CFD EVALUATION OF THE POTTERY WATER WALL IN HOT ARID CLIMATE OF LUXOR, EGYPT

BY

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ABSTRACT

The research is an attempt to improve the existing water wall by means of experimenting the humidity and temperature levels improvement caused by the pottery water wall. This study aims to evaluate the pottery water wall in hot arid climate specifically Luxor, Egypt using ANSYS Fluent for Computational Fluid Dynamics CFD simulation. The pottery water wall is a passive system in which the concept has been patented by the author at the Egyptian Patent Office. The pottery water wall is a combination of a water wall and porous ceramic pipes for evaporative cooling. It is regarded as an improvised version of the water wall. The study evaluates the efficiency of the pottery water wall in cooling and heating. The study compares between its designs, aiming to decipher the most efficient design of the pottery water wall, by simulating four different models on a room with a volume of 75m3 with three different opening sizes, porous ceramic pipes and surface areas as variances. The most efficient model of the pottery water wall derived from the first simulation will be evaluated for thermal comfort in the worst climatic conditions in Luxor, Egypt. The findings showed that the highest efficiency of the pottery water wall was achieved while using a moderate sized opening (900mm x 900mm), while its efficiency decreases if the opening size of 900mm by 900mm is made smaller or bigger. The simulation findings found that the pottery water wall can help to cool the room by decreasing its indoor air temperature between 4oC and 10oC and heat the room by increasing its temperature between 4oC and 15oC. The decrease and increase in temperature depends on the efficiency of the pottery water wall and its design. The simulation results indicated that the pottery water wall achieved comfortable indoor temperature for 62.5% of the 21st of June 2011 the day resembling extreme summer, achieved thermal comfort for 62.5% of the 21st of January 2012 the day resembling extreme winter and 75% of an average day (21st of April 2012). Based on the simulation results, it can be deduced that an appropriate design of the pottery water wall can cut down the cooling and heating demand by 88% in the extreme climatic conditions of Luxor, Egypt both in summer and winter.

ملخص البحث

تهدف هذه الدراسة إلى تقييم أداء الحائط المائي الفخاري بالمناخ الحار الجاف, و كمثال للمناخ الحار الجاف تم اختيار مدينة الأقصر بمصر, سيتم التقييم باستخدام المحاكاة المحوسبة باستخدام برنامج أنسيس فلوينت. الحائط المائي الفخاري نظام تهوية صديق للبيئة و يعتبر تطوير لنظام سابق و هو الحائط المائي. الحائط المائي الفخاري مسجل باسم الكاتب كبراءة اختراع بمكتب براءات الاختراع المصري. الحائط المائي الفخاري مزيج بين نظامين سابقين هما الحائط المائي و أنابيب من السيراميك عالي النفاذية للتبريد بالتبخر, يهدف هذا المزج إلى استغلال مزايا كل من النظامين و تفادي عيوب كل منهما. سيقوم البحث أولا بتقييم قدرة الحائط المائي الفخاري على التبريد و التدفئة و من ثم المقارنة بين تصميمات مختلفة للحائط المائي الفخاري, عن طريق عمل محاكاة محوسبة لأربع تصميمات تتمايز بحجم الفتحة و مساحة السطح الخاصة بالسيراميك عالي النفاذية بغرفة حجمها خمسة و سبعون مترا مكعبا. من ثم تقييم قدرة الحائط المائي الفخاري على تحقيق الراحة الحرارية في أقصى الأحوال الجوية سوءا بمدينة الأقصر بمصر. وجدت الدراسة أن أكثر التصميمات كفاءة هو التصميم ذو الفتحة المتوسطة (900 مم X 900 مم) و أي زيادة أو نقص بحجم الفتحة تؤدي إلى تقليل كفاءة الحائط المائي الفخاري. وجدت الدراسة أيضا أن الحائط المائي الفخاري له قدرة على التبريد تتراوح بين الأربع درجات مئوية و العشر درجات مئوية و قدرة على التدفئة تتراوح بين الأربع درجات و الخمس عشرة درجة مئوية. وجدت الدراسة أن الحائط المائي الفخاري حقق الراحة الحرارية لاثنين و ستين بالمئة من يوم الحادي و العشرين من يونيو اليوم الذي يمثل أكثر أيام الصيف حرارة. بينما حقق الحائط المائي الفخاري الراحة الحرارية بالمبنى لاثنين و ستين بالمئة من الحادي و العشرين من يناير اليوم الذي يمثل أشد أيام الشتاء برداً. أخيرا وجدت الدراسة أن الحائط المائي الفخاري غطى ثمانية و ثمانين بالمئة من الحاجة إلى التبريد و التدفئة في أقصى أيام الصيف حرارة و الشتاء بردا بمدينة الأقصر بمصر.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as thesis for the degree of Master of the Built Environment.

