Occupant Subjective Well-Being

In contrast, there is much less research into the subjective dimensions of green building occupants. The comprehensive review of the literature identified three recurring themes of occupant comfort and satisfaction, mental health, and lifestyle. Green building occupants should have a higher level of comfort due to better thermal conditions, for instance, and generally express a higher level of comfort and satisfaction with their living environment compared to their conventional counterparts [47,48]. This is not only the case with residential buildings but has also been repeatedly found in office buildings. American scholars [37,49] argue that green retrofitting buildings should reduce the level of mental disorders, and some studies of indoor environmental quality hint that green buildings benefit the mental state of occupants due to improved overall living conditions. Two surveys support this contention in indicating that residents of conventional buildings are exposed

to a higher level of noise and a poorer living environment, which provides a stimulus for a variety of mental disorders [40]. However, more empirical evidence is needed to generalize these conclusions to newly built green buildings in the future.

Furthermore, other aspects are classified as lifestyle, with green building residents in some cases predicted to have a healthier way of life and share an eco-friendlier consciousness than others [50,51]. However, such studies are more theoretical than empirical, and therefore more empirical studies need to be carried out in the future to determine the reasons and mechanisms involved. It is also intriguing to find that green features have a positive relationship with occupant productivity of both adults and schoolchildren alike [34] as well as the social capital of the community as a whole [35]. This and sporadic studies of other scattered issues are all categorized here into the lifestyle dimension in the subjective realm.

### *3.3. How Different Kinds of Green Features Contribute to Each Well-Being Dimension*

The primary stage of the literature review helped to confine the influence of green buildings into six dimensions, comprising bill saving, physical health, and indoor environment quality (objective well-being) and mental health, comfort and satisfaction, and lifestyle (subjective well-being). The next step was to identify the specific aspects that directly or indirectly influence each dimension of occupant well-being from the myriad of green designs and features available. Therefore, as indicated earlier, a search was conducted of all the keywords of green building and each well-being dimension and the articles with the three criteria reviewed. As is well known, most green building certifying schemes contain similar evaluation categories of material aspects (MA), energy use (EU), water use (WU), indoor environment quality (IE), site aspects (SA), and innovation and additions (ID) [52,53]. The names of these evaluation standards can vary in different schemes, but they share more similarities than differences. During the review process, we identified how these aspects linked to the dimensions of occupant well-being and summarized their relationships in Table 1. The full matrix is provided in Table A1 (Appendix A).

Some studies, particularly industry reports, have a wide enough scope to address almost all the dimensions of well-being. They discuss all the six aspects of green building schemes and generally how the different dimensions of well-being will be affected. However, such studies are mostly theoretical and unsystematic. More empirical evidence from other more detailed and targeted studies needs to be obtained to support the links between green features and well-being dimensions. For instance, the energy and water savings of green buildings is the aspect that has been most intensively discussed in the literature, arguing that green buildings have better energy performance and will reduce expenditure [37,38]. From Table 1, it is clear that the technologies and methods related to the standards of energy aspects, water aspects, and material aspects are of special importance for households' bill saving. Table A1 (Appendix A) provides a more vivid description of how these aspects link to expenditure reduction.

**Table 1.** Different green building aspects matched with the dimensions of occupant well-being (“+” denotes a positive relationship, T that the study is theoretical, and E empirical).

