ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 10| Issue: 6| June 2024|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2024: 8.402 || ISI Value: 1.188

WIND-DRIVEN NATURAL VENTILATION – THE WIND TOWER AS A STRATEGY TO REDUCE ENERGY USE IN LOW-RISE BUILDINGS IN HOT CLIMATES

Suparna Sircar (Ojha)[1], Jagbir Singh[2], Bharat Raj Singh, Ph. D.[3]

[1]*Professor, Amity School of Architecture and Planning, Amity University Uttar Pradesh*
[2]*Professor & Director, Amity School of Architecture and Planning, Amity University Uttar Pradesh*
[3]*Professor & Director General – Technical,IET, School of Management Sciences - Technical Campus, Dr APJ-AKTU, Lucknow*

Corresponding Author: Suparna Sircar (Ojha) *Professor, Amity School of Architecture and Planning, Amity University Uttar Pradesh, Lucknow.*

Article DOI: https://doi.org/10.36713/epra17542
DOI No: 10.36713/epra17542

ABSTRACT

Wind-driven natural ventilation is a topic of interest in the field of sustainable architecture, particularly in the context of low-rise buildings located in hot climates. This paper aims to provide a comprehensive assessment of the wind tower as a prominent model for reducing energy consumption in such buildings. A look at the Wind tower as a significant model to cut down on energy consumption in low-rise buildings located in hot climates is presented in this article as part of a discussion on wind-driven natural ventilation. A comprehensive examination of wind-driven natural ventilation is presented herein, with a particular focus on the efficacy of the Wind tower as an exemplary model for mitigating energy consumption in low-rise structures situated in hot climatic conditions. The utilisation of natural ventilation and cooling has been crucial in ensuring optimal comfort conditions. They can greatly impact the reduction of cooling loads and provide the required ventilation rate for buildings. This paper seeks to offer a review of the latest advancements and uses of wind towers in contemporary architecture. The efficiency of a wind tower is also analysed based on its pertinent parameters, such as height, configuration, and cross-section. The potential of wind towers in modern architecture and urban planning is demonstrated by their application in contemporary buildings, their integration into the urban context, and the development of innovative designs and technologies for wind towers.

KEYWORDS: *Wind tower, Natural ventilation, Passive cooling, Thermal comfort, Energy efficiency*

INTRODUCTION

The process of ventilation involves the exchange of air within an enclosed space. Air should be frequently extracted and substituted with air coming from a clean, outside source to sustain excellent indoor air quality, which is considered a condition whereby no identified impurities are present at unhealthy levels. Excessive humidity, condensation, overheating, and the accumulation of contaminants, odours, and smokes can result from a lack of ventilation. Huge fans, ducts, air-conditioning, and heating devices are typically included in HVAC (heating, ventilation, and air-conditioning) systems that are highly energy-intensive in buildings used for business and industry. Ventilation is a component of these systems. The primary ventilation mechanism in domestic buildings is sustainable, based on natural ventilation by means of openings and passage of air [1, 2]. Building mechanical cooling systems are also significant contributors to carbon dioxide emissions, resulting in detrimental effects on the environment and exacerbating global warming, especially in hot climates [3]. Utilising natural ventilation is a viable passive approach to enhance the quality of indoor air [4]. The natural ventilation method effectively introduces fresh air into a space, thereby reducing the concentration of indoor pollution. Increasing the ventilation rate leads to a decrease in pollutant concentration within the indoor environment. As the need for ventilation rate increases, so does the energy load and demand. Hence, the utilisation of natural ventilation is a more effective approach for minimising energy expenses when compared to mechanical systems. Allard [5] proposed that natural ventilation is a more cost-effective option when considering the expenses associated with mechanical systems, such as capital, maintenance, and operational costs.

Wind-driven ventilation versus Stack Effect – The stack effect and wind-driven ventilation are the two primary fundamental principles that are involved in natural ventilation. The stack effect is a phenomenon that occurs when the temperature within a building is greater than the temperature outside the building. This phenomenon is created by temperature variations between the inside and exterior environment of a building. As the warm air from the interior of the structure rises and comes out of the apertures in the building, it gets substituted by the air from below, which is cooler and denser. In their study, Naghman et al. [6] found that the stack effect is diminished when there is a relatively minor temperature differential between the inside and outside

ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 10| Issue: 6| June 2024|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2024: 8.402 || ISI Value: 1.188

environments of buildings. When conditions are hot and humid, there is not much of a difference in temperature between the indoor environments and the outdoor environments. The stack ventilation method cannot provide a larger airflow to achieve satisfactory air changes for the people who are occupying the building because of the low temperature difference. Research conducted by Hughes and Cheuk-Ming [7] found that wind-driven ventilation offers 76% greater interior airflow than buoyancy effects. In accordance with Elmualim [8], it is recommended that natural ventilation through the utilisation of wind towers be utilised wherever it is feasible, particularly during the peak of the summer season.

