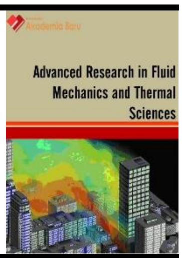
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 76, Issue 3 (2020) 109-116

Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



An Overview of Different Indirect and Semi-Indirect Evaporative Cooling System for Study Potency of Nanopore Skinless Bamboo as An Evaporative Cooling New Porous Material

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ARTICLE INFO

Article history:
Received 29 April 2020
Received in revised form 11 September 2020
Accepted 19 September 2020
Available online 27 October 2020

ABSTRACT

The high energy consumption of compressor-based cooling system has prompted the researchers to study and develop non-compressor-based cooling system that less energy consumption, less environment damaging but still has high enough cooling performances. Indirect and semi indirect evaporative cooling system is the feasible non-compressor-based cooling systems that can reach the cooling performance required. These two evaporative cooling systems has some different in construction, porous material used, airflow scheme and secondary air-cooling method used for various applications. This paper would report the cooling performances achieved by those two-cooling systems in terms of cooling efficiency, cooling capacity, wet bulb effectiveness, dew point effectiveness, and temperature drop. Porous material used in indirect and semi-indirect evaporative cooling would be highlighted in terms of their type, size, thickness and any other feature. The introduction of nanopore skinless bamboo potency as a new porous material for either indirect or semi-indirect evaporative cooling would be described. In the future study of nanopore skinless bamboo, a surface morphology and several hygrothermal test including sorption, water vapor transmission, thermal conductivity test would be applied, before it utilizes as a new porous material for direct or semi indirect evaporative cooling.

Keywords:
Indirect evaporative cooling system; semi-indirect evaporative cooling system; nanopore skinless bamboo potency

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1. Introduction

The rapid consumption energy growth for building cooling applications using compressor-based cooling system, has prompted researchers to develop a lower energy consumption cooling system. However, the study on Indirect Evaporative Cooling (IEC) system has been shown that this system

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https://doi.org/10.37934/arfmts.76.3.109116

