

LOW-ENERGY DESIGN METHODS AND ITS IMPLEMENTATION IN ARCHITECTURAL PRACTICE: STRATEGIES FOR ENERGY-EFFICIENT HOUSING OF VARIOUS DENSITIES IN TEMPERATE CLIMATES

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ABSTRACT

With mounting concerns over climate change and urban population growth, the demand for sustainable housing based on low-energy designs is steadily increasing. A variety of low-energy design methods have been developed to reduce energy and resource consumption; however, research shows that the implementation of such methods has been surprisingly limited. In addition, while the degree of housing density is understood to have an impact on low-energy designs, what that impact is and how it can be strategically applied have not been adequately researched. This research examines how low-energy designs are applied in housing types with various densities in temperate climates, identifies the issues and problems pertaining to the implementation of passive and active design strategies. This research uses a survey, which asks design practitioners to rate the merits of various low-energy design strategies and assesses how often these approaches are implemented in practice. The study uncovers discrepancies between perceived importance of low-energy design aspects and their practical implementation, finding that certain low-energy strategies can be more effective when they are incorporated in an early stage of the design process.

KEYWORDS

sustainable housing; low-energy design; design implementation; perceived importance; temperate climate

INTRODUCTION

As population and environmental concerns increase, the demand for sustainable, low-energy housing is becoming increasingly urgent. In order to promote low-energy designs in architectural practices, studies on passive and low-energy designs have been proposed in various countries (Cheung et al. 2005; Givoni 1994; Watson and Labs 1983). However, little research has

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been conducted on the effective implementation and adoption of low-energy design strategies in relation to housing density. The term “low-energy” is often not clearly defined in many projects and studies (Abel 1994). It can mean “zero energy” requirements or reduced energy consumption (Hui 2001). The concept of low-energy design is linked to significantly reduced energy consumption relative to current building energy standards. Low-energy building designs combine energy-conservation strategies and energy-efficient technologies to reduce energy demand and to meet any remaining energy requirements as efficiently as possible.

Maximizing the energy efficiency of buildings, particularly in temperate climates, usually requires a combination of both passive and active low-energy design strategies. To a large extent, the density of a building influences the optimal combination of strategies, whether it is a passive or an active low-energy design. However, the way in which sustainable housing, density, and low-energy designs relate to one another is an unexplored topic, partly because very few large-scale sustainable developments have been completed, whereas much less has been documented.

A variety of low-energy design methods have been developed to reduce energy and resource consumption; however, research shows that the implementation of such methods has been surprisingly limited (Baden et al. 2006; Blomsterberg 2010). In addition, while housing density is understood to have an impact on low-energy design, what that impact is and how it can be strategically applied have not been adequately researched. This study examines how low-energy designs are applied in housing of various densities, identifies issues and problems related to the implementation of passive and active design strategies, and proposes methods to incorporate low-energy passive designs more effectively. In this research, a survey is designed and administered, asking respondents to rate the importance of various low-energy design strategies as well as how often they are implemented in practice.

The central purpose of the present study is to investigate design practitioners’ decisions regarding low-energy designs as well as the rationale and the outcomes associated with such decisions. In summary, the goals of the survey are to complete the following:

- Highlight the relationship between housing density and passive and active design methods.
- Investigate whether the perceived importance of low-energy design strategies is consistent with the application of these strategies in practice.
- Identify the obstacles to implementing certain low-energy design strategies in sustainable housing design practices.

The research aims to reveal how design practitioners perceive the importance of low-energy strategies in relation to the densities of their project. Despite the increasing popularity and known benefit of “green” or “sustainable” designs, design practitioners often face obstacles to the actual implementation and adoption of these approaches. We strive to identify the difficulties associated with lower-energy design implementation and to offer promising strategies to overcome these difficulties for design practitioners.

LITERATURE REVIEW

Previous studies have looked at the relationship between housing density and energy consumption (Banister et al. 1997; Cheung et al. 2005; Frank and Pivo 1994). Generally, high-density developments with compact buildings are regarded as sustainable low-energy approaches (Jones

and Hudson 1998; Thomas and Ritchie 2003). However, the effects of the degree of urban density on the total energy demand of a city are conflicting and complex (Givoni 1998), as there are numerous entwined energy issues with regard to density. For example, there is transportation energy consumption caused by building and urban design patterns and building energy consumption caused by equipment, systems and materials (Hui 2001). While prior research has primarily focused on the energy consumed through transportation on an urban scale (Banister et al. 1997; Frank and Pivo 1994; Golob and Brownstone 2005; Mindali et al. 2004), few studies have investigated energy consumption at the level of urban planning. Therefore, to bridge the gap between studies of energy consumption at the urban planning level and current residential energy consumption metrics, it is important to also study low-energy designs both at the building and master plan levels in relation to housing density.

Low-energy housing is not just the result of applying one or more isolated technologies; rather it is an integrated whole-building process, including passive and active low-energy design approaches (Table 1). Most large-scale, green buildings integrate passive and active design methods. A passive design method does not require mechanical heating or cooling. Therefore, completely passive systems use no purchased energy. An active system has essentially the opposite characteristics. Active design strategies are the building system technologies that are predominantly powered by generated energy sources and contain motorized components.

For designing low-energy systems, Yeang (2006) breaks down passive and active strategies into five categories: passive mode or bioclimatic design, mixed mode, full mode, productive mode, and composite mode. Examples of passive mode strategies include adopting

TABLE 1. Passive and Active Low-Energy Design Strategies.