WIND TOWERS

Ventilation systems are very important to the planning of buildings. Wind towers were used for a long time as an integral ventilation feature designed to facilitate passive ventilation in structures with a range of climates. A wind tower is a tall structure that looks like a chimney and is built on top of buildings. It works well in all kinds of weather to collect air from the outside and direct it to the room below [9]. Wind towers are made in different ways depending on the weather in a certain area and the need for air flow. More care is taken by designers to keep the humidity level in check in warm and subtropical areas. In other places, though, airflow and taking advantage of the winds or breezes are essential things to think about when designing a building. In dry and semi-dry areas, shade and safety from dust storms can be among the most important things. Most of the time, both scenarios are considered when designing buildings near the coast or in wind corridors. In hot and dry climates, however, passive ventilation and cooling are crucial for buildings, especially in suburbs or rural areas where regular power sources are hard to come by.

A wind tower lowers the interior temperature providing thermal comfort and renders the incoming airflow comfortable [10]. Scientists agree that in areas away from urban centres, wind towers are effective. Thus, wind towers make for a sensible and ecological building ventilation system [11]. Particularly in cases when the fresh wind cannot enter through openings in every corner of a structure or buildings with restricted openings, wind towers are efficient for buildings with insufficient ventilation. Passive ventilation depends on wind entering and changing direction, which is not achievable in these conditions. In buildings with a limited frontage or a low height, wind towers also become practicable [12]. Furthermore, wind towers aid in producing a buoyancy effect in low-velocity air [13,14]. From its windows, a fresh cool and heavy breeze fills a structure, from the wind tower, warm and light wind escapes. The heavier air causes light polluted air to exit, producing airflow.

Wind towers have been used for ventilation since before the advent of electricity, and they can also be effective in densely populated urban areas. Wind towers exhibit greater air circulation capabilities compared to other building fenestrations. A well-designed and adapted wind tower can offer purified air, a feature not achievable with standard urban windows [15]. Research on adapted wind towers on city buildings with poor natural ventilation has demonstrated that the addition of wind towers has improved passive ventilation in these structures. According to the findings, installing wind towers was especially helpful for keeping buildings cool throughout the summer. Additionally, the study noted that wind towers outperformed regular windows in terms of functionality and efficiency [16].

CATEGORIES OF WIND TOWERS

Wind towers have been categorised into many types based on factors such as the number of apertures, number of floors, cross-section, and interior partitions [17].

Wind towers based on the quantity of apertures – Wind towers are categorised based upon the number of apertures, Unidirectional wind towers, Bidirectional wind towers, quadrilateral wind towers, hexagonal wind towers, and wind towers with eight sides [18]. The one-sided wind tower, also known as a windcatcher, is designed with an inlet that allows chilly northern winds to enter inside rooms. It does not have any openings in the east, west, or south directions [17,18]. However, just a mere 3 per cent of wind towers in Yazd are unidirectional. Wind towers that are designed with only one side are more resilient to storms compared to other wind tower designs [19]. The term "twin wind towers" refers to two-sided wind towers [20]. Brick blades are utilised to divide them into two distinct sections. According to Roaf [21], 17 per cent of wind towers in Yazd are two-sided and were exclusively utilised by wealthy individuals. Quadrilateral wind towers are more elevated and larger compared to other wind towers. Traditionally, these wind towers were employed in regions characterised by arid conditions. Their heights are subject to variation based on climate conditions [22]. The predominant type of wind tower is the four-sided variety [23]. Wind towers in hot and humid regions are all quadrilateral in shape. Around 2 per cent of the wind towers in Yazd are of the octagonal variety, which is typically utilised for water storage [21, 22].

Wind towers based on cross-section types – There are five primary cross-sectional classes of wind towers. Different types of wind towers include cylindrical, square, and rectangular, hexahedral and tetrahedral wind towers. Cylindrical wind towers are harder to build than square, rectangular, tetrahedral, and hexahedral ones. However, cylindrical wind towers are efficient because they are designed for wind aerodynamics. Square wind towers outnumber circle, hexahedral, and tetrahedral ones. However, rectangular wind towers are most common [18]. Hexahedral and tetrahedral wind towers are shorter and used to store water [21, 22].