would cooling the outdoor air without modifying outdoor air moisture content. In a conventional IEC system, there is no directly contact between water as a cooling medium and outdoor air. It would be applied two air streams for the IEC system, first the primary air stream (outdoor /product air) which is flowing in dry channel and the secondary air stream which is flowing in wet channel. The dry and wet channel is separated by a plate heat exchanger, at which the sensible heat of outdoor air (primary air) in the dry channel would be absorbed by heat surface in dry channel side and aids the evaporation of the secondary air in wet channel, thus the primary air is cooled conductively in the dry channel without adding its moisture content, the product air become cold and dry, meanwhile the secondary (working) air would receive the latent heat of vaporized water and adding the moisture content of the secondary air. It can be stated that using the conventional IEC, the product air resulted is far from its dew point temperature as the cooling of the product air is limited by the wet bulb secondary (working) air temperature in the wet channel, which limiting the amount sensible heat could be absorbed to evaporate water in the wet channel. However, the IEC system was providing more attractive evaporative cooling option than that DEC system, as it worked at constant moisture [1]. This conventional IEC system could provide a 20% of energy saving when it combined with dehumidifier into air retraction and air delivery of radiant cooling system [2]. The integration of direct and indirect evaporative cooling in a single and two stage operation mode could result a 51% energy saving during intermediate seasons but required 36% more energy input during cooling seasons [3]. However, the conventional IEC has provided a low energy consumption evaporative cooling system, a cooling process without modifying outdoor air moisture content, but it required the present of the secondary air to favor the cooling of the primary air and the outdoor air has not been able to cool to its dew point temperature yet. It could be considered that there are three basic energy requirements in the conventional IEC system including input energy to supply the primary (outdoor) air stream into dry channel, to supply the secondary (working) air stream into the wet channel and input energy for spraying water into the wet channel, these input energies would influence the cooling effectiveness of the conventional IEC system. The purpose of cooling the outdoor air into its dew point temperature (DPT) in the conventional IEC system could be improved by employing a Regenerative Indirect Evaporative Cooling (R-IEC) or Dew Point Indirect Evaporative Cooling (DP-IEC) and Maisotsenko Indirect Evaporative Cooling (M-IEC). In the R-IEC system, the primary air would be cooled by a regenerated secondary air stream which is extracting from the primary air stream at outlet. This part of the primary air has already cooled, so then the corresponding wet bulb temperature (WBT) of secondary air in the R-IEC system has become lower than the regular secondary air WBT compare to using outdoor air or returned air as the secondary air. This lower secondary air WBT would lowering the limit at which the primary air can be cooled, then it would decrease the primary air temperature at outlet [4-9]. The main advantage of the R-IEC is the outdoor air is cooled at a constant moisture below its WBT of the outdoor air, as the cooled primary air was extracting become the secondary air. Then the disadvantage of the R-IEC is the primary air flow rate become decreased due to those air extracting process. In this system, the primary air could only be cooled until obtaining the WBT of the secondary air at inlet, this system was also named as *sub wet bulb IEC* [10]. It is cooled the primary air not so close to its DPT. The improvement of the R-IEC system is the DP-IEC system, at which it would cool the primary air near to the limit of its DPT at inlet. It consists two stages of R-IEC equipment, at which the outlet primary air would be partly used as the secondary air for first stage and the rest of the primary air would be flowing to the second stage as the primary air. The secondary air of this system would be much cooler than that of the secondary air in classic IEC system and the primary air could be continue cooled to reach near its DPT of the primary air at inlet and this become the advantage of the DP-IEC, the most disadvantage of the DP-IEC is the primary air flow rate become decreased with the number of stage. Due to the primary air behavior, this system was also named *as* *dry bulb IEC* [10]. The DP-IEC system has presented a better primary air-cooling process than the R-IEC system, as the primary air could nearly reach its DPT of the primary air at inlet. A super performance of dew point air cooler has been studied by Peng Xu *et al.,* [11]. It established of using a super performance wet material layer, better heat and mass exchanger and an intermittent water supply scheme at which could produce a higher cooling performance. It consists of a complex exchanging sheets which contain many dry and wet channel, and works as the IEC system with primary and secondary air stream scheme, so then the outdoor air (primary air) could be cooled into nearly its DPT. The research results showed that this system have obtained wet-bulb cooling effectiveness of 114%, dew point cooling effectiveness of 75% and a significant higher COP of 52.5, at standard condition dry bulb temperature (TDB) of 37.8^{o}C and wet bulb temperature (WBT) of 21.1^{o}C. It also indicated that the lower the inlet air relative humidity would lead to a higher cooling efficiency. These results indicated that this system has a 100 – 160% higher COP and reduce the electricity used by 50-70% compared to the existing dew point cooler. Furthermore, the improved performance in terms of cooling the primary air into its dew point temperature at constant moisture content for the DP-IEC has been provided by the M-IEC system. This M-IEC system representing an alternative dew point evaporative cooling system at which the primary air can be cooled more closer to its DPT at constant moisture content. It consists of two dry channels, one for the primary stream and the other one for the secondary air. The secondary air stream has multiple passages from its dry channel into wet channel at which in each passage of the equipment, the secondary air moisture content would be increased until it reached the saturation condition, as the evaporated water would be diffused into the secondary air as moisture [10]. The uses of many passages for the secondary air would result a better sensible cooling for the primary air, at which the final DBT of the primary (product) air at outlet could reach near the DPT of the primary air at inlet, it very closes to its DPT. The main merit of the M-IEC is the outdoor air can be cooled near its DPT in constant moisture content, but it required most complex construction and air flow scheme.

