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Effects of Climate Responsive Strategies and Adaptive Behavior of Occupants on Thermal Comfort in Indoor Environments of Vernacular Architecture: A Review of Necessities and Goals

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ABSTRACT

This study addresses the goals, reasons, and necessities of analyzing the effects of climate responsive strategies and adaptive behavior on thermal comfort in the indoor environments of vernacular architecture. For this purpose, 86 studies were reviewed, including 71 studies about climate responsive strategies and 15 others about adaptive behavior in vernacular architecture and dwellings that were carried out between 2000 and 2018. The research methodology included a statistical survey and analysis of necessities and goals of the studies reviewed in this paper. To this end, the designated studies were analyzed and reviewed from different aspects, such as the history and process of formation, keywords, goals, reasons, and necessities of research.

According to the findings, the most important research goals of climate responsive strategies include (1) analyzing the thermal performance of buildings, and (2) identifying the effects of these strategies on the thermal quality of indoor environments. Moreover, the most prominent research goals of adaptive behaviors in vernacular architecture and residences include (1) evaluating thermal comfort, (2) identifying and analyzing adaptive methods and behaviors, and (3) identifying the existing obstacles. The research necessities of these two areas can also be divided into three sections, i.e. identification of advantages, practical reasons, and addressing research gaps. Another research finding was identification of the concepts pertaining to these two areas.

Keywords: climate responsive strategies, adaptive behavior, thermal comfort, vernacular architecture, indoor environments

INTRODUCTION

In a constructed environment, the human presence is directly related to the procurement of thermal comfort conditions. Therefore, thermal comfort has become an important discipline, and now an essential matter, in architecture. According to a review of the contemporary literature and analysis of buildings of the past, architects have always been concerned about ensuring thermal comfort in buildings.

An in-depth study of thermal comfort and methods of providing it in modern buildings was commenced by Haldane in England in the early 20th century, and evolved in the second half of that century (Heidari, 2014). According to the literature, this subject has been considered in different aspects and analyzed by ongoing studies to the present day. There have been significant advances in some of the studies regarding humans as the subject of thermal comfort in different physiological, psychological, and sociological aspects. These studies have resulted in the codification and evolution of classic thermal comfort theory, led by Fanger (1972), and adaptive approach, led by Humphreys (1978) as cited in Barger et al., (1998).

In another group of studies about thermal comfort, researchers have addressed the simultaneous interplay of architecture, humans, and their thermal comfort in real environments. According to the findings of these studies, they can be divided into two groups. The first group includes the studies addressing the importance, roles, and effects of building-related techniques and strategies in the procurement of comfort conditions. Inspired by the adaptive approach, the second group focuses on climate responsive strategies alongside humans' adaptive behaviors and roles.

This study aimed to identify the background to these two groups of research works in the indoor environments of vernacular architecture. Hence, it analyzes the research literature on the effects of climate responsive strategies and adaptive behavior of residents on the thermal comfort of indoor environments in vernacular architecture.

METHOD AND METERIALS

Method

The purpose of this article is to analyze studies that have sought to discover methods used in vernacular dwelling and architecture to provide thermal comfort in indoor environments. An initial review of literature indicated that climate responsive strategies and adaptive behavior were the most important methods of achieving thermal comfort in the vernacular architecture of most regions. Therefore, "climate responsive strategies," "adaptive behavior," "thermal comfort," and "vernacular architecture" were selected as the relevant keywords and were searched for in *ScienceDirect* and *Scopus*. A review of the designated papers had three specific results: 1) papers which were related to this study and used in the analysis; 2) papers which were not necessarily related and were deleted, despite having the keywords; and 3) new papers cited in the texts of the reviewed papers; these papers were then accessed from the aforesaid databases or other scientific databases after new searches.

The research methodology included a statistical survey and analysis of necessities and goals of the studies reviewed in this paper. To this end, the designated studies were analyzed and reviewed from different aspects, such as the history and process of formation, keywords, goals, reasons, and necessities of research.

Designated Papers

For research goals, all the studies covering the four subjects ("climate responsive strategies," "adaptive behavior," "thermal comfort," and "vernacular architecture") were considered. The search results included over 110 studies, all of which had been conducted by 2018. There were two distinct groups of studies; the first group included 71 studies analyzing climate responsive strategies, while the second group included 15 studies analyzing the role of adaptive behavior in providing thermal comfort conditions. Among the studies in the second group, two papers addressed different spaces; There was one study relating to the indoor environment of a school, and one study in that dealt with apartment

spaces. Given the importance of methodology and analysis of adaptive behavior of residents in both studies, these two cases were classified as belonging to the second group. The rest of the searched studies were not relevant and were discarded.

To facilitate analysis of resultant papers, all of them were summarized in an Excel file to classify their important features. Overall, 32% of these studies had been conducted in a hot and dry climate, 27% in a warm and humid climate, and 20% in a cold climate. The rest of them had been carried out in other climates (Figure 1).

These studies had been published in 32 different journals. In fact, over 53% of them (46 papers) had been published in 5 journals (Table 1), and the other 35 papers had been published in 27 journals (1 to 3 papers per journal).