Wind towers based according to positions of blades – Wind tower efficiency is also determined by interior blades. They split up wind tower cross-sections and modify airflow velocity and turbulence. Thus, wind towers with different divisions have different properties and perform differently. Four divisions exist in square wind towers [24]. Hexahedral and tetrahedral wind towers have one division each. In these divisions, blades link to tetrahedral and hexahedral tips. X, +, H and K blades are used in rectangular wind towers. Wind towers are 1.5 times taller than wide. The most common dividing is rectangular wind tower and + blades [25].

WIND TOWER PERFORMANCE

Wind towers have greater advantages than other openings [26, 27, 28]. In dense metropolitan areas, windows are inefficient, therefore wind towers can provide the necessary ventilation. A three-story house with poor ventilation studied by Drach [29] found that a wind tower increased natural ventilation in this house. High pressure coefficient is another benefit of wind towers over conventional openings. Pressure coefficient at opening determines ventilation rate [30]. In urban Australia, Sadeghi et al. [31] compared wind tower performance to window ventilation. The study found that the pressure difference among the intake (wind tower) and outflow (window) was three times greater than when the window was employed for ventilation. An optimised wind tower has three times the average interior airflow velocity of window ventilation in Sydney's six warm months. Thus, wind towers are an effective passive cooling technology that can lower cooling loads in modern buildings [32].

Novel approaches to wind tower design – Conventional wind towers, however, had certain drawbacks in addition to their benefits. The shafts of wind towers allow dust and insects to enter interior rooms. Occasionally, a portion of the airflow that enters interior regions disappears through a different opening and does not circulate inside. In situations where the wind velocity is low, wind tower efficiency is low. Some or all these limitations must be addressed by contemporary wind towers. When combined with innovative designs and cutting-edge technologies, they have an increased probability of success [33].

- ***Scoop / Wind cowls –*** Wind cowls are roof ventilators. The terms "cowl" and "scoop" are employed interchangeably at times. A scoop is a device that admits air into buildings and cowl is an air extractor. Scoops can be static or spin about an axis to face the wind. Cowls are similar, but the opening faces leeward. This exploits partial negative pressure from wind-blown apertures or cowl rotation. Windcatchers often use wind cowls and scoops [34].
- ***Wind towers with moist columns and surfaces –*** Two innovative wind towers with moist columns and surfaces were compared to classic ones by Bahadori et al. [35]. This comparison shows these two novel models outperform traditional ones. The suggested wind tower has a revolving head and stationary column. Pumps wet the inlet grid pad and the wetted pad and revolving head improved wind tower efficiency substantially [18].
- ***Down-draft evaporative cool tower –*** A novel sort of wind tower, the PDEC wind tower operates in three phases. The first step involves using a pressure differential to let air into a wind tower. The second step is spraying water. By undergoing this process, the air that is entered becomes denser. In the last step, the air is infused with the kinetic energy of the sprayed drops, and the denser air is forced to descend. The weather determines how effective this wind tower will be [36]. When the weather is dry, water spraying works better than when it is humid [37]. A high-density wind tower is used at the Torrent Research Centre in India [38].
- **Air tree –** A cluster of sixteen wind towers, each with a metal frame and a plastic covering of two layers make up the Air tree. It is situated on a major street in Madrid. Shadowing, ventilation, and cooling through evaporation are the three ways in which Air trees raise the temperature of the surrounding air. An electrical fan and numerous water pipelines around the floor have been used for ventilation and cooling by evaporative means [39].
- ***Adsorption cooling channel aided by wind tower –*** An absorption chiller and wind tower are used in this system to provide both natural ventilation and cooling. The inside temperature can be lowered from 10°C to 20°C with this approach. This system operates more efficiently in dry settings than in humid ones [40].
- ***Earth-to-air heat exchanger with wind tower –*** The earth's soil temperature at shallow depth is close to the annual average. The soil depth is warmer in winter and cooler in summer than outside. Thus, leveraging such a benefit could boost thermal comfort [41]. The earth-to-air heat exchanger adjusts temperature based on ground depth. A few pipes are arranged in the soil's depth in this arrangement. These pipes pump air and exchange heat with the soil. Pumping air over the surface heats or cools the environment depending on pipe length, depth, soil type, and diameter [42–45]. This technique is efficient, according to Baghdad climatic research by Dwivedi and Sharma [46–48].