On the other hand, there is a Semi-Indirect Evaporative Cooling (SIEC) system which could work as direct evaporative cooling or indirect evaporative cooling depend on the outdoor air and return air stream relative humidity [12]. It usually consists of porous material tube, at which its external surface would act as the heat exchange surface which has directly contact to the outdoor air, while water would be sprayed into the inside of porous tube to cool the secondary air and capillarity transported into the external surface to absorb the sensible heat of the primary air. When the vapor pressure of the outdoor air lower than the vapor pressure of the water in the heat exchange surface (low relative humidity ambient air), the SIEC would act as direct evaporative cooling, at which the water would evaporate and adding the moisture content of the outdoor air. In contrary, when the vapor pressure of the outdoor air higher than the vapor pressure of water in the heat exchange surface (high relative humidity ambient air), the SIEC would work as indirect evaporative cooling (sensible cooling), at which the cooled heat exchange surface would absorb only the sensible heat of the outdoor air conductively into the wet channel without modifying outdoor air moisture content. Further study has investigated two types of the SIEC system which were named Semi-Indirect Evaporative Recuperator made with Ceramic Pipe (SIERCP) and Semi- Indirect Evaporative Cooling made with Hollow Bricks (SIECHB) [12]. The SIERCP consists of porous ceramic pipe with the secondary air flowing inside the pipe and has a counter flow contact manner with the water sprayed, then allowing the evaporative cooling phenomena occurred. The secondary air in the inside of the pipe could be the outdoor air or any return air which associated to an energy recovery system. The water from inside the pipe would be capillarity transported to the external surface of pipe and absorbed the sensible heat of the outdoor air. So, then the outdoor air would be cooled sensibly without modifying its moisture content. If the outdoor air vapor pressure lower than that of water present in the external surface of pipe, the SIERCP would act as direct evaporative cooling at which allowing the humidification of the outdoor air. In reverse, it would act as indirect evaporative cooling and the porous pipe would work as a heat exchange that sensibly cooling the outdoor air without modifying its moisture content. While the SIECHB consists of hollow bricks which filled with stagnant cold water. The water is previously cooled in a cooling tower that utilized return air from conditioned air chamber and in such way the water would capillarity transported into the external hollow brick surface. When the vapor pressure of the outdoor air higher than the water in the external surface, the SIECHB would act as indirect evaporative cooling and conversely it would work as direct evaporative cooling [13]. The experiment test on both semi-indirect evaporative cooling system in various outdoor air velocity, various humidity level, various outside dry bulb temperature has been resulting an evaporative cooling system that can cool the outdoor air close to its dew point temperature as that in indirect and dew point evaporative cooling system. This system can be used for cooling system in hot-arid or hot-humid area.

Other supply air cooling method in the SIEC system would give cooling effect to the tube external surface by using a cold stagnant water inside the tube which is externally cooling by the secondary air in a cooling chamber. Instead of using a solid plate heat exchange as in indirect system which is separated primary air and secondary air exclusively, the SIEC use only the porous tube as the heat exchange medium, which allowing water capillarity transport to the tube external surface and this would simplify and shorten the evaporative cooling process. The most material used for the SIEC system including porous ceramic tube [14-18], combined porous ceramic tube and heat pipe [19], hollow bricks [12]. Regarding those papers reviewed, it seems that there has not been specific study about the use of nanopore porous material for semi indirect evaporative cooling yet. This really encourage to be studied even further to investigate the hygrothermal and surface morphology characteristics of nanopore skinless bamboo as a new porous material for semi indirect evaporative cooling.