Figure 1

Separating Papers Based on Climate Type

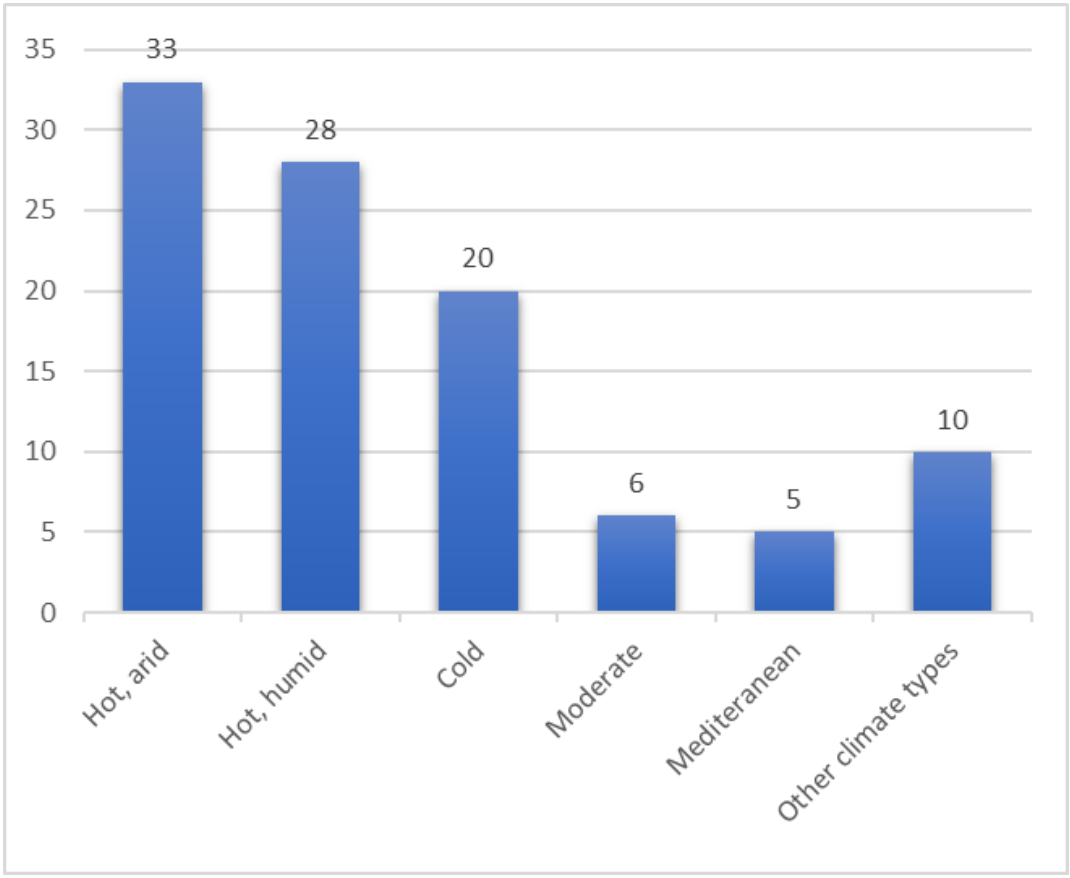


Table 1

Journals With the Largest Number of Papers

Journal	***Number***	***Percent***
Building and Environment	19	22%
Energy and Buildings	14	16%
Procedia Engineering	5	5.8%
Procedia - Social and Behavioral Sciences	4	4.6%
Architectural Science Review	4	4.6%

RESULTS

Keywords of Designated Papers

Based on the research goals, the main search keywords were “climate responsive design,” “adaptive behavior,” “thermal comfort,” and “vernacular architecture.” A review of resultant papers indicates the correlation of other keywords with the designated ones; thus, these other keywords were also analyzed. The contents of the resultant papers included two distinct concepts, i.e. (1) analyzing the efficiency of climate responsive strategies, and (2) analyzing adaptive behavior of occupants. Hence, this section analyzes the keywords in relation to these two categories.

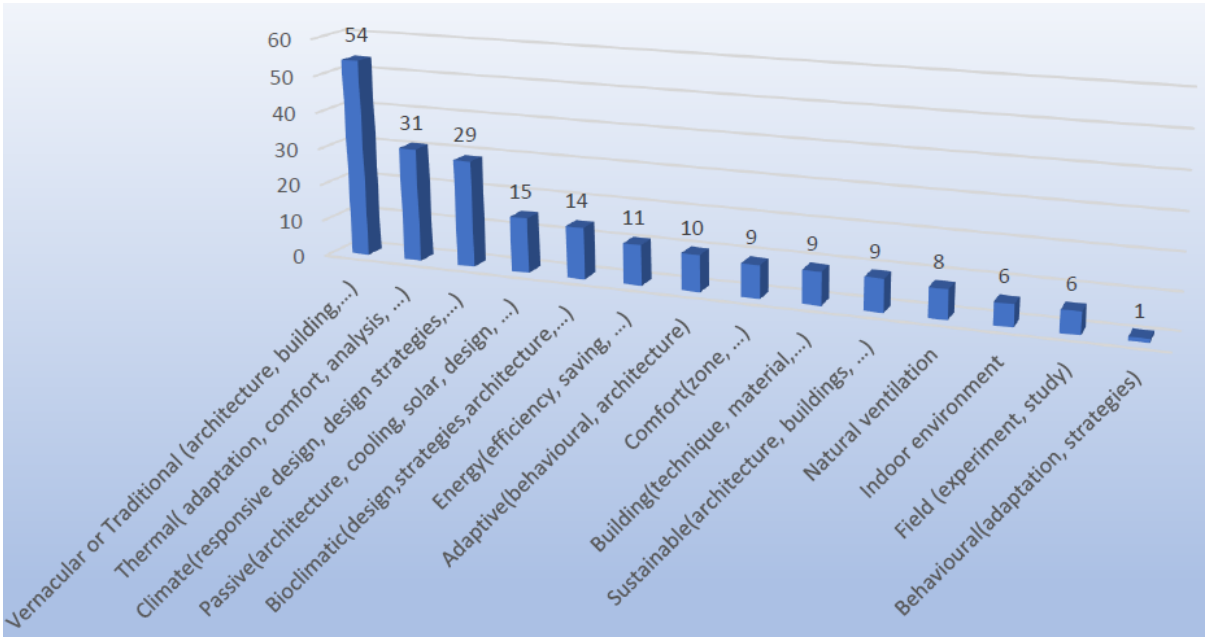
Keywords Pertaining to Climate Responsive Strategies