Well-Being	Green Features	R	E/T
Overall well-being	<b>Green buildings in general:</b> (Abrams [44]; Bay [46]; Bluysen et al. [54]; Taylor and Pineo [55]; WBI [50]; and WGBC [51])	+	T 5
	<b>Material aspects, indoor environment quality, and site aspects:</b> (Abrams [44]; Bay [46]; Bluysen et al. [54]; Taylor and Pineo [55]; WBI [50]; and WGBC [51])	+	T 5
	<b>Energy aspects:</b> (WBI [50]) <b>Water aspects:</b> (Abrams [44]; WGBC [51]; Taylor and Pineo [55]; and Ahn et al. [56]) <b>Innovations and additions:</b> (WBI [50]; and WGBC [51])		E 1
Bill-saving	<b>Material aspects:</b> (Eichholtz et al. [39]) <b>Energy aspects:</b> (Bordass et al. [57]; Dowson et al. [58]; Eichholtz et al. [39]; Gbadegesin et al. [59]; Ornetzeder et al. [27]; and Turner and Frankel [37]) <b>Water aspects:</b> (Cook et al. [60]; Eichholtz et al. [39]; and Meng et al. [61]) <b>Indoor environmental quality:</b> (Gbadegesin et al. [59]; Ornetzeder et al. [27])	+	E 8
Objective	<b>Physical health</b> <b>Material aspects and indoor environmental quality:</b> (Breyse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Jacobs et al. [63]; Jacobs et al. [64]; MacNaughton et al. [65]; Poland and Dooris [66]; and Ucci and Yu [67]) <b>Site aspects:</b> (Breyse et al. [40]; Ucci and Yu [67]; Jacobs et al. [63]; MacNaughton et al. [65]; Poland and Dooris [66]; and Coombs et al. [62])	+	T 1 E 8
	<b>Indoor environment</b> <b>Material aspects:</b> (Bluysen et al. [54]; Breyse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Jacobs et al. [64]; Jacobs et al. [63]; MacNaughton et al. [65]; Middel et al. [68]; Poland and Dooris [66]; and Ucci and Yu [67]) <b>Energy aspects:</b> (Altomonte and Schiavon [45]; Gbadegesin et al. [59]; and Ornetzeder et al. [27]) <b>Indoor environmental quality:</b> (Abbaszadeh et al. [69]; Altomonte and Schiavon [45]; Breyse et al. [40]; Colton et al. [70]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Gbadegesin et al. [59]; Hwang and Kim [71]; Jacobs et al. [64]; Jacobs et al. [63]; MacNaughton et al. [65]; Middel et al. [68]; Ornetzeder et al. [27]; Paul and Taylor [72]; and Poland and Dooris [66]) <b>Site aspects:</b> (Altomonte and Schiavon [45]; Gbadegesin et al. [59]; Ornetzeder et al. [27]; and Ucci and Yu [67])	+	T 1 E 18
Subjective	<b>Mental health</b> <b>Material aspects and Indoor environment quality:</b> (Breyse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Jacobs et al. [64]; Jacobs et al. [63]; and Poland and Dooris [66]) <b>Site aspects:</b> (Breyse et al. [40]; Jacobs et al. [63]; and Poland and Dooris [66])	+	E 7
	<b>Lifestyle</b> <b>Material aspects:</b> (MacNaughton et al. [65]) <b>Indoor environmental quality:</b> (Li et al. [22]; MacNaughton et al. [65]; and Xia et al. [47]) <b>Site aspects:</b> (Li et al. [22]; MacNaughton et al. [65]; Mutdoğan and Wong [73]; and Xia et al. [47]) <b>Innovations and additions:</b> (Li et al. [22]; Mutdoğan and Wong [73]; Pastor and Morello-Frosch [74]; and Zhao et al. [75])	+	E 7
	<b>Comfort and satisfaction</b> <b>Material aspects:</b> (Breyse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Jacobs et al. [63]; Poland and Dooris [66]; and Ucci and Yu [67]) <b>Energy aspects:</b> (Altomonte and Schiavon [45]; Gbadegesin et al. [59]; and Ornetzeder et al. [27]) <b>Indoor environmental quality:</b> (Abbaszadeh et al. [71]; Altomonte and Schiavon [45]; Breyse et al. [40]; Coombs et al. [62]; Fabian et al. [41]; Fabian et al. [42]; Gbadegesin et al. [59]; Hwang and Kim [72]; Jacobs et al. [63]; Kyu-in and Dong-woo [48]; Ornetzeder et al. [27]; Paul and Taylor [70]; Poland and Dooris [66]; Ucci and Yu [62]; and Xia et al. [47]) <b>Site aspects:</b> (Abbaszadeh et al. [71]; Altomonte and Schiavon [45]; Breyse et al. [40]; Gbadegesin et al. [59]; Jacobs et al. [63]; Ornetzeder et al. [27]; Paul and Taylor [70]; Poland and Dooris [66]; Ucci and Yu [62]; and Xia et al. [47])	+	T 1 E 14