2. Literature Review

Further discussion on indirect evaporative cooling (IEC) should be mentioned a requirement to improve the efficiency of the IEC, as in fact, the IEC has a lower efficiency that the direct evaporative cooling (DEC) system [20]. It then is introduced a semi-indirect evaporative cooling (SIEC) system that was a successful attempt to improve the efficiency of the IEC system. It should be clear that the terms of “semi-indirect” is used to describe this IEC system as it designed to operate either as a direct evaporative cooling or indirect evaporative cooling depending on the relative humidity of outside air and return air stream [12]. The SIEC is usually composed of porous material pipes, such as porous ceramic pipes, hollow brick and it has two air flow supplies, first air flow, supply air flow is used for cooling and the second one to be used to conduce heat and mass transfer process by forcing it against the downstream sprayed water [20]. The whole process was occurred in the inside and outside of a single pipe from a bank porous pipes, in which the cooling effect was provide by two heat exchange processes, i.e. first heat exchange process between supply and return air, and the second one between supply air and pipe external surface. Several studied has been conducted relates to the semi-indirect evaporative cooling system. Martin *et al.,* [20] studied experimentally the semi-indirect evaporative cooling as a device used in energy recovery in air conditioning system, which is assessed in various air flow and relative humidity level. It employed three air flow levels of 140, 260, 380 m^3/h and three relative humidity levels of less than 30%, between 30-60%, and more than 60%, then five temperature levels of 40, 36.5, 33, 29.5, 26^oC. The results showed this system is better used in tropical climate region with high ambient air temperature and humidity, in which the high humidity of supply air or primary air would be decreased using the cooling effect of evaporative cooling the secondary air. Gomez *et al.,* [12] investigated fundamental operation of two different configuration of the SIEC system which described as, first, semi-indirect evaporative recuperator made with ceramic pipes (SIERCP) and second one, semi-indirect evaporative cooler made with hollow brick (SIECHB) and characterize those both system behavior based on different outside air condition. The tests would be performed in different air volume flow rate, dry bulb temperature and relative humidity for each of those two systems. The air volume flow rate was varied of 290, 410 and 515 m3/h for SIERCP and 180, 360 and 540 m3/h for SIECHB, the different air volume flow rate setting for SIERCP and SIECHB due to the different in pressure drop as the air handling unit was not possible to provide the same air volume flow rate. This setting could not be valid as the two system has been performed with different sets of air volume rate. In order to develop enough data for a comparative analysis, the same relative humidity levels for each of dry bulb temperature would be applied, in which for 20^{o}C the relative humidity was set to 50%, then 25, 30, 35, and 40^{o}C with 45, 35, 25, and 20% relative humidity. It concluded that the SIECHB system obtained a slightly higher cooling capacity, thermal conductance and wet bulb thermal effectiveness than SIERCP system, and it found as well that the performance of these system improves when the outdoor air temperature increase within a lower air relative humidity. Gomez *et al.,* [18] studied a semi-indirect cooler used a porous ceramic as a heat exchange medium between outdoor air and conditioned return air which is directly force against the water sprayed. It found that this system is then would introduce as the semi-indirect evaporative cooling which recover energy between outdoor air and conditioned return air. As well, this introduced system had a ceramic structure that acts as a filter to eliminate outdoor air contamination, as it has not been in directly contact with sprayed water and avoid the product air from Legionnaire's disease spreading. Wang *et al.,* [15] studied a novel indirect evaporative cooling system with made of a porous ceramic tube type, to improve surface hydrophilicity of wet channel and reduce pump energy consumption compared to the traditional IEC system. It resulted the increasing of secondary/primary air ratio to 0.9 and the decreasing of spray water rate would improve the wet bulb efficiency or cooling efficiency of IEC system. This novel IEC system enables to save 95% pump energy consumption compared to the traditional IEC, as well as this system work stable under the typical hot and dry condition within a wet bulb efficiency fluctuation of 40.3% to 42.2% and obtained the highest COP of 34.9. Previous study by Martinez *et al.,* [16] investigated the comparison between indirect evaporative cooling (IEC) using an aluminum plate as the interchanger and semi-indirect evaporative cooling (SIEC) made with solid porous ceramic. In this IEC system, it only heat transfer taking place on the primary air stream (air supply), while for SIEC, both heat and mass transfer are taking place, allowing sensible and latent cooling of the primary air stream. The primary air flow for IEC and SIEC are setting on 118.8 or 220.2 m^3/h and 140 or 260 m^3/h respectively, while different humidity range are applied for IEC on 20-40%, 40-60%, and more than 60%, while for the SIEC system on less than 30%, 30-60% and more than 60%. The results showed the SIEC system has a better performance as it allowed the sensible and latent heat transfer taking place, which not only lowering air supply temperature but also reduce air supply moisture content due to evaporative cooling process on the porous ceramic tube surface. Zhao *et al.,* [17] investigated the selection of various material that suitable used as heat and mass transfer medium for IEC system, in which thermal conductivity (TC) and water retaining capacity (porosity) has a little influence in this material selection. The more important influenced factors would be the holding ability, durability, compatibility, contamination risk and cost. It concluded that the most suitable material for IEC system in terms of heat and mass transfer capability are included the wick attained copper or aluminum (metal type), low porosity wooden or flax fiber (fiber type), low porosity ceramic, low porosity and high thermal conductance zeolite and carbon. Riffat and Zhu [19] has been studied the mathematical model of SIEC using porous ceramic and heat pipe as cooling sources and heat transfer device respectively. It applied two air passage distinctively, first air passage for indoor air and the second for outdoor air. It constructed with a porous ceramic which filled with water for the first air passage and a heat pipe is situated along the two-air passage. The heat pipe would transfer the cold from porous ceramic passage to the interior of building and absorb the indoor air heat. It found that the high cooling capacity would be obtained in the dry and windy weather and to achieve a higher cooling efficiency, the indoor air velocity should be set at 0.6 m/s [20].