External influences affecting wind tower ventilation – The performance of the wind tower also depends significantly on various factors such as the direction of the flow of wind, solar radiation, neighbourhood typology of the building, the roof design and various other factors. The roof design can be controlled by the architect and therefore logically could be used to impact the performance of the wind tower most effectively.

- ***The impact of the roof design of the building –*** Roof topology is an important design component that affects ventilation. Understanding the impact of roof shape on wind tower efficiency helps guide the integration of both systems to achieve ventilation requirements [49]. CFD modelling by Su et al. [50] examined the performance of a circular four-sided wind tower on a level and pitched roof. The results showed that flat roofs are less efficient than sloped ones. Flow separation was greater on the flat roof. Ameer et al. [49] used the wind tunnel and CFD approach to examine the ventilation efficiency of a four-sided (square) wind tower with constricted, tilted, curved, flat, and pitched roofs. Roof design affects wind characteristics and can increase wind tower ventilation and air dispersion if planned well.

CONCLUSION

This paper seeks to review old wind towers and modern wind tower technologies to see how the new wind tower is successfully being used in conjunction with other techniques to improve ventilation in buildings in hot climates. The major consideration being the exploitation of natural ventilation in two stages namely, buoyancy and wind-driven force. Wind towers have many advantages over other openings in a building. Wind towers outperform mechanical ventilation economically hence using a wind tower saves energy and money. The number of apertures, velocity, wind angles, and configuration characteristics affect wind tower performance. Understanding these criteria helps choose and employ the right type. One-sided wind towers work best in one-direction wind, but in changeable wind directions other types must be used. New wind towers use dampers, louvres, fans, rotating head wind towers and thus engineer inventiveness. Air trees cool the environment through ventilation, evaporation, and shadowing. These technologies and innovative wind tower designs can help adapt to a new lifestyle and contribute to sustainable architecture and cooling load reduction, especially in hot and dry areas.

RECOMMENDATIONS FOR FUTURE WORKS

A review of the wind tower research has been done to identify the key parameters that influence the ventilation performance. The wind tower's geometric properties, external design factors influenced by the surrounding environment, and how it interacts with other passive natural ventilation systems have been reviewed. Prior researchers have mostly focused on studying various wind tower geometry and design factors, including cross-section, internal partitions, apertures, height, roof, louvres, and dampers. Several studies have examined the impact of external design variables, particularly the shape of the building roof, on the efficiency of wind towers. There are still undiscovered applications for wind towers, even though the technology has advanced significantly. Microclimates in urban contexts provide several challenges, including issues related to thermal comfort, the quality of the air, and the heat island effect. Wind towers can be employed, particularly in regions with high temperatures, where it has the potential to lower air temperature, based on research findings.