Passive Design Strategies	Active Design Strategies
Passive Heating <ul style="list-style-type: none"> • Solar Geometry • Building Orientation • Shape of the building (plan, Section) • South-facing glazing • Thermal mass for storing heat • Minimising heat loss with insulation • Draught sealing and advanced glazing. • Proper floor plan zoning Passive Cooling <ul style="list-style-type: none"> • Maximize natural ventilation • Shade (natural or architectural) to control heat gain • Building orientation • Shape of the building to control air flow • Thermal mass Daylighting <ul style="list-style-type: none"> • Daylight-optimized building footprint • Daylight-optimized window shape and placement • Climate-responsive window-to-wall area ratio • Daylight redirection devices 	Energy Efficient Heating and Cooling Equipment <ul style="list-style-type: none"> • Heat exchanger • Heat recovery system • Combined heat and power (CHP) • CHP with district heating and cooling • Thermal storage • Heat pumps for space heating and cooling Computerized Building Control Systems Renewable Energy Use <ul style="list-style-type: none"> • Active Solar • Geothermal • Wind

appropriate building configurations and orientation in relation to the locality's climate, appropriate façade design, solid-to-glazed area ratio and suitable thermal insulation levels, use of natural ventilation, and use of vegetation. Mixed mode is where some electro-mechanical (M&E) systems such as ceiling fans, double façades, flue atriums, and evaporative cooling are used. In full mode, fully active systems such as conventional mechanical and engineering systems are used. Productive mode is where the built system generates its own energy (e.g., solar energy using photovoltaic system, or wind generators, etc.). Composite mode combines of all the above modes and is a system that varies over the seasons of the year.

According to Jones (1998), there are various ways to provide comfort depending on climate conditions. Passive design can provide comfort without using mechanical or electrical systems. Therefore, in good bioclimatic design, passive design is primarily employed, then supplemented with active design (Jones 1998). Yeang (2006) also suggested using passive mode for improved comfort conditions over external conditions and supplementing with mixed or full mode.

Battle McCarthy's Solar City report (1995) describes in detail how the development's passive and active design strategy was employed. In low-density housing, energy management depends on the building's orientation towards the south. In addition, more than 30% window-to-floor area ratio is indispensable to having passive solar radiation and natural ventilation. Residents should have the ability to control shading and insulation systems and thermal mass should be included. A wind block, shade from trees, and natural cooling by water are also possible as passive strategies through site design. On the other hand, in high-density housing, the building orientation is less important than in low-density housing, but the level of thermal mass or insulation should be high. A forty degree obstruction in solar accessibility increases heating energy use due to overshadowing by about 20%. This can be compensated for by energy recovery or a high level of insulation. In winter, it is necessary to have mechanical ventilation with heat recovery, airtight construction and windows. In high-density housing, buildings themselves serve as wind shields and provide shade. In the case of mixed-density housing, both passive and active methods can be employed.

Regarding the adoption of low-energy designs, a few researchers have investigated barriers to low-energy building implementation. Blomsterberg (2010; 2011) identifies technological and non-technological barriers to the implementation of low-energy residential buildings in northern European countries. Those countries, such as Sweden, Finland, Denmark, Norway, Poland, Latvia, Estonia and Lithuania, have implemented only a relatively small number of low-energy buildings. While some of the countries have an official definition or standards for low-energy buildings, which are mainly passive houses, other countries have no such definition or standards. Blomsterberg conducts problem detection studies, targeting the participants—the designers, the building industry and building authorities—of the low-energy buildings in each country. He finds barriers commonly in four areas: markets, requirements/regulations, knowledge, and costs. However, he argues that these barriers can be overcome by developing common legislation/standards/specifications for low-energy buildings, improving the educational level of designers and contractors, and publishing more good examples as benchmarks.

Some studies have focused on the adoption of low-energy design standards, such as Leadership in Energy and Environment Design (LEED). One study, relying on the principles of innovation adoption theory, inventories and analyzes decision-support tools related to the green building design process (Keysar and Pearce 2010). This study finds, among many available decision-support tools, that only a small number of them are applicable to LEED

projects. Investigating the policy aspects of LEED adoption in the U.S., Retzlaff (2009) argues that LEED-related government requirements and incentives are very narrowly applied, therefore positing that planners should play an important role in administering green design policies from a holistic and integrative perspective. Hart (2009), examining the role of public policymakers in improving the efficiency of LEED, argues the need for government intervention or support to facilitate the market transformation toward green buildings. Corbett and Muthulingam (2007) examine the adoption process of 442 LEED-certified buildings and find that green building standards tend to be adopted through interaction between signaling—an organization's wish to communicate their green design practices—and intrinsic benefits—the expected economic and environmental benefits.

Despite the many previous studies on the adoption of green building designs, few studies have investigated the barriers or obstacles, particularly during the design process, to low-energy building adoption and implementation. Our research fills this gap, specifically focusing on the importance of and obstacles to low-energy designs as perceived by design practitioners during their design and implementation process.

Based on the literature review, we address the three research questions as follows:

Is the perceived importance of passive and active design methods by design practitioners correlated with their projects' density? Housing density is critical in determining whether a particular passive design strategy should be applied alone or in combination with an active design strategy. Overall, building energy consumption can be reduced through a considered application of passive design, and the efficiency of the passive design techniques that are adopted depends on the density of the buildings. Hence, we hypothesize that design practitioners perceive that passive design methods are more efficient in lower densities, while active design methods work best in higher densities.

Is the perceived importance of low-energy design strategies consistent with the application of these strategies in practice? Despite growing interest in low-energy buildings in the field of architecture, there are various barriers to low-energy building implementation (Blomsterberg 2010; 2011; Keysar and Pearce 2010). Due to the barriers, it is expected that the levels of low-energy design implementation are lower than the perceived importance levels of low-energy design strategies.

What are the obstacles to implementing certain low-energy design strategies in sustainable housing design practices? Based on the literature review and preliminary interviews, we expect barriers in four areas: clients (markets), requirements/regulations, knowledge, and costs.