Most study has been investigated bamboo, in engineering aspect, as a building constructions material, or as a natural fiber from plants to reinforce composite material or even to replace polymeric fiber with plants fiber. The study in using skinless bamboo as a porous material in evaporative air-cooling application has not been done yet. Bamboo is an abundance plant that has significant low density, high strength and stiffness [21]. In choosing bamboo for evaporative cooling purposes, some physical and morphology characteristics of material should be considered including density, porosity, wall thickness. Bamboo tree has composed of inner most, culms and skin. Varied mechanical and physical properties of bamboo is depend on the structure of bamboo culms, density, average size, and also their vascular number [22-23]. The low density of bamboo would be useful for mass and heat transfer in evaporative cooling, as it has a higher porosity. The reduction of bamboo wall thickness as a result of diminution process would decrease the bamboo diameter from the bottom to the top portion [24]. A thinner material would provide a better heat and mass transfer for indirect and semi indirect evaporative cooling. In addition, the height of bamboo can be indicated by the length of its internodes [25]. Those bamboo properties have been appropriate to the working principle of the evaporative cooling proposed. The thermal engineered bamboo then would be test to study its hygrothermal and surface morphology characteristics before it employed to be a nanopore porous material for semi indirect evaporative cooling.

3. Future Development of Nanopore Skinless Bamboo Potency as An Evaporative Cooling New Porous Material

Based on the paper have been reviewed, although various porous material has been used in those evaporative cooling systems, the uses of the nanopore skinless bamboo as an evaporative cooling porous material has not yet been investigated. For the future development, it would be utilized the use of local bamboo, bamboo tali (gigantochloa apus), which would be thermal engineered to develop a nanopore porous material for semi indirect evaporative cooling. Thermal engineering process would be conducted by applying four pyrolysis stage including drying, pre-carbonization, carbonization and calcination, before its carbon activated. Once those thermal engineering processes was accomplished, the nanopore skinless bamboo porous material would be examined their surface morphology and several hygrothermal properties including sorption, water vapor transmission, drying, thermal conductivity test, and thermal analysis based on ISO and or ASTM standard.