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Srazali Aripin
Supervisor

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Head, Department of
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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or any other institutions.

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CHAPTER ONE

INTRODUCTION

1.0 INTRODUCTION

For the past few decades, since 1973 energy crisis surfaced, and hence passive solar design has been researched, upgraded and harnessed to reduce energy consumption for heating and cooling of buildings. One of these passive design systems is the thermal storage wall (solar wall), a passive solar system mainly used for heating and cooling the interior of buildings. The thermal storage wall is a medium for thermal storage using either water or masonry placed between the collector and the living quarters. The thermal storage medium stores the heat from the sun and redistributes it throughout the day and night for heating. The thermal storage wall is mainly designed for cold and severe cold climates with the purpose of increasing the indoor temperature, while not affecting humidity or inducing ventilation which are the main issues for human comfort in hot arid climates. However, it can be used for cooling, as it has been used and commercialised for cooling mainly in the United States, while using other means to compensate ventilation and lack of humidity as argued by Bainbridge (2005).

In the context of vernacular traditional architecture of the Middle East, which has mainly hot arid climates, evaporative cooling systems are applied to address the issue of the lack of humidity, using systems such as the *malqaf*, the *badgir* and the *Muscatese evaporative cooling window,* which is explained further in Chapter Four. The common factor among these systems is to induce outside air into the room for cooling. Then air passes along water – which is sprayed or in pottery jars - to induce evaporation and convection, causing the decrease of air temperature, the increase of humidity and the introduction of ventilation. These three elements are the key factors of human comfort in hot arid climates. It has the capability to address the issues of the thermal storage walls i.e. poor ventilation and lack of humidity altering capability. The study is an attempt to combine the two systems creating a system called the pottery water wall, which is the fusion of both thermal storage walls and evaporative cooling.

The study aims to investigate the pottery water wall. By combining the thermal storage walls with its big heat capacity and evaporative cooling, human comfort in hot arid climates can be achieved for longer period. The pottery water wall is an improvised version of the thermal storage wall. It combined the water wall (solar wall) and evaporative cooling to increase its efficiency as discussed above. The pottery water wall is a water wall that uses pottery (porous ceramic) piping as an evaporative cooling medium. This concept was patented by the author in the Egyptian Patent Office in April (2010) [Egypt patent application No. 20101663]. This patented concept of pottery water wall needed further evaluation as it has not been tested. Therefore, one of the main objectives of the study is to evaluate the efficiency of the pottery water wall through a simulation study of the local climatic condition of Luxor, Egypt.

1.1 THE STUDY

The study investigates and evaluates the thermal storage wall specifically the water wall in comparison with its upgraded of the pottery water wall in hot arid climate specifically Luxor, Egypt. First, the research aims to compare the water wall’s efficiency to that of the pottery water wall, to decipher the effect of adding evaporative cooling to the water wall's efficiency. Then, the study deduces the pottery water wall's ability to achieve human comfort compared with ASHRAE's criteria. The research aims to find the most efficient design and dimension of the pottery water wall components such as the pottery piping length and thickness. Secondly, the research also aims to decipher the pottery water wall's efficiency in reducing the cooling and heating demands in Luxor, Egypt. Computational Fluid Dynamics (CFD) specifically using the program ANSYS Fluent is used to model and simulate both the water wall and the pottery water wall under the climatic conditions of Luxor, Egypt. The study uses CFD simulation to create multiple variables of the pottery water wall to find the most efficient design, while also comparing the results to that of the water wall and the ASHRAE human comfort standards.

1.2 RESEARCH BACKGROUND

The research begins with a review on passive design, thermal storage walls emphasising on water walls, evaporative cooling and the pottery water wall. Section 1.2 describes passive design as it is the main emphasis of the study. The thermal storage walls as the passive system are also researched and elaborated in the study. An emphasis on the water wall and a review of its disadvantages that lead to the creation of the pottery water wall follow subsequently. Then, a review on evaporative cooling and how it may solve the issues of the water wall, emphasising on the role of pottery as an evaporative cooling medium are put forward. This section also describes the upgraded version of the water wall i.e. the pottery water wall, previewing its design which combines the water wall and evaporative cooling to achieve human comfort in hot arid climates, highlighting how it can potentially solve the issues of the water wall.