METHODS

In order to collect the data pertaining to the perceived importance and implementation of low-energy design strategies, we surveyed design practitioners, including architects and consultants with experience in sustainable housing projects of low, medium, and high density levels. The data was compiled by consolidating various lists of passive and active design strategies. The respondents were asked to choose one sustainable housing project that they had worked on and to answer the survey questions based on that experience. They rated the importance and frequency of the implementation of each strategy. Some questions were open-ended in order to elicit original responses rather than have the respondents choose from a list of possible answers. The collected data was analyzed using descriptive statistics and tau-b, which estimates the associations between ordered measures.

Survey Instrument

To develop a survey instrument, we conducted interviews during the first stage of the research to clarify issues and problems surrounding housing density and sustainability. Based on the main themes, issues, and concepts discussed during the interviews, the survey instrument was developed to investigate the factors that impact the implementation of low-energy designs. The instrument contained 25 questions of two different types: structured (fixed-response) questions and non-structured (open-ended) questions. Structured questions offered a closed set of responses from which the respondent can choose and include questions with rating scales based on Likert scales. Open-ended questions were used to gain more insight into respondent opinions about a subject. The survey questions were divided into three sections: (1) participants' background, (2) general project information, and (3) participants' perceived importance and actual implementation of low-energy design strategies. In order to improve the validity and reliability of the instrument, we tested the questionnaire in advance with a small number of architects. The instrument was revised, reflecting their responses. However, the responses to the pilot survey were excluded from the final dataset.

The invitation to participate in the survey was sent by email and recipients were asked to forward the survey link to colleagues who also had experience in the design of sustainable housing projects. Survey participants were asked to complete a 15- to 20-minute survey by the iCommons Poll Tool, a web-based survey tool developed by Harvard University.¹ Online surveys have a number of advantages over in-person, mail, or telephone surveys. They allow for immediate access to individuals who are in distant locations or otherwise difficult to reach, and provide the convenience of automated data collection, thus reducing researcher time and effort (Fawcett and Buhle Jr 1995). The iCommons Poll Tool enables the distribution of the questionnaire and the review of results online. The tool also allows researchers to download the results into tab-delimited spreadsheets.

Participants

Rather than being randomly selected, respondents with extensive experience in and knowledge about sustainable housing projects in temperate climates were chosen to participate. The list of potential respondents was obtained by searching through LEED-certified housing lists, well-known sustainable consulting firms worldwide, and sustainable housing development organizations found on the Internet. Although our population is small with not many low-energy buildings, at least 30 correspondents were required to ensure the reliability of the survey. Thirty responses provide an acceptable level of accuracy only if the researcher (1) has a very small population overall, (2) has very little variance in the responses, and (3) is willing to accept very low accuracy (Bennekorn 2002). We contacted 70 respondents in total, and 34 of them returned a completed questionnaire, yielding a 50% response rate.

Among the 34 respondents, 72% had over ten years of experience in their field, and 24% had over 20 years of experience. The respondents included project architects (50%), project designers (15%), project managers (3%), and environmental consultants (29%). In addition, a majority of the survey participants were extensively involved in projects throughout the design process, from concept design (79%), schematic design (82%), and design development (82%). About half of the participants were involved in construction documentation (59%), bidding (44%), and construction administration (44%). Considering that low-energy design

¹Available at <http://surveytools.harvard.edu>

TABLE 2. Rational for Applying Low-Energy Design Strategies.

Categories (Code)	%	(Freq.)	Categories (Code)	%	(Freq.)
Previous experience			Consultant's opinion		
Mean:4.3			Mean:4.1		
Never (1)	0	(0)	Never (1)	0	(0)
Rarely (2)	2.9	(1)	Rarely (2)	11.8	(4)
Sometimes (3)	8.8	(3)	Sometimes (3)	17.7	(6)
Very Often (4)	47.1	(16)	Very Often (4)	23.5	(8)
Always (5)	41.2	(14)	Always (5)	47.1	(16)
Rule of thumb			Design guidelines (LEED, etc.)		
Mean: 3.9			Mean: 3.8		
Never (1)	0	(0)	Never (1)	0	(0)
Rarely (2)	0	(0)	Rarely (2)	12.5	(4)
Sometimes (3)	36.7	(11)	Sometimes (3)	15.6	(5)
Very Often (4)	33.3	(10)	Very Often (4)	53.1	(17)
Always (5)	30.0	(9)	Always (5)	18.8	(6)
Computer simulation			Physical model		
Mean: 3.8			Mean: 2.7		
Never (1)	0	(0)	Never (1)	6.7	(2)
Rarely (2)	15.2	(5)	Rarely (2)	40.0	(12)
Sometimes (3)	18.2	(6)	Sometimes (3)	36.7	(11)
Very Often (4)	42.4	(14)	Very Often (4)	13.3	(4)
Always (5)	24.2	(8)	Always (5)	3.3	(1)

strategies are developed throughout the various stages of the design process, participants were well qualified to respond to this survey based on their practical experience.

Table 2 shows the design method relied on by the respondents for low-energy designs. The five categories—Never, Rarely, Sometimes, Very Often, and Always—are coded as 1, 2, 3, 4, and 5, respectively. Low-energy design decisions were heavily influenced by previous experience and the opinions of environmental specialists who served as consultants on projects. Therefore, consultant responses from this survey, as well as those from architects, are expected to provide valuable information on low-energy design practices.

Data

The surveys were distributed fairly evenly to sustainable design practitioners in North America and Europe. Most responses were received from Europe, especially from Germany and the United Kingdom. For that reason, about half of the projects (52%) were located in Europe and 38% were located in North America. Ten percent of the projects were located in Asia but were designed by North American or European firms, demonstrating the spread of low-energy design knowledge across the globe.