The review of relevant papers indicated that “vernacular or traditional,” “thermal comfort (and adaptation),” “climate responsive design,” “passive architecture,” “bioclimatic design”, and “energy” were the most frequent keywords used in the papers. Other keywords followed with respect to the rate at which they occurred. Figure 2 shows the frequency of the keywords related to climate responsive strategies. Apart from “vernacular or traditional” (54) and “thermal comfort (and adaptation)” (31), which were the most frequent keywords with relevance to the research field, “climate responsive design” (29), “passive architecture” (15), and “bioclimatic design” (14) were the most frequent keywords. Apparently, these terms have been observed in a considerable number of topics pertaining to climate responsive strategies.

The analysis of other keywords indicates that climate responsive strategies are closely related to “energy efficiency or saving” and “sustainable architecture or building”, a claim which is backed by the frequent presence of “energy” (11 times) and “sustainable” (9 times). At the same time, the analysis of relevant papers shows that the concept of “adaptive behavioral or architecture” with the environment (10) is not merely related to the human behavior and is an architectural feature realized by climate responsive strategies. Another concept of climate responsive strategy is “natural ventilation” (8). Although the act of opening windows is an exemplar of adaptive behavior, it is considered as a climate responsive strategy in architecture.

Figure 2

Frequency of Keywords in Papers on Climate Responsive Strategies



Keywords Pertaining to Adaptive Behavior of Occupants

There are far fewer studies related to this group of keywords than those related to the first group. The main reason is the serious challenge of studying the typical routines of residents living in one or more buildings during the day and night. As Figure 3 indicates, “behavior” and “thermal comfort” were the most frequent keywords in the designated studies, appearing 7 and 6 times, respectively. The keyword “traditional” came next, with a frequency of 4. “Adaptive,” “comfort temperature,” and “opening the windows” had a frequency of 3 each.

The analysis of these keywords points out that the adaptability of residents is very important. According to Humphreys et al. (2013), adaptability is achieved in two ways, the first of which involves adaptive behaviors performed by an individual to adapt himself to thermal environmental conditions. The second method emphasizes adaptive behavior imposed on the surrounding environment to bring about thermal comfort conditions there. Hence, the research of Humphreys et al. includes keywords like “rate of clothes” (2), which is an instance of behavior related to the first adaptive method. These papers also include another instance of adaptive behavior, i.e. “opening the windows,” which belongs to the second adaptive method.

History of Research into Climate Responsive Strategies and Adaptive Behavior in Terms of Thermal Comfort

The idea of adaptive thermal comfort stems from the collaboration of Humphreys and Nicol in the 1960s and 1970s (Nicol et al., 2012). Nevertheless, the adaptive theory was first proposed by Nicol and Humphreys (1973), and the first adaptive equation was introduced by Humphreys in 1978 (Humphreys, 1978, as cited in Barger et al., 1998; Humphreys et al., 2013). This theory was developed mainly due to dissatisfaction with Fanger’s model of thermal comfort (heat exchange equation) for the prediction of thermal comfort and the response of the scientific society to oil shocks observed in the mid-1970s, as well as studies conducted by Humphreys and Nicol (Brager & de Dear, 1998; Nicol et al., 2012). Since the late 1980s, this topic has gradually emerged in relevant standards such as ASHRAE Standard 55 (Cena & de Dear, 2001). It has long been regarded as an important approach to the analysis of thermal comfort in buildings. As the principles of this approach were established, the in-situ studies started to be conducted on buildings in the early 21st century.

Figure 3

Frequency of Keywords in the Papers Pertaining to the Adaptive Behavior of Residents