4. Conclusions

By selecting the appropriate density, porosity, permeability of the skinless bamboo, it would be developed a novel indirect evaporative cooling system named Semi Indirect Evaporative Cooling made of Nanopores Skinless Bamboo (SIECNSB). In this novel system, the appropriate nanopores skinless bamboo would be utilized as a new porous material for semi indirect evaporative cooling system. It has a great potential to act as a better cooling medium in absorbing heat and mass transferred during the cooling process. It expected to have a higher nanopore distribution that could enlarge heat and mass transfer area. This new nanopore material could then to be expected to improve cooling efficiency and cooling capacity for semi indirect evaporative cooling.

Acknowledgement
This article's publication is supported by The Indonesian Ministry of Research Technology and High Education for Doctor Dissertation Research Grant 2018/2019.

References

[1] Duan, Zhiyin, Changhong Zhan, Xingxing Zhang, Mahmud Mustafa, Xudong Zhao, Behrang Alimohammadisagvand, and Ala Hasan. "Indirect evaporative cooling: Past, present and future potentials." *Renewable and Sustainable Energy Reviews* 16, no. 9 (2012): 6823-6850. https://doi.org/10.1016/j.rser.2012.07.007

[2] Mariotti, Marco, and Lorenzo Moro. "Indirect Evaporative Cooling Combined with Dehumidification in a MVHR System for Radiant Cooling." *Energy Procedia* 101 (2016): 448-455. https://doi.org/10.1016/j.egypro.2016.11.057

[3] Kim, Min-Hwi, and Jae-Weon Jeong. "Cooling performance of a 100% outdoor air system integrated with indirect and direct evaporative coolers." *Energy* 52 (2013): 245-257. https://doi.org/10.1016/j.energy.2013.02.008

[4] Bellemo, Lorenzo, Brian Elmegaard, Lars O. Reinholdt, and Martin Ryhl Kærn. "Modeling of a regenerative indirect evaporative cooler for a desiccant cooling system." In *4th IIR Conference on Thermophysical Properties and Transfer Processes of Refrigerants*. 2013.

[5] Bruno, Frank. "On-site experimental testing of a novel dew point evaporative cooler." *Energy and Buildings* 43, no. 12 (2011): 3475-3483. https://doi.org/10.1016/j.enbuild.2011.09.013

[6] Kiran, T. Ravi, and S. P. S. Rajput. "An effectiveness model for an indirect evaporative cooling (IEC) system: Comparison of artificial neural networks (ANN), adaptive neuro-fuzzy inference system (ANFIS) and fuzzy inference system (FIS) approach." *Applied Soft Computing* 11, no. 4 (2011): 3525-3533. https://doi.org/10.1016/j.asoc.2011.01.025

[7] Lee, Joohyun, BongSu Choi, and Dae-Young Lee. "Comparison of configurations for a compact regenerative evaporative cooler." *International Journal of Heat and Mass Transfer* 65 (2013): 192-198. https://doi.org/10.1016/j.ijheatmasstransfer.2013.05.068

[8] Mathews, E. H., M. Kleingeld, and L. J. Grobler. "Integrated simulation of buildings and evaporative cooling systems." *Building and Environment* 29, no. 2 (1994): 197-206. https://doi.org/10.1016/0360-1323(94)90070-1

[9] Wani, Chandrakant, Satyashree Ghodke, and Chaitanya Shrivastava. "A review on potential of Maisotsenko cycle in energy saving applications using evaporative cooling." *International journal of advance research in science, engineering and technology* 1, no. 01 (2012): 15-20.

[10] Porumb, Bogdan, Paula Ungureşan, Lucian Fechete Tutunaru, Alexandru Şerban, and Mugur Bălan. "A review of indirect evaporative cooling technology." *Energy Procedia* 85 (2016): 461-471. https://doi.org/10.1016/j.egypro.2015.12.228

[11] Xu, Peng, Xiaoli Ma, Xudong Zhao, and Kevin S. Fancey. "Experimental investigation on performance of fabrics for indirect evaporative cooling applications." *Building and Environment* 110 (2016): 104-114. https://doi.org/10.1016/j.buildenv.2016.10.003

[12] Gómez, E. Velasco, FJ Rey Martínez, and A. Tejero González. "Experimental characterisation of the operation and comparative study of two semi-indirect evaporative systems." *Applied thermal engineering* 30, no. 11-12 (2010): 1447-1454. https://doi.org/10.1016/j.applthermaleng.2010.03.004

[13] S.K. Wang. *Incorporating Evaporative Cooling with Other Coolers*. Handbook of Air Conditioning and Refrigeration, McGraw-Hill, New York, 1994.