In the projects discussed in this survey, the number of units varied as follows: fewer than fifty (48%), fifty to one hundred (10%), one hundred to two hundred (3%), two hundred to three hundred (14%), three hundred to four hundred (14%), and over five hundred (10%). Although about half of the surveyed projects have fewer than fifty units, this does not mean that these projects are developed on a small scale. Large-scale developments involve several zoning lots planned as a unit on a tract of land that is either (1) at least three acres (1.2 hectares) with a minimum of five hundred dwelling units, or (2) at least 1.5 acres (0.6 hectares) with a minimum of three principal residential buildings (New York City Department of City Planning 1980). Land for sustainable housing developments is typically divided into several lots and many small housing complexes designed by various architects, as developers aggregate their plans to promote diversity.

More than half of the sustainable housing projects in this survey were built by private developers. Twenty-one percent were developed by public-private partnerships, 10% by municipalities and 7% by cooperative housing associations. Although sustainable housing tends to be costlier to construct, the demand for it is high, and private developers are evidently the primary beneficiaries of this trend.

Analysis

We assigned numeric integers to the three- or five-point scales (for example 1 to Not Difficult, 2 to Less Difficult, 3 to Moderately Difficult, 4 to Difficult, and 5 to Very Difficult) and used descriptive statistics to analyze the data. Then, tau-b statistics, a measure of ordered correlation, was used to test the association between density and the effectiveness of low-energy strategies as well as between the perceived importance levels and actual implementation levels of the design approaches. The tau-b coefficients range from -1 (100% negative association, or perfect inversion) to $+1$ (100% positive association, or perfect agreement). A zero tau-b coefficient indicates no association between two variables. Stata 11 was used to calculate tau-b coefficients and associated z-values to test for statistical significance. Generally, the interpretation of the strength of the tau-b coefficients is as follows: less than 0.10: very weak; 0.10 to 0.19: weak; 0.20 to 0.29: moderate; and 0.30 and above: strong (Meier et al. 2011). The formula for computing tau-b (τ_b) is shown below.

$$\tau_b = \frac{N_s - N_d}{\sqrt{(N_s + N_d + T_x)(N_s + N_d + T_y)}}$$

Here, N_s is the number of same pairs, N_d is the number of different pairs, T_x is the number of pairs tied on the variable X, and T_y is the number of pairs tied on the variable Y.

FINDINGS

The relationship between housing density and passive and active design methods

Housing density of the participants' projects is categorized as low, medium, and high (coded as 1, 2, and 3, respectively), depending on building height and typology. For the purposes of this survey, low-density housing refers to single detached, row houses, town houses, and three-story walk-ups. Mid-density housing refers to six-to-thirteen-story elevator apartment or condominium buildings. High-density housing is an elevator apartment or condominium

building of more than thirteen stories. The number of questionnaires received per density type was 13 for low (38.2%), 9 for medium (26.5%), and 12 for high (35.3%).

Responding to a question about the relationship between housing density and the importance of passive and active strategies, the majority of the participants (38%) believed that active strategies become more important as density increases, while approximately half of that percentage (17%) stated that passive strategies become more important as density increases. Thirty-one percent of the respondents answered that the balance of active and passive strategies changes as density increases but exactly how depends on the project. On the other hand, 14% said that there is no change in balance between passive and active strategies as housing density increases.

More specifically, the respondents described the most effective passive or active design methods that they employed in their projects. The results demonstrate that there are certain low-energy strategies that work well for specific density levels. In low densities, 58% of participant responded that passive solar strategies worked most effectively. Respondents also indicated that having good insulation (41%), natural ventilation (33%), high thermal mass (33%), and the application of active solar technology (33%), such as photovoltaic and solar collectors, works well in low-density housing. In high-density housing, 45% of survey participants said that heat exchange system was the most effective. Some mentioned that improved glazing systems (27%), geothermal (18%), and high performance facades (18%) also worked well. However, there were no specific low-energy design methods that all participants agreed upon in high densities.

Table 3 shows the distribution of the responses on the importance of passive and active methods as well as the association between density of their projects and the importance of the design methods in general. The three categories (Slightly Important, Important, and Very Important) are coded as 1, 2, and 3, respectively. The average perceived importance of the passive and active design methods are almost equally high (2.8 and 2.7, respectively), indicating that passive and active design methods are perceived as almost equally important in achieving energy efficiency. The tau-b coefficient of the density-passive design is negative, meaning that respondents tend to perceive passive design methods are more important when the density of their project is low. However, this association is not statistically significant at the

TABLE 3. Association between Density and Perceived Importance of the Design Methods (Passive and Active).

Importance of Design Methods				
	Importance of Passive Design Methods	Density- Passive Design Association	Importance of Active Design Methods	Density- Active Design Association
Categories (Code)	% (freq.)	tau-b (z)	% (freq.)	tau-b (z)
Slightly Important (1)	5.9 (2)	-0.23 (-1.53)	8.8 (3)	0.05 (0.32)
Important (2)	11.8 (4)		14.7 (5)	
Very Important (3)	82.4 (28)		76.5 (26)	

TABLE 4. Association between Perceived Importance and Actual Implementation of Sustainable Design Aspects.