1.2.1 Passive Design

Many researchers regarded that employing passive design was an efficient way to reach occupants' comfort, while using the least possible energy as derived from, Winter (1998), Anderson and Wells (1992) and Santamouris (2007). Winter (1998) mentioned that passive design was to use the sun's energy, natural lighting, outdoor air and the insulation of the earth to make buildings more energy efficient. Passive design splits into two main streams: passive strategies and passive systems.

Passive strategies are to utilize nature in the most direct way by either exploiting directly its elements such as solar radiation, or negating the negative effects of the natural element like overheating in summer. Some of the most important methods employed in passive strategies to achieve human thermal comfort in an indoor environment are building orientation, shading devices and natural ventilation. Winter (1998), Anderson and Wells (1992) and Santamouris (2007)

Passive systems are more complex ways to harness and increase the benefits gained from nature's elements by using simple physics laws. The main passive systems are the direct gain system, the thermal storage walls (solar walls), the solar space (green house) and the solar chimney (convective loop system). These systems use the sun in an indirect way by mainly collecting and storing solar radiation and heat for later use or use solar heat to create a difference in pressure to induce air movement to ventilate the building. The study focuses on the second stream of passive design that is the passive systems, emphasising on the thermal storage walls which will be elaborated in the next subsection.

1.2.2 Thermal Storage Walls (Water Walls)

Winter (1992) and Anderson and Wells (1992) describe the solar walls as the system where a thermal storage medium is placed between the collector (window or glazing) and the living quarters. Its theory depended on using a storage medium with large heat capacity to store solar heat. Then, it is redistributed throughout the day, especially when it is needed the most at night. On the other hand, it can be used for cooling in certain climates where there are huge swings of temperature between day and night. In such climates the solar wall radiated stored heat into the building during the night and did the opposite during the day, by absorbing heat from the building to cool the building as described by Winter (1992). Nowadays, it has been commercialised and used for cooling in the southern states of America as claimed by Bainbridge (2005).

Solar walls are classified by the material used for thermal storage. If masonry is used for solar wall it is referred as Trombe wall. Meanwhile it is called a water wall if water was used as the storage material, which is the focus of the study. Bainbridge (2005) described the water wall as ‘the use of water as thermal mass in passive solar homes for heating and cooling’. Water walls dated back to 1947, when the first water wall was built by Hottel, Hoyt. Then water walls disappeared until their return in 1972 when they were reconstructed by Baer, Steve, and since then commercialised in the United States and other countries. Winter (1992) claimed that water is better than masonry in heat storage, as it has nearly double the heat capacity of masonry.

However, thermal storage walls transfer heat by convection and radiation to control indoor air temperature, while not affecting humidity or introducing outdoor air for ventilation. Humidity and ventilation are important factors to achieve human comfort in hot arid climates due to dryness. Therefore thermal storage walls are not efficient enough to achieve thermal comfort in hot arid climates. The study emphasises on the upgrade of thermal storage walls using evaporative cooling in hot arid climate. Since evaporative cooling uses ventilation and humidification it could achieve thermal comfort in hot arid climate.

1.2.3 Passive Direct Evaporative Cooling

Santamouris (2007) stated that '*water will evaporate if air with a lower dew point passes by*'. This phenomenon is called evaporative cooling, which causes the cooling and humidification of air passing by water. Evaporative cooling has been used in vernacular architecture in the Middle East around a thousand years ago. It is even argued by Fathy (1986) that evaporative cooling dated back to 1300 B.C in Old Egypt as evident by drawings on a tomb's wall in Thebes (modern Luxor, Egypt), where it displaye a wind catcher with water jars inside it to cool the air caught by the wind catcher. Schiano-phan (2004) mentioned that evaporative cooling was used in the *Muscatese* evaporative cooling window, where is a pottery jar is placed in a *Mashrabbiya (*wooden grille) in the way of incoming air to cool and humidify it. Other vernacular systems that use evaporative cooling are the *Malqaf* and the *Badgir*, traditional wind catchers that have a *Salsabil* (water fountain) or water filled pottery jars to induce evaporation for cooling and humidifying incoming air caught by the wind catcher to achieve thermal comfort in hot arid climates.