Additionally, we retrieved 38 papers on the benefits to occupant physical health, typically involving multiple rounds of surveys to investigate the effects after green renovation [40,63]. Other studies have also confirmed the superiority of the indoor environmental and indoor air quality of green buildings [44,45]. However, all the studies only focus on certain aspects of green features such as indoor environmental quality, material aspects, and site aspects, which are closely linked with indoor air quality and the noise level of the environment, etc. These green features are also crucial for the overall indoor environment and some studies have investigated health issues (both physical and mental) together with indoor environmental quality.

In contrast, studies of subjective well-being due to green buildings are less proliferated although it should be highlighted that indoor environmental quality is the most important influence of all the green features on the three subjective dimensions of occupant well-being. Unlike the conventional techno-engineering perspective, which places greater stress on other green features and takes the building as an object, Table 1 reveals that the indoor environment is the fundamental factor affecting the subjective well-being of occupants. This is a new perspective for not only green building practitioners, but also for the standards and policymakers. Additionally, of note is that innovations and other aspects, although often neglected by researchers, are key to subjective dimensions such as lifestyle. Many innovative designs provide occupants with an inducement to change their lifestyle and enhance the eco-friendly consciousness urgently needed during the ongoing rapid urbanization process of many developing countries. The subjective dimensions are often underrepresented by the current green building standards and studies and yet are of key importance for the overall well-being of occupants.

#### **4. The Way Forward: Healthy and Sustainable Green Buildings for the Occupants**

Green buildings have acquired a global momentum in many different regions of the world, and many empirical and theoretical studies indicate they are indispensable for occupant well-being. In the coming era of cities, where most of the population lives in an increasingly green built environment, it is important to revisit how these designs, features, and technology will reshape occupant well-being. The comprehensive review of current research indicates that healthy buildings are likely to be a prominent aspect of future green buildings, as mental and physical health are pivotal dimensions of occupant well-being. On the one hand, more future empirical studies will help identify the most cost-effective green features for large-scale universal adoption. Current studies are all comparisons between green and conventional buildings. It would be equally meaningful for future research to investigate the differences between green buildings (at different grading levels or from different certifying schemes). On the other hand, more specific green building standards for hospitals, residences, and restaurants, for example, should be made to better cater for their separate functions. This has already been adopted in some certifying schemes, but the standards of material, site, and indoor environment aspects need to be further refined based on future empirical studies. Similarly, other assessment standards that apply throughout the construction and operation stages of buildings need to be developed in the future. Another potential merit of green buildings that have not been fully deliberated is their contribution to human capital. Many conventional green designs will substantially enhance the comfort and satisfaction of the occupants, indirectly promoting their productivity in some cases. This will be even more the case when conventional designs and technologies are combined with advancements in information and communication technologies, which enable smart interactions between inhabitants and green buildings. Under such circumstances, the green building becomes a live eco-environment that interacts and remolds the behaviors and lifestyle in the long run. Such subjective benefits are difficult to measure quantitatively by universal standards. The industry and government need to evaluate such aspects, which have always been hitherto understated. Moreover, many innovations, such as properly installed interactive facilities and designed green land in the community, will also strengthen the social capital of the community, which is a more important factor for

maintaining its sustainable development. To date, these are seen as a bonus without few detailed standards in the certifying schemes, and their relationship with potential aspects of occupant well-being need to be further studied.