REFERENCES

1. *Faye C. McQuiston, Jerald D. Parker, Jeffrey D. Spitler, (2005), "Heating, Ventilating and Air Conditioning: analysis and design," 6th edition, John Wiley and Sons, Hoboken, NJ.*
2. *N. Khan, Y. Su, S.B. Riffat, (2008), "A review on wind driven ventilation techniques," ENERGY AND BUILDINGS 40 (8), pp. 1586–1604.*
3. *O. Saadatian, L.C. Haw, K. Sopian, M.Y. Sulaiman, (2012), "Review of windtower technologies," Renewable and Sustainable Energy Reviews 16, pp. 1477–1495.*
4. *B. Blocken, T. Van Hooff, L. Aanen, B. Bronsema, (2011), "Computational analysis of the performance of a venturi-shaped roof for natural ventilation: venturi-effect versus wind-blocking effect," Computers and Fluids 48, pp. 202–213.*
5. *F. Allard, (1998), "Natural Ventilation in Buildings, James & James (Science Publisher) Ltd., William Road, London NW1 3ER, UK, pp. 35–37.*
6. *K. Naghman, S. Yuehong, S.B. Riffat, (2008), "A review on wind driven ventilation techniques", Journal of Energy and Buildings 40, pp. 568–1604.*
7. *B.R. Hughes, M. Cheuk-Ming, (2011), "A study of wind and buoyancy driven flows through commercial wind towers," Energy and Buildings. http://dx.doi.org/10.1016/j.enbuild.2011.1003.1022.*
8. *A.A. Elmualim, (2006), "Verification of design calculations of a wind tower/tower natural ventilation system with performance testing in a real building," International Journal of Ventilation 4 (4), pp. 393–404.*
9. *Stouhi, D. What Is a Traditional Windtower. 3 November 2021. Available online: https://www.archdaily.com/971216/what-isa-traditional-windtower (accessed on 28 July 2022).*
10. *Dehghan, A.A.; Esfeh, M.K.; Manshadi, (2013), "M.D. Natural ventilation characteristics of one-sided wind towers: Experimental and analytical evaluation," Energy Build. 61, pp. 366–377.*
11. *Sadeghi, H.; Kalantar, V., (2018), "Performance analysis of a wind tower in combination with an underground channel." Sustain. Cities Soc. 37, pp. 427–437.*
12. *Bahadori, M.N. (1994,) "Viability of wind towers in achieving summer comfort in the hot arid regions of the middle east." Renew. Energy 5, pp. 879–892.*
13. *Khalili, M.; Amindeldar, S. (2014), "Traditional solutions in low energy buildings of hot-arid regions of Iran." Sustain. Cities Soc. 13, pp. 171–181.*
14. *Ramzy, N. (2015), "Sustainable spaces with psychological connotation: Historical architecture as reference book for biomimetic models with biophilic qualities." Archnet IJAR 9, pp. 248–267.*
15. *Drach, P.R.C. (2009), "A study on air circulation: The case of house vi of "Vila" 37 with the application of wind-catch." Build. Simul., 2, pp. 5.*
16. *Elmualim, A.A. (2006), "Verification of Design Calculations of a Wind Tower/Tower Natural Ventilation System with Performance Testing in a Real Building." Int. J. Vent., 4, pp. 393–404.*
17. *P. Nejat, (2018), "Windtower as a Persian sustainable solution for passive cooling," Civ. Eng. Res. J. 6 (07).*
18. *M.N. Bahadori, A.R. Dehghani-Sanij, (2014) "Wind Towers: Architecture, Climate and Sustainability," Springer International Publishing, Switzerland.*
19. *M. F. Nasri and R. Hekmatpanah, (2010), "Productivity and energy management in desert urban," World Academy of Science, Engineering and Technology, 4(9), pp. 379-382.*
20. *P. Ghaemmaghami, (2005), "Wind tower natural cooling system in Iranian traditional architecture," in International Conference "Passive and Low Energy Cooling for the Built Environment, pp. 73.*
21. *S. Roaf, (1988), "The Windtower of Yazd," department of Architecture, Oxford Polytechnic, PhD thesis.*
22. *A. Amirkhani, Z. Ehsan, A. Saidian, M. Khademi, (2010), "Wind towers: remarkable example of Iranian sustainable architecture," J. Sustain. Dev. 3 (05).*
23. *M. Baghaiepoor, G. Jovanovic, M. Stanimirovic, (2019), "Climate adapted houses in Iran: hot, cold and humid climate," Facta Univ. Ser. Archit. Civ. Eng. 17, pp. 429–443.*
24. *M. Mahmoudi, (2006), "Wind tower: an attractive and charming feature of Yazd city," Bagh-e Nazar, 3 (5) pp. 91–100.*
25. *P. Ghaemmaghami and M. Mahmoudi, (2005), "Wind tower natural cooling system in Iranian traditional architecture," in International Conference "Passive and Low Energy Cooling for the Built Environment, pp. 73.*
26. *H. Montazeri, R. Azizian, (2008), "Experimental study on natural ventilation performance of one-sided wind tower," Build. Environ. 43 (12), pp. 2193–2202.*
27. *I. Abd Wahab, H. Aziz, N. Salam, (2019), "Building design effect on indoor natural ventilation of tropical houses," Int. J. Sustain. Constr. Eng. Technol. 10 (06).*