Evaporative cooling was revived and commercialised in desert coolers in 1920, an apparatus similar to an air conditioner but uses water instead of the compressor and (chlorofluorocarbons) CFC gases. Then Bahadori (1985) revived and upgraded the traditional *Badgir* and *Malqaf* that led to the creation of the Downdraught Evaporative Cooling Towers (DECTs), a modern upgrade of the wind catcher that uses water sprinklers instead of the *Salsabil* and pottery jars to humidify and cool incoming air. A recent research funded by the European community, conducted at 2003, named passive downdraught cooling system using porous ceramic created a system called EVAPCOOL. EVAPCOOL is porous ceramic boxes filled with water and stacked upon each other in the way of incoming air using the concept of evaporative cooling to cool and humidify air. A simulation study using CFD carried out by Schiano-phan (2004) showed that the application of EVAPCOOL in residential buildings around Spain could potentially reduce the energy loads by approximately 12%. The system proposed in this study combines the water wall with evaporative cooling is named the pottery water wall, is elaborated in the next subsection.

1.2.4 The Pottery Water Wall

The pottery water wall explored in this research is an improvised version of the water wall, a combination between the ordinary water wall and passive evaporative cooling using pottery (porous ceramic). The conceptual idea has been patented by the author in April (2010) under Egypt Patent Application No. 2010/663. It is believed that by adding the pottery piping to the water wall, its efficiency will increase, due to the addition of evaporative cooling to the radiant and convective heat transfer of the water wall. It is argued that by this addition it will overcome the issues of the water wall, by the addition of humidification and the introduction of ventilation to the building, therefore improving its ability to achieve thermal comfort in hot arid climates. This is since both humidity and ventilation are critical for human comfort in hot arid climates. However, no previous research has been done on the pottery water wall. Therefore, the study aims to evaluate and validate the pottery water wall in comparison to the water wall.

Chapter two, three, four and five will elaborate further on these research topics providing more detailed descriptions and elaborations on the issues and challenges of the study. The following problem statements are established in the research.

1.3 PROBLEM STATEMENTS

A literature review on the water wall has been carried out and the following issues are highlighted.

1. The water wall does not introduce outdoor air to ventilate the Building.

Since the water walls are mainly used for heating, outdoor air was not regarded in the design. It depends on thermal storage and radiation of thermal energy not ventilation and radiation of energy. While in hot arid climates ventilation is needed the most for human comfort.

2. The water wall does not affect the indoor humidity of the room.

Although thermal storage walls are efficient to achieve comfortable indoor air temperature, they use only radiant heat transfer to reach the human comfort zone as proved by Malcolm's and Wells (1992) and Winter (1992). This means the lack of ventilation to enhance indoor air quality and the lack of the use of evaporative heat transfer to control humidity in the building. While the main issue in hot arid climates is humidity due to dryness.

These two issues are to be addressed in this study in order to achieve indoor thermal comfort using pottery water wall.

1.4 RESEARCH QUESTIONS AND HYPOTHESIS

The hypothesis of the study is that the pottery water wall can achieve thermal comfort in hot arid climate and the efficiency of the pottery water wall is greater than the water wall. However, the pottery water wall is just a theory and needs to be validated, and further experiment and analysis are needed to define the optimum dimensions, materials and thicknesses.

The research questions are formulated based on these hypothesis;

1- What is the opening dimension of the opening of the pottery water wall?
2- How efficient is the pottery water wall in altering indoor temperature, relative humidity and air velocity in hot arid climates?
3- How does the efficiency of the water wall affect the pottery water wall?
4- To what extent can the pottery water wall increase the air velocity and introduce ventilation to buildings in hot arid climates?
5- To what extent can the pottery water wall achieve comfortable indoor air temperature and relative humidity in hot arid climates?

1.5 RESEARCH AIM AND OBJECTIVES

The research aims to evaluate the pottery water wall's ability to achieve comfortable indoor air temperature and relative humidity in hot arid climates. That is done by evaluating its ability to manipulate indoor air temperature and relative humidity, finding the most efficient design of the pottery water wall and its ability to achieve thermal comfort throughout the year under the climatic conditions of Luxor, Egypt.

The objectives of the research are:

1. to define the optimum opening dimension of the pottery water wall,
2. to evaluate the efficiency of the pottery water wall in altering indoor temperature, relative humidity and air velocity,
3. to identify the relationship between the efficiency of the water wall and the pottery water wall,