Compared to the more subjective dimensions that have been gradually gaining recognition, research into the energy, water, and material aspects involved has been in its prime throughout the last decade. With more emphasis on passive designs in upcoming new technologies and materials, such studies seem destined to continue to boom. However, an alternative perspective to the conventional techno-engineering discourse needs to be provided. Examining how these technologies, designs, and features mold occupant lives and how they will improve their well-being will help answer the question: do green buildings make a difference to their occupants? Furthermore, it will make the general public feel how green buildings can work in their life and increase public awareness and participation. The essence of sustainability in urban eras is to promote a more sustainable way of life and an occupant-oriented perspective will make green buildings more inclusive and more easily understood by the general population.

Finally, all the benefits of different well-being dimensions are longitudinal. Figure 5 provides an illustration. Some of the reviewed studies show that the benefits in occupant health, for example, are cumulative and change over time. This is also the case with other dimensions. Therefore, it would be useful to have longitudinal studies examining the changes in benefits to different well-being dimensions in successive years. The benefits to occupant well-being may increase and stabilize at a certain level or, as indicated in Figure 5 (h), may further increase with the upgrading of future technologies. Similarly, most current studies focus on only one well-being dimension, and more comprehensive studies of more dimensions targeting the same sample of occupants over successive years will be rewarding for the future development of green building schemes.

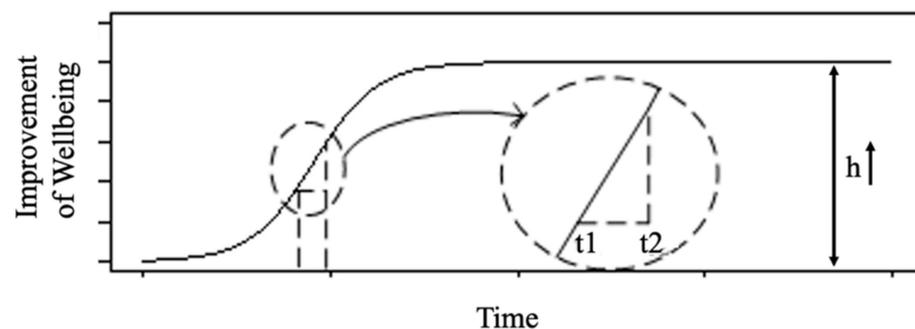


Figure 5. Longitudinal benefits to occupant well-being.

## 5. Conclusions

This paper provides an alternative occupant-oriented perspective to the techno-engineering centered discourse of green buildings in an era of cities. Greening of the buildings alone is a very different approach to promoting urban sustainability in general. In effect, it has remolded the lives of occupants in multiple ways and has been exerting an increasing influence on their well-being. A systematic and comprehensive perusal of current articles and reports reveals that green features and designs improve occupant well-being in both objective and subjective realms. Green buildings are potentially effective in making a difference to the occupants by improving their social, economic, physical, and psychological conditions. A conceptual framework is established to link the dimensions of well-being with green building rating criteria. The most recurring research theme is the material, energy, and water aspects as key factors in the economic well-being of occupants, as they reduce resource consumption while increasing energy efficiency. Other aspects discovered in the review are that, for instance, indoor environment, site aspects, and innovations will contribute considerably to the health and other subjective dimensions of

occupant well-being. This is much neglected and understated to date by both academia and industry. However, they are at least of equal importance for maintaining a sustainable life.

Three suggestions are proposed to better tailor green buildings schemes to the needs of their occupants and be more inclusive of the public in general. First, as has been promoted to some extent in some schemes already, green buildings should be healthy buildings with more detailed and specific standards for different building types. The target is to find diversified yet cost-effective standards benefiting both the psychological and mental conditions of the occupants. Another target is for green buildings to be socially sustainable to their occupants by investing in the human capital of the occupants as well as the social capital of the community—most likely to be the core of sustainable urban life in the forthcoming urban era. Such aspects as the site, innovations, and overall design should be clarified to promote the green awareness of the occupants and eventually precipitate a sustainable way of life. In addition, it should be noted that the benefits to occupants are most probably of a longitudinal nature. Therefore, green buildings need to be treated as an eco-environment that constantly interacts with their inhabitants, and the benefits involved are revisited both comprehensively and longitudinally.

