EFFECT OF WATER IN BUILDING PASSIVE COOLING STRATEGIES: A CASE OF SHISH MAHAL COMPLEX OF MUGHALS

BY

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ABSTRACT

Water, in modern cities, is often seen as an infrastructural asset, rather than analyzed, appreciated, and inserted in urban context in its morphological, architectural, and environmental dimensions. This thesis studies the water elements of 16th-century Mughal building complexes, with a focus on the Shish Mahal Complex of Lahore Fort, which is argued as a kind of peak or apotheosis of Mughal architecture-based water systems. By looking at both urban-morphological and architectural-engineering dimension, it re-engages with the holistic nature of Mughal architecture in which water systems is seen in its spiritual, aesthetic, and environmental dimension. It then focuses on the environmental analysis of one feature- the coupling of water with thermal mass system of the basement of Shish Mahal, to study its modeling mechanisms and the potential passive impact of the coupling of thermal mass and water elements under such hot arid climate. This was done and further simulated and visualizes the actual indoor thermal condition of the basement of Shish Mahal if the water elements are not present. A fieldwork measurement of Shish Mahal Complex is conducted and acquired for Computational Fluid Dynamics (CFD) ANSYS Fluent simulation process. The thesis contributes to a narrative that investigates both the historical and analytical 'performance-based' perspective, in which the 'morphological' form and shape of the 2 and 3-dimensional shape are initially discussed, and then the impact of water in buildings are studied as a combination of vertical waterwalls and horizontal pools to verify its climatic performance. It is found that the coupling of waterwall with thermal mass will result 8˚C to 18˚C in reduction to the indoor temperature under hot arid climate conditions when the outdoor temperature rises to 40 ˚C without resorting to any mechanical cooling. The results also demonstrated that the exploitation of low mean airspeed of 0.5 m/s provides a significant contribution to decrease the indoor temperature. Low mean airspeed provides ample time for the evaporative cooling of the indoor environment to become more efficacious and cooled air to circulate within the premise boundary, this is however work if cross-ventilation strategy is adopted at the same time.

خلاصة البحث

غالبًا ما يُنظر إلى المياه ، في المدن الحديثة ، على أنها أحد أصول البنية التحتية ، بدلاً من تحليلها وتقديرها وإدراجها في السياق الحضري بعادها المورفولوجية والمعمارية والبيئية. تدرس هذه الأطروحة عناصر المياه في مجمعات المباني المغولية في القرن السادس عشر ، مع التركيز على مجمع شيش محل في قلعة لاهور ، والذي يُقال إنه نوع من ذروة أو ليه أنظمة المياه القائمة على العمارة المغولية. من خلال النظر إلى كل من البعد الحضري المورفولوجي والهندسة المعمارية ، فإنه يعيد المشاركة مع الطبيعة الشاملة للعمارة المغولية التي تُرى فيها أنظمة المياه في أبعادها الروحية والجمالية والبيئية. ثم يركز على التحليل البيئي لميزة واحدة – اقنزان الماء بنظام الكتلة الحرارية في الطابق السفلي لشيش محل ، من أجل دراسة آليات النمذجة والتأثير المحتمل لاقنزان الكتلة الحرارية وعناصر الماء تحت مثل هذا الجفاف الحار. مناخ. تم القيام بذلك ومزيد من المحاكاة وتصور الحالة الحرارية الداخلية الفعلية للطابق السفلي من شيش محل إذا لم تكن عناصر المياه موجودة. يتم إجراء القياس الميداني لمجمع شيش محل والحصول عليه من أجل عملية محاكاة ديناميكيات السوائل الحاسوبية ANSYS Fluent (CFD).
تساهم الأطروحة في سرد يبحث في المنظور التاريخي والتحليلي "القائم على الأداء" ، حيث تتم مناقشة الشكل والشكل "المورفولوجي" للشكل ثنائي الأبعاد وثلاثي الأبعاد في البداية ، ومن ثم يتم مناقشة ثير الماء في المباني تمت دراستها كمزيج من المسطحات المائية العمودية والبرك الأفقية للتحقق من أدائها المناخي. لقد وجد أن اقنزان الجدار المائي لكتلة الحرارية سينتج عنه 8 درجة مئوية إلى 18 درجة مئوية في تقليل درجة الحرارة الداخلية في ظل ظروف المناخ الجاف الحار عندما ترتفع درجة الحرارة الخارجية إلى 40 درجة مئوية دون اللجوء إلى أي تبريد ميكانيكي. أظهرت النتائج أيضًا أن استغلال متوسط سرعة هواء منخفض يبلغ 0.5 م / ث يوفر مساهمة كبيرة في خفض درجة الحرارة داخل المباني. يوفر متوسط سرعة الهواء المنخفضة وقتًا كافيًا للتبريد التبخيري للبيئة الداخلية ليصبح أكثر كفاءة وتبريد الهواء للدوران داخل حدود المبنى ، ومع ذلك فإن هذا العمل إذا تم اعتماد استزاتيجية التهوية المتقاطعة في نفس الوقت.

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 a thesis for the degree of Master of Science (Built Environment).

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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 other institutions.