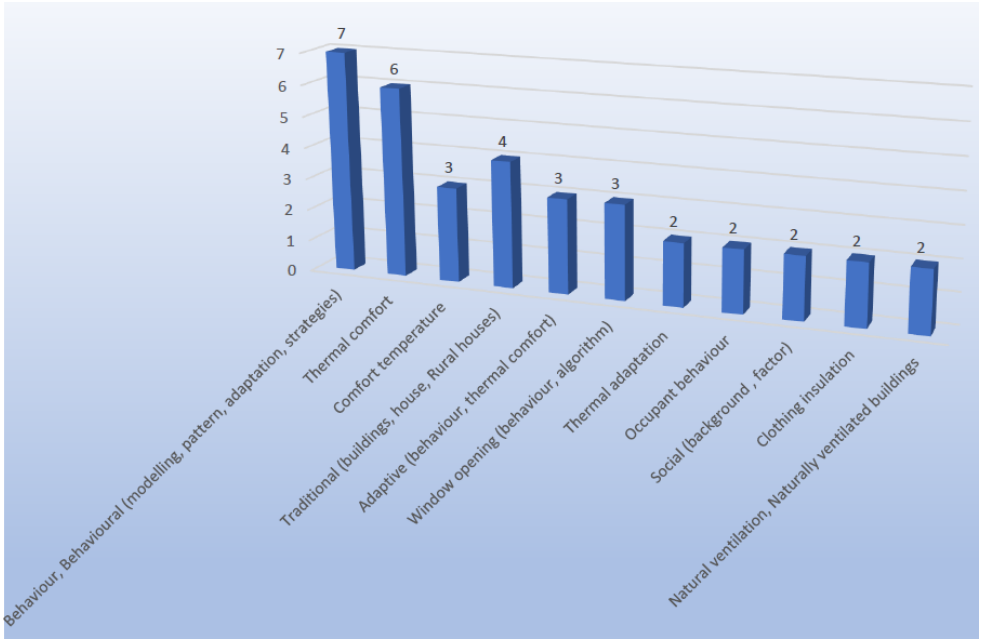


Figure 4

Classification of Papers Based on the Publication Year

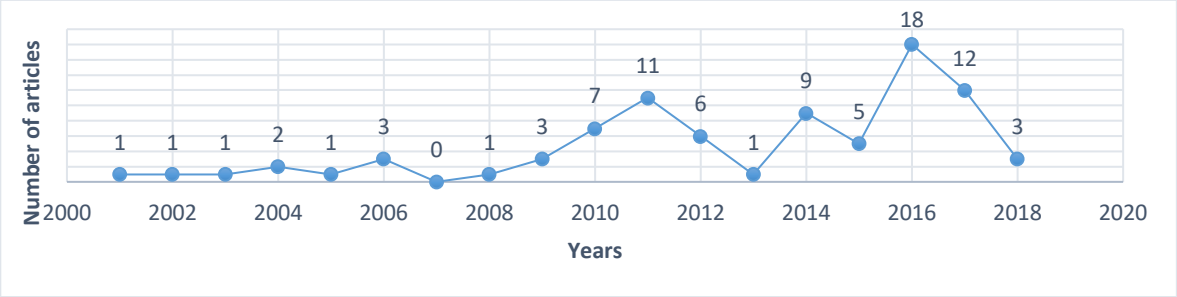


Figure 4 shows the development of studies pertaining to climate responsive strategies and adaptive behavior.

As summarized in this graph, research in this area has been conducted mostly after 2000, with 72 out of 85 studies having been carried out between 2010 and 2018, indicating the growing concern for this type of research over recent years, especially since 2010. It appears that climate responsive strategies and adaptive behavior have been accepted as the significant methods of achieving thermal comfort with the lowest dependence on fossil fuels since at least 2010.

Research Goals for Climate Responsive Strategies and Adaptive Behavior

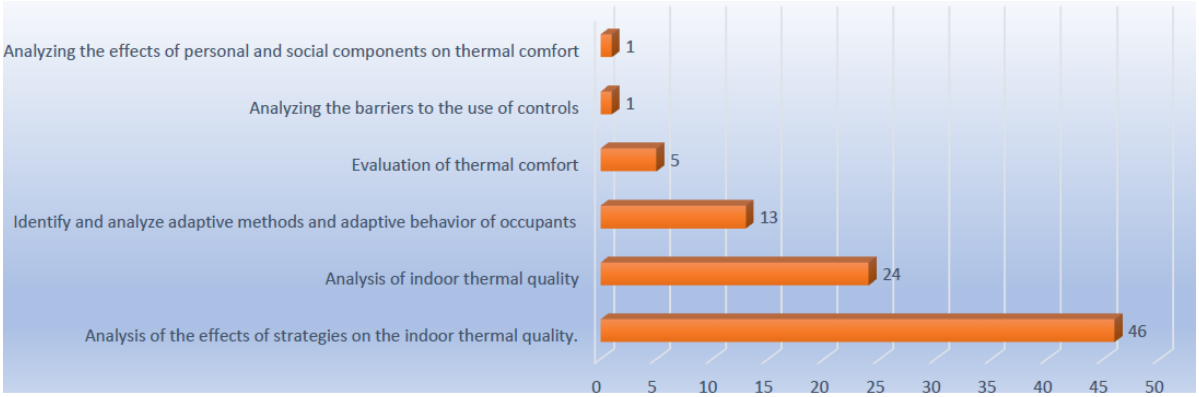
According to the analysis of goals pursued by the papers reviewed in this study, the studies of climate responsive strategies focused on the thermal quality of buildings and effects of strategies on the indoor thermal quality. In a few cases, studies pursued higher goals such as defining principles for the renovation of vernacular architecture (Oikonomou & Bougiatioti, 2011), perceiving climate traditions (Rubio-Bellido et al., 2018), and discussing forces affecting housing evolution and obtaining evolved types (Dincyurek et al., 2003).

At the same time, studies of adaptive behavior indicate that the research goals shifted towards the evaluation of thermal comfort, identification and analysis of adaptive methods and behavior of residents, and also analysis of barriers to the use of controls (based on adaptive behavior).

As summarized in Figure 5, research goals focus mainly on analysis of the effects of strategies on indoor thermal quality. Nearly 66% of research objectives goals of research into climate responsive strategies, and 51% of the objectives of the entire body of research we reviewed, pertain to this goal (Alev et al., 2014; Bodach et al., 2014; Canas & Martin, 2004; Cantin et al., 2010; Desogus et al., 2016; Dili et al., 2010b; Dincyurek et al., 2003; Fernandes et al., 2015; Foruzanmehr & Vellinga, 2011; Gou et al., 2015; Huang et al., 2016; Iyendo et al., 2016; Keshtkaran, 2011; Keskin & Erbay, 2016; Khalili & Amindeldar, 2014; Kubota & Toe, 2015; Mohammadi et al., 2018; Molanaei & Soleimani, 2016; Motealleh et al., 2018; Nguyen et al., 2011; Oikonomou & Bougiatioti, 2011; Oree & Anatah, 2017; Ozay, 2005; Philokyprou et al., 2017; Philokyprou et al., 2018; Pozas & González, 2016; Priya et al., 2012; Rubio-Bellido et al., 2018; Saljoughinejad & Rashidi Sharifabad, 2015; Samani et al., 2016; Shaeri et al., 2018; Shao et al., 2017; Shastry et al., 2016; Singh et al., 2009; Singh et al., 2011; Soleymanpour et al., 2015; Suhendri & Koerniawan, 2017; Tahbaz & Jalilian, 2011; Tahbaz & Jalilian, 2016; Taleb, 2014; Upadhyay et al., 2006; Victoria et al., 2017; Zaki et al., 2012; Zohoori Ghare Darvishloo, 2015).