Importance of Elements in Achieving Sustainable Housing Development			Extent of actual Implementation			Importance-Implementation Association	
Categories (Code)	%	(Freq.)	Categories (Code)	%	(Freq.)	tau-b	(z)
a. Energy efficiency (passive design, renewable energy, waste reuse, etc.)							
Mean: 4.9			Mean: 4.7			0.25	(1.38)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	0.0	(0)	Not very (2)	2.9	(1)		
Moderately Important (3)	0.0	(0)	Implemented (3)	2.9	(1)		
Important (4)	8.8	(3)	Somewhat (4)	20.6	(7)		
Very Important (5)	91.2	(31)	Very Much (5)	73.5	(25)		
b. Ecology (green space, green network, etc.)							
Mean: 4.4			Mean: 4.1			0.35	(2.56)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	0.0	(0)	Not very (2)	2.9	(1)		
Moderately Important (3)	8.8	(3)	Implemented (3)	23.5	(8)		
Important (4)	47.1	(16)	Somewhat (4)	32.4	(11)		
Very Important (5)	44.1	(15)	Very Much (5)	41.2	(14)		
c. Environment (fit into the natural surrounding context, etc.)							
Mean: 4.3			Mean: 4.0			0.28	(2.06)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	0.0	(0)	Not very (2)	8.8	(3)		
Moderately Important (3)	8.8	(3)	Implemented (3)	23.5	(8)		
Important (4)	50.0	(17)	Somewhat (4)	29.4	(10)		
Very Important (5)	41.2	(14)	Very Much (5)	38.2	(13)		
d. Sociability (sense of community, identity, diversity, etc.)							
Mean: 4.4			Mean: 4.2			0.10	(0.60)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	0.0	(0)	Not very (2)	2.9	(1)		
Moderately Important (3)	8.8	(3)	Implemented (3)	26.5	(9)		
Important (4)	38.2	(13)	Somewhat (4)	23.5	(8)		
Very Important (5)	53.0	(18)	Very Much (5)	47.1	(16)		

0.05 alpha level. Lastly, the analysis identified a positive, albeit a very weak and insignificant, association between density and perceived importance of active design methods.

The relationship between the perceived importance of low-energy design strategies and their application in practice

The result in Table 4 indicates that the importance of design aspects, such as energy efficiency, ecology, environment, and sociability, perceived by design practitioners is relatively high. The importance of energy efficiency is rated as the highest by respondents, while the importance of sociability, ecology and environments are rated lower. The tau-b coefficients indicate that the perceived importance of sustainable design aspects is positively associated with the extent to which they are implemented in practice. However, while the tau-b coefficients of ecology and environments are statistically significant, those of energy efficiency and sociability are insignificant.

The survey responses (Table 5) indicate that building insulation, the quality of construction, and active design strategies such as energy-efficient mechanical systems are the most important strategies for achieving energy efficiency. Interestingly, the quality of construction is considered to be very important, thus demonstrating that quality control of low-energy strategies should extend beyond the design phase. Passive design elements, such as solar accessibility, ventilation, the building's orientation and layout, and window locations, are also considered to be highly important. The concepts of building compactness, building depth, and building height are rated fairly low on the importance scale.

The tau-b coefficients and z-values in Table 5 reveal that there is a discrepancy between the perceived level of importance of a given design element in achieving energy efficiency and its implementation. In particular, the level of implementation of passive design elements such as solar accessibility, the building orientation and layout, and window locations are lower than their perceived importance. Also, the association between the perceived importance of passive design elements, e.g., solar accessibility, ventilation, building orientation and layout, and window locations, and their implementation are not statistically significant. This result implies that basic passive designs and building form strategies such as the building orientation and layout were considered to be important but tended to be integrated less into the design.

The importance of design elements that are related to building compactness, including the surface-area-to-volume ratio, the building depth, and the building height, are statistically significantly associated with their implementation levels. However, this may result from these elements' relatively lower levels of perceived importance. Lastly, active design elements such as energy-efficient mechanical systems have a high level of importance and are statistically significantly associated with their level of implementation. Overall, the survey results demonstrate that there is considerable difficulty in actually applying passive design methods.

Obstacles to implementing certain low-energy design strategies in sustainable design practices

Among the nine obstacles to low-energy design shown in Table 6, budgetary considerations, such as a tight budget and a high initial cost and value, rank as the most difficult obstacles. Other difficulties, such as a lack of knowledge, clients who are unwilling to take risks, a tight schedule, and zoning regulations, are also considered as critical obstacles to low-energy designs. On the other hand, a lack of design guidelines as well as design requirements set by the client and a lack of interest in the client are evidently not especially difficult obstacles to overcome.

Respondents describe specific difficulties in adopting low-energy methods. One of the comments points out budgetary constraints: “In this high-cost environment, a building facade system with a high insulation level was used but was not the best insulation system due to cost and union concerns.” Another respondent emphasizes strict zoning regulations, stating, “The building form is completely constrained by zoning. Zoning basically dictates the box into which the building must fit” and that “The footprint was identified by a previous master plan... thus, the building runs north and south along the east edge of the new quad instead of having a more preferable solar orientation.” Another respondent notes that “there was no choice on the site for building form-related passive design elements such as those related to solar accessibility, building orientation and layout, building compactness, the building’s depth, and the building’s height.”

Despite the obstacles, the survey indicates that the consideration of low-energy design elements in the earlier stages of the design process, such as the pre-design, concept design, schematic design, and design development stages, is more effective and has greater potential to save energy than their application at later stages of the process (Table 7). The implementation of low-energy design at later stages, such as the construction documentation, bidding, construction administration, and post-occupancy stages, tends to be less efficient. Several respondents emphasized the importance of incorporating low-energy strategies in the earlier design stages: “Energy experts need to be introduced much earlier in the design.” “I believe that the involvement of occupants is important in the design phase.”

CONCLUSIONS

This study investigates the relative merits of passive and active design strategies at different levels of density and the degree to which they are implemented in practice using a survey administered to architects, urban planners, and sustainability consultants. The survey results provide valuable information regarding the challenges that design practitioners currently face in the application of low-energy designs.

