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Reviewing the thermal and microclimatic function of courtyards

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ABSTRACT

Currently, sustainability is one of the most important subjects in architecture and urban design. Sustainable design strategies reduce energy consumption of buildings and environmental pollution. Moreover, these strategies improve the microclimatic conditions of urban spaces. In this regard, courtyard design is an efficient sustainable strategy to improve thermal and microclimatic conditions of urban spaces. For 5000 years, courtyards have been developed to adapt to severe climatic conditions, particularly in hot and arid climates. Inaccurate courtyard thermal estimations may occur due to the complexity of optimal thermal design and insufficient tools for simulating the thermal conditions of indoor and outdoor spaces simultaneously. In the last four decades, researchers have recommended several methods to study the thermal function of courtyards. Although the variety of the modelling particularities makes it difficult to obtain appropriate results that encompass all influential factors of courtyard climatic performance, this paper provides a comprehensive review of the papers of this type of building form. The main goal is to clarify if and how the construction of courtyards can decrease energy consumption and improve the microclimate of buildings. The present study focuses on the impact of courtyard design factors (such as proportion, orientation, geometry, opening characteristics, and material) and its components (such as shading devices, vegetation, and water pool) on energy consumption, indoor and outdoor temperatures, solar radiation, and natural ventilation in different climates. Regarding the researchers' frameworks in the reviewed papers, three main categories are identified: 1- those examining the microclimatic function of courtyards, 2- those based on the thermal function of courtyards, and 3- those that incorporate an integrative approach (considering the thermal and microclimatic functions of courtyards simultaneously). Afterward, the paper reviews the role of three main climatic factors — solar gain, humidity, and natural ventilation — in each category.

1. Introduction

Finding a solution for global crises such as environmental pollution, carbon emission, climate change, increasing energy demand, and lack of natural resources is the subject of many studies. More than 30% of carbon emissions, which is the main reason for climate change, is from the energy consumption of buildings. Hence, conducting research on sustainable design strategies to decrease energy demand is inevitable. In this regard, the construction of courtyards is an effective sustainable strategy to control the microclimate and the energy consumption of buildings.

In the late 1960s, Martin and March [1] studied six urban block forms at Cambridge University. After the detailed analysis and comparison of the built potential and daylight amount, they concluded that the courtyard creates optimum land use. Ratti et al. [2] studied three urban blocks based on Martin and March [1] in a hot and arid climate. They calculated the surface to volume proportion, sky view factor, daylight, and shade amount and further concluded that the courtyard layout had the best performance among the various building forms. The implementation of courtyards has always been regarded as a suitable design to offer privacy, comfort, and minimum energy usage. Furthermore, courtyards provide a good amount of daylight, natural ventilation, and thermal performance. Meir [3] also believes that applying courtyard structures as microclimatic modifiers has been considered during the last four decades, particularly in hot and arid weather [4–7]. Additionally, research in the United Arab Emirates showed that the annual energy consumption of an optimized courtyard is 11.16% lower than that of conventional building forms [8].

Due to complex interactions between the microclimatic and thermal functions of the courtyard, simultaneous simulation of the thermal conditions of indoor and outdoor spaces is inevitable.

The interactions between the building and its surroundings occur at three levels: the building, neighbourhood, and urban levels. The integrative approach of indoor and outdoor thermal conditions has been

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used before: Yi and Peng [4] demonstrated the interaction between building indoor thermal performance and outdoor microclimates using three simulation software programs at three microclimate levels: CCWorldWeatherGen at the city level, ENVI-met at the neighbourhood level, and DesignBuilder at the building level.

Many studies with different methods examined the climatic aspects of courtyards. Furthermore, the authors of this paper found two review papers about the climatic aspects of courtyards. The first discussed the historical and cultural evolution of transitional spaces, such as courtyards, patio, and atriums, in different climates [9]. Additionally, this review compared the environmental characteristics of low-rise residential courtyard in different climates. The second review paper focused on thermal comfort in Middle Eastern courtyards in houses [10]. Although the previous reviews covered some climatic aspects of courtyards, a comprehensive review on measurement-based and simulation-based papers on courtyards as an effective passive design strategy is necessary.

The innovation of the present review is the understanding of the thermal and microclimatic functions of courtyards and considering the importance of the interaction between indoor and outdoor thermal conditions. Furthermore, this review article intends to cover the effect of climatic aspects of courtyards at both the building and neighbourhood level.

1.1. A brief review of courtyards

The Cambridge Dictionary defines a courtyard as “An area of flat ground outside that is partly or completely surrounded by the walls of a building.”