Figure 5

Classification of Research Goals



The analysis of indoor thermal quality is another goal pursued by the reviewed studies. This group comprised 34% of research goals pertaining to climate responsive strategies and 27% of research goals in the entire body of reviewed studies (Asadi et al., 2016; Barbero-Barrera et al., 2014; Bassaran, 2011; Becerra-Santacruz & Lawrence, 2016; Borong et al., 2004; Dili et al., 2010a; Du et al., 2014; Etemad Sheikholeslami, 2011; Faizi et al., 2014; Fezzioui et al., 2009; Gorji & Daneshvar, 2010; Gorji et al., 2012; Hashemi & Heidari, 2012; Heidari & Ainifar, 2011; Huang et al., 2017a; Huang et al., 2017b; Hyde et al., 2016; Manu et al., 2019; Merghani, 2006; Mohazabie et al., 2016; Ooka, 2002, as cited in Oikonomou & Bougiatioti, 2011; Priya et al., 2012; Singh et al., 2010b; Xu et al., 2016).

Regarding the analysis of adaptive behavior, researchers were more willing to identify and analyze adaptive methods and adaptive behavior of occupants than other areas. Nearly 65% of research goals in this group of studies, and 14% of research goals in the entire group of reviewed studies, pertained to adaptive behavior (Cena & de Dear, 2001; Chang et al., 2017; Indraganti, 2010; Kim et al., 2017; Kumar et al., 2016; Liu et al., 2012; Merghani, 2006; Montazami et al., 2017; Rijal et al., 2009; Rijal et al., 2018; Rijal et al., 2008; Tassiopoulou et al., 1996; Yan et al., 2016).

The evaluation of thermal comfort is another goal pursued by the studies of adaptive behavior. It was found that analysis of thermal comfort comprised 25% of research goals pertaining to adaptive behavior, and 5.5% of the goals of all reviewed research (Cena & de Dear, 2001; Kumar et al., 2016; Liu et al., 2012; Rijal et al., 2018; Yan et al., 2016).

There was one study analyzing the barriers to the use of controls (Indraganti, 2010). There was also another study analyzing the effects of personal and social components on thermal comfort (Song et al., 2014).

Analysis of Climate Responsive Strategies and Thermal Comfort in Vernacular Architecture

Climate responsive strategies of vernacular architecture play key roles in reducing the consumption of fossil fuels, in addition to providing thermal comfort for residents (Hatamipour et al., 2007; Nguyen et al., 2011; Rubio-Bellido et al., 2018; Xu et al., 2016). Hence, it is necessary to identify these strategies and determine their roles in improving the thermal quality of environments and reducing energy consumption. Research necessities and objectives of studies on climate responsive strategies of vernacular architecture can be divided into the following sections:

Identifying Advantages

A motive for analyzing the environmental aspects of vernacular architecture is to prove its ability to provide thermal comfort conditions without relying on fossil fuels or by minimizing their use. According to the literature, this type of

architecture is highly compatible with climate conditions and can provide thermal comfort conditions (Bodach et al., 2014). It has been emphasized that vernacular architecture is responsive to various climate conditions (Gou et al., 2015) and can benefit from solutions in proportion to different climates to control the indoor environments. Many qualitative and quantitative studies have shown that the procurement of thermal comfort conditions is an advantage of vernacular architecture in different climates and regions (Dili et al., 2010b; Nematchoua et al., 2014; Nguyen et al., 2011; Rubio-Bellido et al., 2018; Tahbaz & Jalilian, 2011; Tahbaz & Jalilian, 2016; Victoria et al., 2017).

In addition to providing thermal comfort conditions, the most important feature of passive vernacular architecture is the role of architectural strategies in reducing energy consumption. In this aspect, vernacular architecture is widely known as a practical, effective, and popular strategy for curbing the detrimental effects of global warming and reducing the consumption of fossil fuels (Nguyen et al., 2011). In fact, it has been proven that climate responsive strategies, known as passive design strategies, affects thermal comfort and energy retention (Nematchoua et al., 2014; Rubio-Bellido et al., 2018; Tahbaz & Jalilian, 2011; Tahbaz & Jalilian, 2016; Victoria et al., 2017; Yao et al., 2018). It should be emphasized that these climate responsive strategies help reduce the energy consumption by increasing the intervals in which there is no need for active heating or cooling in relation to different climates (Yao et al., 2018).

Climate responsive strategies are divided into different categories: passive cooling strategies, passive heating strategies, atmospheric precipitation coping strategies, humid coping strategies, and outdoor microclimate control strategies (Philokyprou et al., 2017). Various methods are employed in these categories to reduce energy consumption. Previous studies have adopted some of these strategies to achieve expected goals, and have analyzed the use of local materials, natural ventilation, shading, thermal resistance of exterior walls, analysis of shading components of buildings with a combination of evaporative cooling, regulating natural ventilation, and nocturnal ventilation (Dili et al., 2010b; Gou et al., 2015; Singh et al., 2010a; Thravalou et al., 2018).