The analysis reveals that passive design methods tend to be perceived as more important in low-density projects. This result is consistent with design practitioners’ comments that passive solar designs, such as an optimum building orientation, south-facing windows, and consideration of the thermal mass worked most effectively. Many respondents in the survey also note that good insulation, natural ventilation, and a high thermal mass are effective in low-density housing. However, it is surprising that respondents rated the importance of a building’s degree of compactness, its height, and its depth as fairly low, thus contradicting the theory that the more compact the building, the lower the energy use (Jones and Hudson 1998; Thomas and Ritchie 2003). This contradiction may result from design practitioners’ perceptions that the dimensions of a building are primarily determined by regulations and other economic factors. In contrast, active design methods are positively, yet very weakly, associated with density levels. Therefore, as passive design methods tend to be more effective in low-density projects, active design strategies are more heavily relied upon in high-density buildings, relative to passive methods, to achieve low-energy designs.

The varying levels of the effectiveness of the strategies according to density suggests the need for more specific sustainable design strategies and guidelines that take into account site conditions, including the density. Despite the numerous sustainable design guidelines and codes that are currently available, few of them are flexible enough to be adapted to different

TABLE 5. Association between Perceived Importance and Actual Implementation of Sustainable Design Elements.

Importance of Design Aspects in achieving Energy Efficiency			Extent of actual Implementation			Importance- Implementation Association	
Categories (Code)	%	(Freq.)	Categories (Code)	%	(Freq.)	tau-b	(z)
a. Solar accessibility							
Mean: 4.5			Mean: 4.1			0.23	(1.50)
Unimportant (1)	0.0	(0)	Not at all (1)	2.9	(1)		
Slightly Important (2)	0.0	(0)	Not very (2)	8.8	(3)		
Moderately Important (3)	8.8	(3)	Implemented (3)	11.8	(4)		
Important (4)	35.3	(12)	Somewhat (4)	26.5	(9)		
Very Important (5)	55.9	(19)	Very Much (5)	50.0	(17)		
b. Ventilation							
Mean: 4.5			Mean: 4.2			0.20	(1.32)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	2.9	(1)	Not very (2)	5.9	(2)		
Moderately Important (3)	2.9	(1)	Implemented (3)	20.6	(7)		
Important (4)	35.3	(12)	Somewhat (4)	26.5	(9)		
Very Important (5)	58.8	(20)	Very Much (5)	47.1	(16)		
c. Thermal mass							
Mean: 3.8			Mean: 3.2			0.41	(3.43)
Unimportant (1)	2.9	(1)	Not at all (1)	5.9	(2)		
Slightly Important (2)	11.8	(4)	Not very (2)	20.6	(7)		
Moderately Important (3)	20.6	(7)	Implemented (3)	38.2	(13)		
Important (4)	35.3	(12)	Somewhat (4)	17.7	(6)		
Very Important (5)	29.4	(10)	Very Much (5)	17.7	(6)		
d. Building orientation & layout							
Mean: 4.4			Mean: 3.6			0.14	(0.83)
Unimportant (1)	0.0	(0)	Not at all (1)	2.9	(1)		
Slightly Important (2)	2.9	(1)	Not very (2)	20.6	(7)		
Moderately Important (3)	8.8	(3)	Implemented (3)	20.6	(7)		
Important (4)	35.3	(12)	Somewhat (4)	23.5	(8)		
Very Important (5)	52.9	(18)	Very Much (5)	32.4	(11)		

Importance of Design Aspects in achieving Energy Efficiency			Extent of actual Implementation			Importance- Implementation Association	
Categories (Code)	%	(Freq.)	Categories (Code)	%	(Freq.)	tau-b	(z)
e. Building compactness (surface area to volume ratio)							
Mean: 3.8			Mean: 3.8			0.29	(1.81)
Unimportant (1)	0.0	(0)	Not at all (1)	5.9	(2)		
Slightly Important (2)	8.8	(3)	Not very (2)	5.9	(2)		
Moderately Important (3)	23.5	(8)	Implemented (3)	26.5	(9)		
Important (4)	47.1	(16)	Somewhat (4)	29.4	(10)		
Very Important (5)	20.6	(7)	Very Much (5)	32.4	(11)		
f. Building depth							
Mean: 3.6			Mean: 3.6			0.58	(5.12)
Unimportant (1)	2.9	(1)	Not at all (1)	2.9	(1)		
Slightly Important (2)	2.9	(1)	Not very (2)	14.7	(5)		
Moderately Important (3)	35.3	(12)	Implemented (3)	26.5	(9)		
Important (4)	50.0	(17)	Somewhat (4)	35.3	(12)		
Very Important (5)	8.8	(3)	Very Much (5)	20.6	(7)		
g. Building height							
Mean: 2.9			Mean: 3.0			0.64	(9.34)
Unimportant (1)	2.9	(1)	Not at all (1)	8.8	(3)		
Slightly Important (2)	23.5	(8)	Not very (2)	23.5	(8)		
Moderately Important (3)	55.9	(19)	Implemented (3)	32.4	(11)		
Important (4)	17.7	(6)	Somewhat (4)	32.4	(11)		
Very Important (5)	0.0	(0)	Very Much (5)	2.9	(1)		
h. Window size							
Mean: 4.1			Mean: 3.8			0.52	(4.85)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	2.9	(1)	Not very (2)	14.7	(5)		
Moderately Important (3)	14.7	(5)	Implemented (3)	23.5	(8)		
Important (4)	55.9	(19)	Somewhat (4)	29.4	(10)		
Very Important (5)	26.5	(9)	Very Much (5)	32.4	(11)		

TABLE 5. (continued)