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## Appendix A

**Table A1.** The influences of green building on different dimensions of occupants' wellbeing.

Citation	Title	Overall-Well-Being	Bill Savings	Physical Health	Indoor Conditions	Mental Health	Comfort and Satisfaction	Lifestyle	Overall Green Features	Material Aspects	Energy Aspects	Water Aspects	Indoor Environment Quality	Site Aspects	Innovations and Additions	Empirical/Theoretical	Relationship
World Green Building Council [51]	Health, Well-being & Productivity in Offices	1	0	1	1	1	1	1	1	1	0	0	1	1	1	T	+
International Well Building Institute [50]	The well buildings standard	1	0	1	1	1	1	1	1	1	1	1	1	1	1	T	+
Bluyssen [54]	Assessment of well-being in an indoor office environment	1	0	1	1	1	1	0	0	1	0	0	1	1	0	E	+

Table A1. Cont.

Citation	Title	Overall-Well-Being	Bill Savings	Physical Health	Indoor Conditions	Mental Health	Comfort and Satisfaction	Lifestyle	Overall Green Features	Material Aspects	Energy Aspects	Water Aspects	Indoor Environment Quality	Site Aspects	Innovations and Additions	Empirical/Theoretical	Relationship
Abrams et al. [44]	Making healthy places: designing and building for health, well-being, and sustainability	1	0	1	1	1	1	1	1	1	0	1	1	1	0	T	+
Bay [46]	TOWARDS A FOURTH ECOLOGY: Social and Environmental Sustainability with Architecture and Urban Design	1	0	1	1	0	1	1	1	1	0	0	1	1	0	T	+
Ucci and Yu [67]	Low-carbon buildings, health and well-being: current perspectives and critical challenges, Indoor Built Environ.	0	0	1	1	0	1	0	0	1	0	0	1	1	0	T	+
Turner and Frankel [37]	Energy performance of LEED for new construction buildings	0	1	0	0	0	0	0	0	0	1	0	0	0	0	E	+
Dowson et al. [58]	Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal	0	1	0	0	0	0	0	0	0	1	0	0	0	0	E	+
Eichholtz, Kok and Quigley [39]	The economics of green building	0	1	0	0	0	0	0	0	1	1	1	0	0	0	E	+
Bordass, Cohen, Standeven and Leaman [57]	Assessing building performance in use 3: energy performance of the Probe buildings.	0	1	0	0	0	0	0	0	0	1	0	0	0	0	E	+
Gbadegesin, Nna, Shitta, and Adegbenro [59]	Towards Increasing Energy Efficacy of an Old Building (A Case Study of the Main Auditorium of University of Lagos, Lagos, Nigeria.	0	1	0	1	0	1	0	0	0	1	0	1	1	0	E	+
Meng et al [61]	Virtual water accounting for building: case study for E-town, Beijing	0	1	0	0	0	0	0	0	0	0	1	0	0	0	E	+
Middel, Chhetri and Quay [68]	Urban forestry and cool roofs: Assessment of heat mitigation strategies in Phoenix residential neighborhoods	0	0	0	1	0	0	0	0	1	0	0	1	0	0	E	+
Cook, Sharma and Gurung [60]	Evaluation of alternative water sources for commercial buildings: A case study in Brisbane, Australia	0	1	0	0	0	0	0	0	0	0	1	0	0	0	E	+
Breysse et al. [40]	Health Outcomes and Green Renovation of Affordable Housing	0	0	1	1	1	1	0	0	1	0	0	1	1	0	E	+
Jacobs et al. [63]	Health and Housing Outcomes From Green Renovation of Low-Income Housing in Washington, DC.	0	0	1	1	1	1	0	0	1	0	0	1	1	0	E	+
Fabian et al. [42]	A simulation model of building intervention impacts on indoor environmental quality, pediatric asthma, and costs	0	0	1	1	1	1	0	0	1	0	0	1	0	0	E	+
Fabian et al. [41]	The effects of indoor environmental exposures on pediatric asthma: a discrete event simulation model	0	0	1	1	1	1	0	0	1	0	0	1	0	0	E	+
MacNaughton et al. [65]	Environmental perceptions and health before and after relocation to a green building	0	0	1	1	0	0	1	0	1	0	0	1	1	0	E	+
Poland and Dooris [66]	A green and healthy future: the settings approach to building health, equity and sustainability	0	0	1	1	1	1	0	0	1	0	0	1	1	0	E	+
Colton et al. [69]	Indoor Air Quality in Green Vs Conventional Multifamily Low-Income Housing	0	0	0	1	0	0	0	0	0	0	0	1	0	0	E	+