These strategies emerge in the body and the physics of the buildings (Philokyprou et al., 2017). Relevant studies have analyzed design techniques, construction and material selection techniques and systems, the interplay of buildings with the ground, sunlight, and wind, and the diversity and layout of architectural spaces, components, and elements. They are all regarded as the most important manifestations of climate responsive strategies. Table 2 shows an overview of these manifestations.

Another identifiable category identified in studies of vernacular architecture comprises the lessons which can be learnt from this style of architecture. According to the review, vernacular architecture is the result of hundreds of years of local and climate-adaptive residence, with its many lessons in climate responsive design (Foruzanmehr & Vellinga, 2011; Philokyprou et al., 2017; Rubio-Bellido et al., 2018).

Table 2

Climatic Manifestations Used in Vernacular Architecture

Design Techniques	***Construction Techniques and Material Types***	***Use of Ground, Wind, and Sunlight***	***Diversity and layout of Architectural Spaces***	***Architectural Elements and Components***
- Design and plan form - Orientation - Height	- Material type - Properties of walls	- Section-ground - height - Openings - Shadings - Wind-catchers	- Type of architectural space: open, semi-open, and close - Type of layout	- Yard - Dome - Wind-catcher - Use of water and plants

Different strategies for achieving thermal comfort have been developed in this style of architecture. Accordingly, numerous strategies for different climates have resulted in a valuable collection of architectural knowledge in both empirical and theoretical contexts (Rashid & Ara, 2015).

On an actual scale, these strategies are generating benefits and playing roles. This often happens through trial and error, providing an important source of learning (Keskin & Erbay, 2016).

The popularity of vernacular architecture and its durability contexts are among other considerable results of relevant studies. Proper thermal functions and low energy requirements of vernacular architecture have led to its popularity because most contemporary buildings are unsatisfactory in thermal comfort (Du et al., 2014). These findings indicate that vernacular architecture can provide a sustainable alternative, even when it may be rejected by some architectural academics (Rubio-Bellido et al., 2018).

Practical Reasons

Other reasons for analyzing the thermal comfort of vernacular architecture are practical. Evaluation of the environmental capabilities of vernacular dwellings is the main reason for many studies, conducted to analyze the thermal comfort in vernacular architecture. Analyzing the thermal quality of vernacular dwelling in different climates and identifying the thermal responses of people in a given society is one of the common research areas pertaining to the thermal comfort of vernacular architecture (Shastry et al., 2016). Increasing energy efficiency in buildings is regarded as another effective strategy for reducing energy consumption and coping with global warming (Holmes & Hacker, 2007), and is another motive for research in this area. The adoption of passive design strategies and employment of previous methods as ideal solutions for increasing energy efficiency in buildings and better controlling the building environments comprise an effective strategy for enhancing energy sustainability in buildings (Baran et al., 2011; Kim, 2006). Another dimension of vernacular architecture research pertains to the environmental and historical value of buildings. Analyzing and proving the capabilities of historical buildings can lay the foundation for protecting vernacular buildings in different cultures (Alev et al., 2014).

Addressing Research Gaps

A significant number of researches has focused on filling study gaps. In the field of thermal comfort, the need for detailed studies to achieve specific understandings of the thermal performance of vernacular buildings is a necessity that has highlighted the need for research in these areas; Lack of thorough evaluation of environmental functions of vernacular buildings (Huang et al., 2017b), discovery, documentation, and analysis of design principles and vernacular architecture components (Oikonomou & Bougiatioti, 2011), and lack or insufficiency of quantitative studies conducted to prove the effectiveness of different climate solutions to energy productivity (Bodach et al., 2014; Du et al., 2014; Fernandes et al., 2015; Xu et al., 2016) are all considered current research necessities. Special attention has been paid to this problem in hot climates in summer and cold climates in winter (Huang et al., 2017b). Lack of quantitative evaluations, unclear effects of passive solutions, need for scientific understanding of conventional passive solutions and their documentation (Huang et al., 2016; Philokyprou et al., 2018; Singh et al., 2011), and lack of qualitative and quantitative evaluations for the perception of actual functions of historical buildings with regard to thermal comfort (Rubio-Bellido et al., 2018) are among other areas which have so far been addressed by studies conducted in relation to climate responsive strategies in vernacular architecture.

Addressing research gaps is not the only reason for research in this area. Failing to make vernacular architecture known can pose a threat to this important cultural aspect in many nations. This can be an important factor for research into vernacular architecture in different ways. Vernacular residential buildings are prone to extinction due to abandonment by local people, which is directly related to lack of research into these buildings and failure to identify the advantages of this type of architecture (Prasetyo et al., 2014). In addition, the extensive destruction of vernacular architecture worldwide and replacement with modern styles of

architecture have intensified the necessity for studying and discovering the advantages of vernacular architecture (Huang et al., 2016). Proving the capabilities and efficiency of vernacular architecture in different areas, including thermal comfort and reduction in energy consumption, is an effective method for highlighting the importance of vernacular architecture and increasing motivation for retaining and maintaining it.