Importance of Design Aspects in achieving Energy Efficiency			Extent of actual Implementation			Importance- Implementation Association	
Categories (Code)	%	(Freq.)	Categories (Code)	%	(Freq.)	tau-b	(z)
i. Window locations							
Mean: 4.2			Mean: 3.5			-0.07	(-0.41)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	0.0	(0)	Not very (2)	32.4	(11)		
Moderately Important (3)	8.8	(3)	Implemented (3)	11.8	(4)		
Important (4)	61.8	(21)	Somewhat (4)	29.4	(10)		
Very Important (5)	29.4	(10)	Very Much (5)	26.5	(9)		
j. Interior layout							
Mean: 3.2			Mean: 3.3			0.54	(4.38)
Unimportant (1)	2.9	(1)	Not at all (1)	3.0	(1)		
Slightly Important (2)	17.7	(6)	Not very (2)	21.2	(7)		
Moderately Important (3)	41.2	(14)	Implemented (3)	33.3	(11)		
Important (4)	32.4	(11)	Somewhat (4)	27.3	(9)		
Very Important (5)	5.9	(2)	Very Much (5)	15.2	(5)		
k. Building insulation							
Mean: 4.7			Mean: 4.4			0.36	(2.28)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	0.0	(0)	Not very (2)	5.9	(2)		
Moderately Important (3)	2.9	(1)	Implemented (3)	5.9	(2)		
Important (4)	26.5	(9)	Somewhat (4)	29.4	(10)		
Very Important (5)	70.6	(24)	Very Much (5)	58.8	(20)		
l. Building façade system							
Mean: 4.2			Mean: 3.9			0.57	(4.42)
Unimportant (1)	0.0	(0)	Not at all (1)	2.9	(1)		
Slightly Important (2)	5.9	(2)	Not very (2)	11.8	(4)		
Moderately Important (3)	14.7	(5)	Implemented (3)	17.7	(6)		
Important (4)	29.4	(10)	Somewhat (4)	23.5	(8)		
Very Important (5)	50.0	(17)	Very Much (5)	44.1	(15)		

Importance of Design Aspects in achieving Energy Efficiency			Extent of actual Implementation			Importance- Implementation Association	
Categories (Code)	%	(Freq.)	Categories (Code)	%	(Freq.)	tau-b	(z)
m. Building material							
Mean: 3.7			Mean: 3.7			0.48	(3.24)
Unimportant (1)	0.0	(0)	Not at all (1)	5.9	(2)		
Slightly Important (2)	14.7	(5)	Not very (2)	8.8	(3)		
Moderately Important (3)	23.5	(8)	Implemented (3)	20.6	(7)		
Important (4)	44.1	(15)	Somewhat (4)	35.3	(12)		
Very Important (5)	17.7	(6)	Very Much (5)	29.4	(10)		
n. Energy-efficient mechanical system							
Mean: 4.5			Mean: 4.2			0.65	(7.01)
Unimportant (1)	0.0	(0)	Not at all (1)	0.0	(0)		
Slightly Important (2)	2.9	(1)	Not very (2)	9.1	(3)		
Moderately Important (3)	8.8	(3)	Implemented (3)	12.1	(4)		
Important (4)	23.5	(8)	Somewhat (4)	24.2	(8)		
Very Important (5)	64.7	(22)	Very Much (5)	54.6	(18)		
o. Quality of construction							
Mean: 4.6			Mean: 4.0			0.55	(4.29)
Unimportant (1)	0.0	(0)	Not at all (1)	5.9	(2)		
Slightly Important (2)	0.0	(0)	Not very (2)	8.8	(3)		
Moderately Important (3)	2.9	(1)	Implemented (3)	17.7	(6)		
Important (4)	32.4	(11)	Somewhat (4)	17.7	(6)		
Very Important (5)	64.7	(22)	Very Much (5)	50.0	(17)		

site conditions (Garde 2009; Sharifi and Murayama 2013). Hence, design approaches and guidelines that select and apply effective low-energy design strategies for a given project's density and local conditions can improve the energy efficiency of buildings.

The results identify, despite the perceived importance of integrating low-energy concepts into building design, that low-energy designs are frequently not implemented in practice. For example, the survey results in Table 5 shows that most design practitioners consider energy efficiency to be the most important aspect (91%) of sustainable design. However, this result is in sharp contrast with the percentage of practitioners (74%) who actually implemented

TABLE 6. Difficulty of Implementing Low-Energy Design Strategies.

Categories (Code)	%	(Freq.)	Categories (Code)	%	(Freq.)
Tight budget			Initial cost and value		
Mean: 3.7			Mean: 3.1		
Not Difficult (1)	2.9	(1)	Not Difficult (1)	5.9	(2)
Less Difficult (2)	8.8	(3)	Less Difficult (2)	26.5	(9)
Moderately Difficult (3)	38.2	(13)	Moderately Difficult (3)	29.4	(10)
Difficult (4)	17.7	(6)	Difficult (4)	29.4	(10)
Very Difficult (5)	32.4	(11)	Very Difficult (5)	8.8	(3)
Lack of knowledge			Client reluctant to take risks		
Mean: 3.0			Mean: 2.9		
Not Difficult (1)	17.7	(6)	Not Difficult (1)	11.8	(4)
Less Difficult (2)	17.7	(6)	Less Difficult (2)	35.3	(12)
Moderately Difficult (3)	29.4	(10)	Moderately Difficult (3)	17.7	(6)
Difficult (4)	17.7	(6)	Difficult (4)	20.6	(7)
Very Difficult (5)	17.7	(6)	Very Difficult (5)	14.7	(5)
Tight schedule			Zoning regulation		
Mean: 2.7			Mean: 2.5		
Not Difficult (1)	14.7	(5)	Not Difficult (1)	20.6	(7)
Less Difficult (2)	32.4	(11)	Less Difficult (2)	23.5	(8)
Moderately Difficult (3)	29.4	(10)	Moderately Difficult (3)	44.1	(15)
Difficult (4)	11.8	(4)	Difficult (4)	8.8	(3)
Very Difficult (5)	11.8	(4)	Very Difficult (5)	2.9	(1)
Lack of design guidelines			Design requirements set by client		
Mean: 2.2			Mean: 2.2		
Not Difficult (1)	26.5	(9)	Not Difficult (1)	26.5	(9)
Less Difficult (2)	41.2	(14)	Less Difficult (2)	38.2	(13)
Moderately Difficult (3)	14.7	(5)	Moderately Difficult (3)	23.5	(8)
Difficult (4)	17.7	(6)	Difficult (4)	8.82	(3)
Very Difficult (5)	0.0	(0)	Very Difficult (5)	2.9	(1)
Lack of client's interest					
Mean: 1.8					
Not Difficult (1)	52.9	(18)			
Less Difficult (2)	26.5	(9)			
Moderately Difficult (3)	8.8	(3)			
Difficult (4)	8.8	(3)			
Very Difficult (5)	2.9	(1)			