The amount of shadow changes in the courtyard during the day, and consequently, temperature differences occur between surfaces and causes a heat transfer through convection between the surfaces and the air in the indoor and outdoor spaces of the courtyard. A fraction of the heat is stored in the thermal mass of the courtyard, which is released at night. The remaining part of the heat transfers through conduction, and natural ventilation occurs through the sky over the courtyard [11] (Fig. 1).

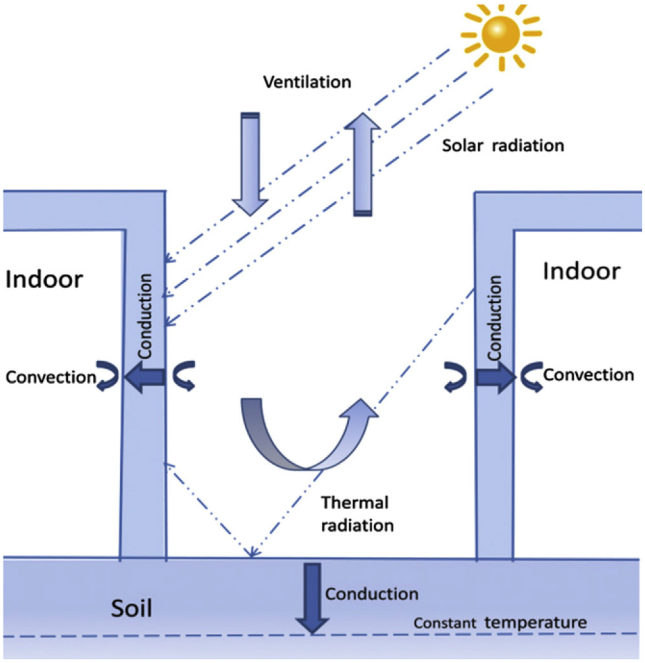

Fig. 1. The illustration of the ventilation process and heat exchange in the courtyard [11] (left).

1.2. Courtyard development through history

For 5000 years, courtyards have been developed to adapt to severe climatic conditions. Taleghani [9] presented the evolution of house courtyards in four categories:

1.2.1. Ancient civilizations from North Africa to China

Troglodyte villages in the Matmatas of Southern Tunisia are the most primitive areas in the world in which courtyard houses were built. In ancient China, which was strongly influenced by the principles of yin and yang, the simplest underground settlement form in Honan (China) is similar to Troglodyte dwellings (Tunisia).

1.2.2. Classical civilizations in Greece and Rome

After discovering the thermal benefit of courtyards, Greeks designed their houses in such a way to have sunlight in the courtyard in the winter and blocked sunlight with eaves on the portico in the summer.

1.2.3. The middle ages

Along the Mediterranean Sea, courtyard houses can be seen. Rapoport [12] notes that in ancient civilizations, certain courtyard forms were adopted due to their cultural benefits. In this regard, courtyards were developed not only for their thermal performance but also for their privacy features in Islamic civilizations. Four season Persian houses, gardens, simple Arab houses, and Syrian houses with simple exteriors and luxuriant interiors are some examples of the manifestations of Islamic philosophy in architecture. Moreover, throughout this period, underground spaces were an addition to Middle Eastern building courtyards.

1.2.4. Modern era

During the last two centuries, the Spanish Colonial Revival movement in Southern California (late 19th century) resulted in the appearance of courtyards on the West Coast of North America. According to Macintosh's observation, in Europe in 1928, Hugo Haring built the first of such houses overlooking a garden to the south. Finally, this type of architecture is still in use almost all over the world [9].

2. Methodology

This study systematically reviews the literature on the climatic aspects of courtyards (Table 1). It classifies current publications into three main categories: 1- those examining the microclimatic function of courtyards, 2- those based on the thermal function of courtyards, and 3- those incorporating an integrative approach (considering the thermal and microclimatic functions of courtyards simultaneously). Afterward, the paper reviews the role of three main climatic factors — solar gain, humidity, and natural ventilation — in each category. Moreover, the level of each study has been analysed to show whether the research was performed at the building or neighbourhood level.

The authors of this paper searched through three main databases: ScienceDirect, Taylor and Francis, and ProQuest. The search terms are related to courtyards, microclimate, energy consumption, and thermal comfort in articles, titles, abstracts, and keywords. The results were classified into seven categories shown in Table 1: the journal and date, main variable, paper emphasis, level of the project, and the method of testing and defining the context of the research (microclimatic function of courtyards, thermal function of courtyards or an integrative approach).

2.1. Objectives

The main objective of this review is to study the microclimatic and thermal functions of courtyards. The present paper clarifies the efficiency of this building type in reducing energy consumption. Additionally, it shows the impacts of different design factors and