[14] Martín, R. Herrero. "Characterization of a semi-indirect evaporative cooler." *Applied Thermal Engineering* 29, no. 10 (2009): 2113-2117. https://doi.org/10.1016/j.applthermaleng.2008.09.008

[15] Wang, Fenghao, Tiezhu Sun, Xiang Huang, Yi Chen, and Hongxing Yang. "Experimental research on a novel porous ceramic tube type indirect evaporative cooler." *Applied Thermal Engineering* 125 (2017): 1191-1199. https://doi.org/10.1016/j.applthermaleng.2017.07.111

[16] Rey Martinez, F.J., and et al.. "Comparative study of two different evaporative system: an evaporative cooler and a semi-indirect evaporative cooler." *Energy and Building* 42 (2004): 2241-2250.

[17] Zhao, Xudong, Shuli Liu, and S. B. Riffat. "Comparative study of heat and mass exchanging materials for indirect evaporative cooling systems." *Building and Environment* 43, no. 11 (2008): 1902-1911. https://doi.org/10.1016/j.buildenv.2007.11.009

[18] Gómez, E. Velasco, FJ Rey Martínez, F. Varela Diez, MJ Molina Leyva, and R. Herrero Martín. "Description and experimental results of a semi-indirect ceramic evaporative cooler." *International journal of refrigeration* 28, no. 5 (2005): 654-662.
https://doi.org/10.1016/j.ijrefrig.2005.01.004

[19] Riffat, S. B., and Jie Zhu. "Mathematical model of indirect evaporative cooler using porous ceramic and heat pipe." *Applied Thermal Engineering* 24, no. 4 (2004): 457-470.
https://doi.org/10.1016/j.applthermaleng.2003.09.011

[20] Martín, R. Herrero, FJ Rey Martínez, and E. Velasco Gómez. "Thermal comfort analysis of a low temperature waste energy recovery system: SIECHP." *Energy and buildings* 40, no. 4 (2008): 561-572.
https://doi.org/10.1016/j.enbuild.2007.04.009

[21] Osorio, Lina, E. Trujillo, Aart Willem Van Vuure, and Ignace Verpoest. "Morphological aspects and mechanical properties of single bamboo fibers and flexural characterization of bamboo/epoxy composites." *Journal of reinforced plastics and composites* 30, no. 5 (2011): 396-408.
https://doi.org/10.1177/0731684410397683

[22] Londoño, Ximena, Gloria C. Camayo, Néstor M. Riaño, and Yamel López. "Characterization of the anatomy of Guadua angustifolia (Poaceae: Bambusoideae) culms." *Bamboo Science and Culture* 16, no. 1 (2002): 18-31.

[23] Zakikhani, Parnia, R. Zahari, M. T. H. Sultan, and D. L. Majid. "Extraction and preparation of bamboo fibre-reinforced composites." *Materials & Design* 63 (2014): 820-828.
https://doi.org/10.1016/j.matdes.2014.06.058

[24] Liese, W. and etal.,. *Proceeding of International Workshop on Bamboo Industrial Utilization*. International Network for Bamboo and Rattan, Xianning,Hubei, China, 2003.

[25] Amada, Shigeyasu, and Sun Untao. "Fracture properties of bamboo." *Composites Part B: Engineering* 32, no. 5 (2001): 451-459.
https://doi.org/10.1016/S1359-8368(01)00022-1