TABLE 7. The Effectiveness of the Design Phases in Achieving Low-Energy Designs.

Categories (Code)	%	(Freq.)	Categories (Code)	%	(Freq.)
Pre-Design			Concept Design		
Mean: 4.4			Mean: 4.6		
Ineffective (1)	2.9	(1)	Ineffective (1)	0.0	(0)
Less Effective (2)	2.9	(1)	Less Effective (2)	2.9	(1)
Moderately Effective (3)	2.9	(1)	Moderately Effective (3)	5.9	(2)
Effective (4)	32.4	(11)	Effective (4)	23.5	(8)
Very Effective (5)	58.8	(20)	Very Effective (5)	67.7	(23)
Schematic Design			Design Development		
Mean: 4.7			Mean: 4.5		
Ineffective (1)	0.0	(0)	Ineffective (1)	0.0	(0)
Less Effective (2)	3.0	(1)	Less Effective (2)	0.0	(0)
Moderately Effective (3)	0.0	(0)	Moderately Effective (3)	6.1	(2)
Effective (4)	24.2	(8)	Effective (4)	42.4	(14)
Very Effective (5)	72.7	(24)	Very Effective (5)	51.5	(17)
Construction Documentation			Bidding		
Mean: 3.8			Mean: 2.7		
Ineffective (1)	0.0	(0)	Ineffective (1)	15.6	(5)
Less Effective (2)	6.3	(2)	Less Effective (2)	25.0	(8)
Moderately Effective (3)	31.3	(10)	Moderately Effective (3)	37.5	(12)
Effective (4)	40.6	(13)	Effective (4)	18.8	(6)
Very Effective (5)	21.9	(7)	Very Effective (5)	3.1	(1)
Construction Administration			Post Occupancy		
Mean: 3.3			Mean: 3.8		
Ineffective (1)	3.1	(1)	Ineffective (1)	6.3	(2)
Less Effective (2)	18.8	(6)	Less Effective (2)	6.3	(2)
Moderately Effective (3)	37.5	(12)	Moderately Effective (3)	15.6	(5)
Effective (4)	28.1	(9)	Effective (4)	46.9	(15)
Very Effective (5)	12.5	(4)	Very Effective (5)	25.0	(8)

strategies to increase the energy efficiency of their projects. A similar discrepancy between perceived importance and practice emerges, examining specific design elements. Respondents perceive solar accessibility, ventilation, the building orientation and layout, and window locations as highly important design elements to achieve low-energy buildings. However, their levels of implementation are generally lower than their perceived importance, and the association between passive design elements and their implementation tend to be insignificant. Hence, these important low-energy strategies tend not to be applied as often as they should be considering their effectiveness.

This result implies, despite the proven advantage of integrating particular bioclimatic concepts into building designs, that obstacles to doing so create a gap between knowledge and practice. The critical obstacles to low-energy design include tight budgets and high initial costs and values, a lack of knowledge, clients who are unwilling to take risks, tight schedules, and zoning regulations. Despite these difficulties, the survey results confirm that incorporating low-energy designs in earlier stages, such as the schematic, concept, and pre-design stages, is more effective than in the later stages of the design process. In other words, when certain site-specific factors such as the building orientation, configuration, and layout are factored into low-energy design decisions early in the design process, the energy savings tend to be higher.

It is undeniably the case that low-energy designs can be achieved with the help of advanced technology, as design practitioners in the survey indicate that the advice of environmental consultants has a great deal of influence on their decisions. For instance, the involvement of environmental engineers can provide solutions to “fix” any energy consumption deficit or problem in any given design situation. However, their involvement is often requested later in the design process, when the opportunity to apply passive design elements during the building form, layout, and orientation decision stage has passed. In the early design stages, passive design strategies can be optimized considering an active design, which potentially improves the energy efficiency of buildings much more effectively. Therefore, adjusting priorities so that practitioners have more input in design decisions and so that consultants are called in earlier in the process would produce more energy-efficient outcomes at a far lower cost. In such a scenario, the focus of consultant recommendations would be on proactively planning a passive low-energy design rather than mitigating the effects of an inefficient one.

Limitations and Future Research

Although this research sheds light on the challenges currently faced by design practitioners in the application of low-energy designs, its weakness lies in the measurements and small sample size. We used Likert scales, on which respondents are not always able to match their opinions on a topic to points on these scales. Moreover, modifiers such as “moderately” or “slightly” are subjective terms that may be interpreted differently depending on the individual. However, while the Likert scale is an imperfect tool, it allows for more nuanced responses than a simple yes/no survey and thus was deemed to be the best survey method for the purposes of this research. The small sample size is another limitation. It is expected that as more sustainable housing projects are planned, more design practitioners can participate in such a survey. Future research with a larger sample size may yield more reliable findings about the effective application of low-energy strategies in practice. Also, while this study focused on low-energy housing in temperate climates, it would be instructive to investigate housing on other climates as well.

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