Analyzing Adaptive Behavior and Thermal Comfort in Vernacular Architecture

According to previous findings, buildings designed with AC systems account for nearly 80% of residential buildings in the US. Other countries such as China and Japan have been following the same trend (Rijal et al., 2009). Therefore, researchers have resorted to identifying adaptive behaviors of residents aimed at providing thermal comfort conditions through climate responsive strategies. The research necessities and motives for studies pertaining to adaptive behavior are as follows:

Identifying Advantages

A very important advantage of research on adaptive behaviors concerns its contextual methodology for thermal comfort. By definition, thermal adaption is affected by the combination of an individual's thermal history, non-thermal factors, and thermal expectations, which are collectively classified into three different trends: behavioral adjustment, physiological acclimatization, and psychological habituation or expectation (Brager & de Dear, 1998). Unlike the classic method (Fanger, 1972) in which subjects are questioned in the climate chamber; in the adaptive method, residents are asked in actual conditions in their own buildings. Studies utilizing this methodology include large and diverse samples of actual residents. Accordingly, it is possible to analyze a large number of factors, including daily habits, wearing everyday clothing, and behaving with no limits for residents in comparison with simulation in the climate chamber (Cena & de Dear, 2001). Improving prediction standards and models, developing more accurate algorithms for controlling environment, increasing thermal comfort levels and acceptance of those levels by residents, reducing energy consumption, and encouraging architects to design climate responsive buildings are among the capabilities of adaptive methods (Brager & de Dear, 1998).

The adaptive method is based on the following idea: "If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort" (Nicol & Humphreys, 2002). Another analysis pointed out people's ability to achieve thermal comfort in their routine lives. These definitions indicate the role of residents in providing thermal comfort, and only contextual studies can discover how residents can achieve this goal (Humphreys et al., 2007). Unlike the classic method, humans are not mere observers in the adaptive method, but comprise an active element in the surrounding heat environment (de Dear et al., 1997). This freflects a "give and take" relationship between the environment and residents, a situation in which the humans are considered active in the environment (Brager & de Dear, 1998).

Another advantage of the adaptive method is the procurement of adaptive opportunities. Providing adaptive opportunities means providing thermal comfort in buildings which lack mechanical ventilation systems. The solution to this problem depends on the development of environmental controls and construction of buildings that provide residents with more capabilities (Baker & Standeven, 1996). In the adaptive method, the human effect depends on having controls and sufficient adaptive methods (Liu et al., 2012). Humphreys et al. (2007) believed that adaptive opportunities needed to be the standard features of adaptability that should rely on effective and available methods to affect the environment, whether these methods include temperature controls, openable windows, solar controls, or controllable fans.

The most important research areas include adaptive opportunities as methods for controlling the environment, and analyzing the effects on thermal comfort and energy consumption (Humphreys et al., 2007), which can result in accurate identification of occupants' behavior and development of relevant algorithms. Some studies show that opportunities such as opening and closing windows, doors, blinds, curtains, and

fans are among the important behaviors shown to achieve adaptability (Kumar et al., 2016). These studies also determine how to use these controls under the influence of different seasons and climate variety. In one case, Indraganti (2010) analyzed the role of adaptive opportunities in apartments in India. According to the results of that study conducted in summer, although adaptive opportunities could not achieve thermal comfort for all of the residents in a particular month, adaptive behaviors resulted in the procurement of thermal comfort conditions in NV buildings most of the time, and also eliminated the need for mechanical ventilation. According to de Dear and Brager (2002), comfort temperatures are greatly affected by the formation of thermal expectations, resulting from the combination of available controls (adaptive opportunities) and diversity of thermal experiences in NV buildings.

Practical Reasons

Two general reasons have been mentioned for most of the studies on adaptive approach: 1) predicting the behavior of occupants and using different controls; 2) developing specific algorithms related to the control of residents which can be used simulation of thermal control in buildings (Nicol & Humphreys, 2004, as cited in Kumar et al., 2016).

It is necessary to know that incorrect or incomplete assumptions of occupants' behavior can result in false predictions of comfort zones and energy consumption. Solving this problem, presented in contractual assumptions of control behavior of buildings, depends on more high-quality contextual studies on various climates and regions.

According to the relevant studies, more actual models of occupants' behavior can lead to more accurate assumptions of comfort zones and energy consumption (Rijal et al., 2009). The conventional methods of simulation are also based on algorithms for this type of behavior; therefore, identifying the behavior of residents is the prerequisite to improved analyses of thermal comfort and energy consumption (Chang et al., 2017). Rijal et al. (2007) tried to formulate a method for simulating the effect of opening windows on thermal comfort and energy consumption in buildings. In 2008, they conducted another study to improve the opening window algorithm in the adaptive method. Based on a field study, they revised the cooling effect of opening windows through a thermal simulation. For this purpose, they employed an adaptive algorithm of opening windows derived from field studies. According to their findings, opening windows is useful for reducing temperatures that are above the summer comfort threshold. In addition, an adaptive algorithm of opening windows can help in the design of buildings with appropriate thermal comfort and reduced energy consumption through simulation (Rijal et al., 2008).

Addressing Research Gaps

Previous studies addressed different deficiencies of the research area, including the proper perception of the nature of thermal-adaptive behavior of residents. It is insufficient to focus merely on the identification of environmental controls, as viewed in previous studies, to perceive the nature of adaptive behavior. Hence, it is necessary to codify a comprehensive framework for the interplay between adaptive behavior of residents and climate change conditions which can serve as a basis for analyzing environmental adaptability, which can be utilized different climate conditions (Liu et al., 2012).

In addition to pointing out the growing trend in thermal controls in buildings, de Dear and Brager (2002) believe that another new challenge is the question of how to meet this expectation in new buildings. Therefore, it is essential to consider analyzing the modern products and technologies, training engineers and architects, creating documentation, and reducing expenditures. It is also necessary to show when adaptive methods are able to control the environmental conditions.

In another section of these studies, reasons for carrying out research pertain to the obsoleteness of tools required to determine thermal comfort based on adaptive principles (Cena & de Dear, 2001).