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LIST OF ABBREVIATIONS

GBI	Green Building Index
SRI	Solar Reflectance Index
UHI	Urban Heat Island Impact
CFD	Computational Fluid Dynamics
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning
PMV	Predicted Mean Vote
CAD	Computer Aided Design
PISO	Pressure-Implicit with Splitting of Operators
ISO	International Organization for Standardization
UDF	User Defined Functions

LIST OF SYMBOLS

˚C	Degrees Celsius
K	Degrees Kelvin
Rh	Relative Humidity
m^2	Meter square
m/s	Air velocity (meter per second)
T_{mrt}	Mean Radiant Temperature
TL	Time Lag
k-ε	K-epsilon Turbulence Model
g_s	Amount of Evaporated Water per second (kg/s)
ϕ	Evaporation coefficient
A	Water Surface Area (m^2)
X_s	Maximum Humidity Ratio of Saturated Air
X	Humidity Ratio Air
q	Heat loss (Kj/m^2)
h_{we}	Evaporation Heat of Water (Kj/kg)

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

It is increasingly realized that sustainability particularly water includes both responses to the climatic and cultural context of a place. There has been a discussion on how these elements of sustainability must eventually imply 'back to basics' and relive lessons from the past approach in terms of environmental characteristics rather than employing 'high technology' add-on features. Hence, there has been a resurging interest in the role of water in urban design and its potential impact on the climatic situation of an area rather than exist only for aesthetic and recreational activities.

Apart from the sustainability agenda, water provides psychological, visual, auditory, and tactile effects, which are primarily perceived by the senses, and affects human psychologically rather than merely visually and physically (Booth, 1989). Hence in terms of aesthetic dimensions, water elements are primarily perceived by the senses as a 'visual element' in urban spaces. However, symbolizing the beginning and the continuity of life it affects human before psychologically rather than visually leading them to it. Except for the directive effect, water elements have also relaxing effects such as visual, acoustic, and provide concentration with tactile integration on the human (Booth, 1989).

Currently, in the arena of sustainable architecture, passive mechanisms are on the rise as it is seen as a cost-effective and value–engineering principles and contribution to sustainability. While passive cooling strategies such as shading, orientation, natural ventilation, and landscape have been researched in-depth, there is a lack of studies in water due to the difficulty of modeling and testing of this element

especially when the water bodies are placed inside a building. According to Yang & Zhao, (2015), previous studies on thermal effects of urban areas under different climatic conditions have tendencies to focus more on pavements and vegetation elements while waterbodies or urban water features are the elements that least studied on.

Passive cooling has been known to be the hallmark of Islamic architecture, particularly to its large building complexes, as many of them are located in hot climate regions. For example, Willmert (2010) usefully discusses and give insight to the environmental rationale and wisdom of typological elements in the Alhambra complex, Granada, Spain from the integral insertion of courtyards, extensions, and projections of patios, to infusion of the complex with optimum dimensions in fountains and pools. He highlights how the demands of the ruling elite had placed a high level of requirement on the environmental conditioning of such complexes, and the ability of the complex to provide this passive attribute to technology during the medieval era, which comfort conditions must be achieved to the highest expectations of the monarch with minimal use of energy.

Study on the environmental characteristics of Islamic heritage structures to gauge the climatic performance, architectural and ecological wisdom is frequently studied in the field of passive low energy architecture. There has been a wide range of studies focuses on a narrative approach to highlight the environmental and architectural ingenuity of Islamic complexes, including narrative socio-cultural studies, while other have utilized more empirical methods of site measurements and the use of computation simulation to analyze and verify the environmental performance of these heritage building complexes.

Previous Islamic civilization that grew under intensely hot regions, have evolved water-based features and achieved a high degree of comfort with minimum use

of renewable energy, as electricity was non-existent at the time. Islamic architectural monuments and complexes have water elements that have become both a spiritual and ecological landmark. Because in Islam, water symbolizes purity and purification, water is an element valued highly due to its purifying and soothing qualifications, and not merely a functional resource. In these complexes, there are endless variations of water elements which are defined as the elements of space different in terms of scale, location, architectural features, material, and design criteria and easily recognized or discernible from several directions (Lynch, 1960).

Islamic architecture, in the word of renowned Malaysian architect, Hijjas Kasturi, is centered on water. Traditionally, in Islamic civilization, water elements have essentially two main purposes; 'aesthetic' and 'functional', hence, the role of water systems may have developed from its essentially agricultural economic base, but it had evolved in complexity and during the height of the empire, it is seen as a form of integrated urban systems which have both socio-ecological and socio-cultural dimensions rather than merely engineered solutions. Water has been part of both outdoors and indoors environment of architecture, and the analysis of indoor and outdoor impact require different tools and computational resources that governed by different equations. Past large building complexes, including its urban and architecture design, constitute a treasure and resource that has yet to be analyzed to the fullest.

As the centuries passed by, modern Islamic states like Malaysia were perceived by the element of water not as the sole cooling medium but as part of aesthetic design intervention. This can be re-look at the design of a few prominent mosques in Malaysia such as Masjid Tuanku Mizan Zainal Abidin, Putrajaya, and Masjid Negara in Kuala Lumpur. Both buildings implement the same scheme of designing the water element surrounding the main prayer area, but Masjid Negara exhibits better thermal