Table A1. Cont.

Citation	Title	Overall-Well-Being	Bill Savings	Physical Health	Indoor Conditions	Mental Health	Comfort and Satisfaction	Lifestyle	Overall Green Features	Material Aspects	Energy Aspects	Water Aspects	Indoor Environment Quality	Site Aspects	Innovations and Additions	Empirical/Theoretical	Relationship
Coombs et al. [62]	Indoor air quality in green-renovated vs. non-green low-income homes of children living in a temperate region of US (Ohio)	0	0	1	1	1	1	0	0	1	0	0	1	0	0	E	+
Jacobs et al. [64]	Moving Into Green Healthy Housing	0	0	1	1	1	0	0	0	1	0	0	1	0	0	E	+
Ornetzeder et al. [27]	User satisfaction and well-being in energy efficient office buildings: Evidence from cutting-edge projects in Austria	0	1	0	1	0	1	0	0	0	1	0	1	1	0	E	+
Kyu-in and Dong-woo [48]	Comparative study for satisfaction level of green apartment residents	0	0	0	0	0	1	0	0	0	0	0	1	1	0	E	+
Xia et al. [47]	Delivering sustainable communities: a case study in China	0	0	0	0	0	1	1	0	0	0	0	1	1	0	E	+
Paul and Taylor [70]	A comparison of occupant comfort and satisfaction between a green building and a conventional building	0	0	0	1	0	1	0	0	0	0	0	1	1	0	E	+
Altomonte and Schiavon [45]	Occupant satisfaction in LEED and non-LEED certified buildings	0	0	0	1	0	1	0	0	0	1	0	1	1	0	E	+
Abbaszadeh et al. [71]	Occupant satisfaction with indoor environmental quality in green buildings	0	0	0	1	0	1	0	0	0	0	0	1	1	0	E	+
Hwang and Kim [72]	Effects of indoor lighting on occupants' visual comfort and eye health in a green building	0	0	0	1	0	1	0	0	0	0	0	1	1	0	E	+
Li et al. [22]	Green Building and Social Sustainability: Study on Mosuo Folk Housing in China	0	0	0	0	0	0	1	0	0	0	0	0	1	1	E	+
Mutdoğan, Selin and Wong [73]	Towards Sustainable Architecture: The Transformation of the Built Environment in Istanbul, Turkey	0	0	0	1	0	0	1	0	0	0	0	0	1	1	E	+
Li [34]	Impact of housing design factors on children's conduct at school: an empirical study of Hong Kong	0	0	0	1	0	0	1	0	0	0	0	1	1	0	E	+
Pastor and Morello-Frosch [74]	Integrating Public Health And Community Development To Tackle Neighborhood Distress And Promote Well-Being	0	0	0	0	0	0	1	0	0	0	0	0	1	1	E	+
Zhao et al. [75]	Social problems of green buildings: From the humanistic needs to social acceptance	0	0	0	0	0	0	1	0	0	0	0	0	1	1	E	+

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