28. I. Abd Wahab, L. Ismail, A.H. Abdullah, M. Rahmat, N.N. Abd Salam, (2018), "Natural ventilation design attributes application effect on indoor natural ventilation performance of a double storey single unit residential building," Int. J. Integr. Eng. 10 (05).
29. P. R. C. Drach, (2009), "A study on air circulation: the case of house vi of "Vila" 37 with the application of wind-catch," in Building Simulation, Vol. 2, No. 4, pp. 307-316, Berlin/Heidelberg: Springer Berlin Heidelberg.
30. H. Montazeri, R. Azizian, (2009), "Experimental study on natural ventilation performance of a two-sided wind tower," Proc. Inst. Mech. Eng. Part A J. Power Energy 223 (4), pp. 387–400.
31. M. Sadeghi, B. Samali, G. Wood, R. de Dear, (2020), "Comfort cooling by wind towers in the Australian residential context- experimental wind tunnel study of comfort," J. Wind Eng. Ind. Aerodyn. vol.196.
32. M. Sadeghi, R. J. de Dear, B. Samali, and G. Wood, (2016), "Application of wind towers in the Australian residential context –a wind tunnel assessment of thermal comfort performance," In Paper Presented at the Proceedings of 9th Windsor Conference.
33. A.M. Omer, (2008), "Renewable building energy systems and passive human comfort solutions," Renew. Sustain. Energy Rev. 12 (6), pp. 1562–1587.
34. L.O. Adekoya, (1999), "Wind energy end use: performance characteristics of a rotating suction cowl," Renewable Energy 2, pp. 385–389.
35. M. Bahadori, M. Mazidi, A. Dehghani, (2008), "Experimental investigation of new designs of wind towers," Renew. Energy 33 (10), pp. 2273–2281.
36. M. Alshenaifi, S. Sharples, (2018) "Investigating the impact of architectural form and wind direction on the performance of a passive downdraught evaporative cooling tower in Saudi Arabia," In: 34th International Conference on Passive and Low Energy Architecture, 2018-12-10 - 2018-12-12, Hong Kong.
37. D. Kang, R.K. Strand, (2013), "Modelling of simultaneous heat and mass transfer within passive down-draft evaporative cooling (PDEC) towers with spray in fluent," Energy Build. 62, pp. 196–209.
38. L. Thomas and G. Baird, (2007), "Post-occupancy evaluation of passive downdraft evaporative cooling and air-conditioned buildings at torrent research centre, Ahmedabad, India," 01.
39. S. Soutullo, R. Olmedo, M. S´anchez, M. Heras, (2011), "Thermal conditioning for urban outdoor spaces through the use of evaporative wind towers," Build. Environ. 46 (12), pp. 2520–2528.
40. A. Haghighi, S. Pakdel, A. Jafari, (2016), "A study of a wind tower assisted adsorption cooling channel for natural cooling of a 2-storey building," Energy 102, pp. 118–138.
41. G. Mihalakakou, M. Santamouris, D. Asimakopoulos, (1992), "Modelling the earth temperature using multiyear measurements," Energy Build. 19 (1), pp. 1–9.
42. C. Jacovides, G. Mihalakakou, M. Santamouris, (1996), "J. Lewis, On the ground temperature profile for passive cooling applications in buildings," Sol. Energy 57 (3) pp. 167–175.
43. G. Mihalakakou, M. Santamouris, D. Asimakopoulos, (1994), "On the cooling potential of earth to air heat exchangers," Energy Convers. Manag. 35 (5), pp. 395–402.
44. G. Mihalakakou, M. Santamouris, D. Asimakopoulos, (1994), "Use of the ground for heat dissipation," Energy 19 (1) pp. 17–25.
45. M. Benhammou, B. Draoui, M. Zerrouki, Y. Marif, (2015), "Performance analysis of an earth-to-air heat exchanger assisted by a wind tower for passive cooling of buildings in arid and hot climate," Energy Convers. Manag. 91, pp. 1–11.
46. A. Dwivedi, P. Sharma, (2018), "A review- investigation of different process parameters of heat exchange having helical baffles to increase turbulence inside the tube," Int. J. Res. Trends Innov. 3 (6), pp. 89–92.
47. J. Abed, W. Jassim, S. Hassan, and B. Maula, (2020) "Design of wind tower for earth air heat exchangers to rationalize energy consumption," Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, pp. 286–294.
48. JA al Wahid Jassim, (2015), "Sustainable design of wind-tower of an earth-to-air heat exchanger in hot dry areas," International Journal of Scientific and Engineering Research, 6 (2015), pp. 582-589
49. S.A. Ameer, H.N. Chaudhry, A. Agha, (2016), "Influence of roof topology on the air distribution and ventilation effectiveness of wind towers," Energy Build. 130, pp. 733–746, https://doi.org/10.1016/j.enbuild.2016.09.005.
50. Y. Su, S.B. Riffat, Y.-L. Lin, N. Khan, (2008), "Experimental and CFD study of ventilation flow rate of a Mono draught TM wind tower," Energy Build. 40, pp. 1110–1116, https://doi.org/10.1016/j.enbuild.2007.10.001.