Table 3

Classification of Reasons and Necessities of Research on Climate Responsive Strategies and Adaptive Behaviors

	Climate Responsive Strategies	***Occupant's Adaptive Behavior***
Identifying Advantages	- Responding to different weather conditions - Reducing energy consumption. - Increasing the intervals at which there is no need for active heating or cooling - Being the result of hundreds of years of local and climate-friendly residence and have many lessons in climate-friendly design - Being a valuable collection of architectural knowledge in both experimental and theoretical fields - Acting as an important source of learning - Being the basis for the popularity of vernacular architecture and its preservation	- Advantages of the grounded method for thermal comfort - Residents are asked in real conditions in their buildings - Includes larger and more diverse examples of real residents - More factors can be analyzed such as daily habits, wearing everyday clothes and unrestricted behavior - Improving standards and forecasting models leads to the development of more accurate algorithms for controlling the environment - Increasing the levels of thermal comfort and its acceptance for residents along with reducing energy consumption - Encouraging architects to design climate-friendly buildings - Discover how residents can easily access thermal comfort - Providing adaptive opportunities as ways to control the environment - Analysis of the effects of adaptive behaviors on thermal comfort and energy consumption - Determining the exact levels of behavior - Analyzing the role of adaptive opportunities in buildings
Practical Reasons	- Evaluating the environmental capabilities of vernacular dwelling - Analyzing the thermal quality of vernacular dwelling in different climates - Receiving thermal responses of society - Increasing energy efficiency in buildings - Retaining environmental and historical value of buildings	- Predicting the behavior of occupants and using different controls - Growing specific algorithms related to the controls of residents which can be used for the simulation of buildings - An adaptive algorithm can help design buildings with appropriate thermal comfort and reduce energy consumption through simulation

Table 3 (Continued)

	Climate Responsive Strategies	***Occupant's Adaptive Behavior***
Addressing Research Gaps	- Lack of through evaluation of environmental functions of vernacular buildings - Discovery, documentation, and analysis of design principles and vernacular architecture components - Lack or insufficiency of quantitative studies to prove the effectiveness of various climate solutions for energy efficiency - Lack of quantitative evaluations - Unclear effects of passive solutions - Necessity of scientific perception and documentation of passive conventional solutions - Lack of qualitative and quantitative evaluations for the perception of actual functions of historical buildings with regard to thermal comfort - Lack of study on vernacular buildings can be on the discouragement of vernacular buildings due to the modern flow of architecture	- The proper perception of the nature of thermal-adaptive behavior of residents - To codify a comprehensive framework for the interplay between adaptive behavior of residents and climate change conditions - Not being recognized as a basis for environmental adaptation that can adapt to different climatic conditions - How to meet expectation in new buildings - The ability of adaptive methods to control the environmental conditions.

CONCLUSION

This study indicates that previous research studies of climate responsive strategies and adaptive behavior of vernacular architecture addressed different aspects. The main goal of studying climate responsive strategies is to analyze the structure and the physics of the vernacular buildings, whereas the goal of studying adaptive behavior is to identify thermal feeling and behavioral responses in response to the thermal conditions of the environment. Given the nature of these two research subjects, research on the body and the physics of the building is clearly simpler than studying humans and their behavioral responses. Hence, it is unsurprising that there are fewer studies of adaptive behavior than those of the first type.

The results of this study indicate that various reasons and necessities have made the study of thermal comfort inevitable in vernacular architecture. The resultant classification includes three axial categories: discovering advantages, practical reasons, and addressing research gaps.

In the analysis of research goals, the most of which aim to identify the efficiency of climate responsive strategies, adaptive behavior, and their continuity, it is possible to analyze two factors vividly. The first factor is the physics of the vernacular building, which has to the goal of improving the indoor quality through various strategies and techniques. The second factor is the humans residing in buildings designed with vernacular architecture. In fact, humans have taken actions to complete the thermal behavior of the physics and the body of vernacular buildings and provide appropriate conditions through adaptive behaviors and procurement of controls. The integration of these two categories, which are closely related to energy savings and sustainability, as well as thermal comfort conditions, has highlighted the concepts of adaptability and vernacular dwelling. Previous studies have analyzed the dimensions of this problem in different climates and addressed the

hidden aspects of the matter. Thus, extensive concepts have been discussed in this category. For instance, a few studies have pointed out the reliance of climate responsive strategies and adaptive behavior on renewable energy sources such as solar energy, natural ventilation for cooling, and thermal specifications of the Earth, as well as the role of humans in the use of possible controls to provide thermal comfort conditions.

On the other hand, the role of this type of research in introducing the historical values of vernacular architecture is significant. Recognizing the positive aspects of vernacular architecture and its historical value motivates the preservation of historical and vernacular buildings. This issue, despite the dominance of modern architectural styles, can provide the necessary motivation to transfer architectural experiences to future generations.

In addition, thermal simulation of buildings is a new category of research that can be used to predict thermal comfort levels and energy consumption rates in existing or designed buildings. The accuracy of these predictions depends on the data that is input into simulation programs, such as the specifications and efficiency of climate responsive strategies, and adaptive behavior of occupants. Another feature of such studies is the use of results pertaining to climate responsive strategies and adaptive behavior for the improvement of thermal simulation programs for buildings.

This article was developed with the aim of discovering the reasons, necessities and objectives of studies conducted on climate responsive strategies and adaptive behaviors of residents in vernacular architecture. However, several suggestions were made for future studies; these include comparing responsive climatic strategies and adaptive behaviors of residents based on different geographies and climates. In addition, identifying and understanding more details about natural and mechanical ventilation systems, as well as methods for using climate-responsive strategies in new constructions, especially in low-income areas, are other suggestions.

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