

Thermal Performance Analysis of an Ice Cube-Based Cooling Unit Constructed with Locally Sourced Materials



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ABSTRACT

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cooling system, ice cube, thermal efficiency, clean energy, local materials, sustainable design

Design, development, and performance evaluation of a budget-ice cubes as the sole cooling medium centered cooler: The study focused on design, fabrication, and thermal performance analysis of low-cost cooling apparatus using ice cubes as the sole cooling medium. It is developed with locally available materials in order to provide a sustainable and low-cost solution, particularly for air conditioning of places where no utility can be employed. The setup also phoenix contains a basic heat exchanger: Cooling via the passage of coolant through a coil nested inside a tank of ice. Experiments were performed to record the feed-in temperature difference and verify it with the corresponding numerical model established in OpenModelica (OM). The highest drop in temperature was achieved with a good match between simulated and experimental data. Visually, the results prove that ice-based cooling can be considered as two redesigned cisterns, which constitute an energy-efficient and a low investment solution for housing.

1. INTRODUCTION

Energy has been considered a generally recognized first pillar of modern development. The search for sustainable pathways is, nonetheless, further motivated by higher dependence upon conventional energy sources, rising world demands, and worsening environmental issues. These endeavors range from providing new energy sources to maintaining energy-efficient and eco-friendly future systems.

Cooling is simply considered as taking away heat from some substance or space so that the temperature being maintained is below that of the surroundings. Considerable energy is needed for such action, as it works against the flow of heat as described by the second law of thermodynamics. Such an energy-demanding process further accelerates the advent of fossil fuel depletion and the increase in greenhouse gas emissions [1-3].

Throughout history, the development of cooling and refrigeration technologies has been driven by several key factors, including efficiency, cost, reliability, safety, durability, and environmental impact. Over time, the importance of these factors has increased, leading to significant research efforts focused on improving the efficiency and cleanliness of cooling systems. In particular, the past years have seen technological advancements aimed at enhancing safety, reducing energy consumption, minimizing negative environmental effects, and improving the sustainability of cooling technologies [4].

Considerable literature has discussed and reviewed various properties of condensers in thermal systems, covering their various designs and materials of manufacture. One study investigated the performance of shell-and-tube heat

exchangers, an important factor in the industrial heat-transfer process, using Kern's method. Exergy and advanced exergy analyses were applied to evaluate a segmentally baffled water-to-water system installation for inefficiencies and corrective actions. The results indicated exergy destruction of 684.6 kW, with 97.5% being classified as endogenous and avoidable, thus showing an enormous potential for performance enhancement by modifying design, configuration, flow rates, and material selection. Conversely, it was deemed that the exergy destruction associated with the pumps was inevitable and thus design changes in that area would have little benefit [5-7].

In particular, further investigation has introduced a vertical-tube indirect evaporative cooler (VTIEC) with inner-grooved tubes to improve water-film formation and system performance. Experimental results indicate that the grooved surfaces improve film distribution and cooling efficiency. On the other hand, when the working air has low enthalpy, a very substantial increase in cooling capacity contributes to better thermal performance.

Among the conditions tested, a velocity ratio of 1.52 (produced to working air) resulted in the best performance. The cooling capacity rose with the produced air velocity up to 4.05 m/s, although higher velocities led to a decrease in coefficient of performance (COP). The system reached a peak cooling capacity of 307.74 W/m², achieved a wet-bulb efficiency of 81.7%, and a COP of 44.97, demonstrating its potential for use in building cooling applications [8-12]. Many articles present an analytical solution to determine the outlet temperatures of hot and cold fluids in a shell and tube heat exchanger using efficiency, effectiveness (ϵ -NTU), and irreversibility concepts. The system features cold nanofluid (a

50% ethylene glycol–water mixture with CuO nanoparticles) in the shell and hot water in the tube. Nanoparticle volume fractions range from 0.1 to 0.5, with nanofluid flow rates between 0.0331 and 0.0568 kg/s and hot fluid flow rates of 0.0568 and 0.5 kg/s [13-17]. These studies investigated the energy conservation through building energy efficiency, which is a global priority. Four key aspects contribute to this: passive building design aimed at nearly zero energy use before construction, use of low-energy materials during construction, energy-efficient equipment to reduce operational energy, and integration of renewable energy technologies. This paper briefly discusses these elements, highlighting their economic and environmental impacts. Passive design strategies offer heating, cooling, and daylighting benefits, while renewable systems like solar water heating and photovoltaic electrification further enhance sustainability [18-21]. In this study, we presented one of the methods used to reduce the energy used in cooling in remote areas where the energy needed to operate the cooling devices is scarce. Ice cubes were used to increase the efficiency of the condenser and make it operate with less energy.

2. NUMERICAL SIMULATION

The vapor compression refrigeration (VCC) system operates on the principle of using fluid properties—specifically, the pressure-dependent boiling temperature and the latent heat of phase change—to transfer heat from a low-temperature region to a high-temperature region [22].

In this cycle, as shown in Figure 1:

- (1) The refrigerant boils at a low pressure, absorbing heat from the low-temperature space.
- (2) It is then compressed to a higher pressure, raising its boiling point.
- (3) At this high pressure, the refrigerant condenses into a liquid, releasing heat to the higher temperature space.

This core principle applies across a wide range of refrigeration and air conditioning applications—from small room air conditioners to large-capacity chillers.

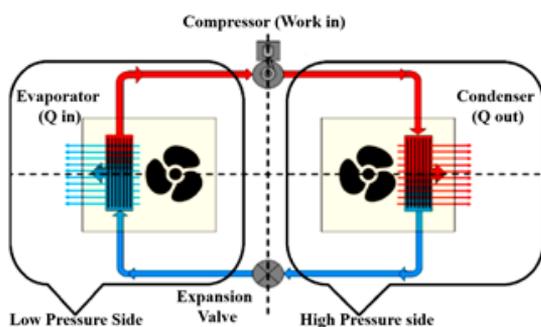


Figure 1. Main components of the vapor compression cycle [23]

The VCC system consists of the following components:

Compressor – process isentropic compression in the compressor.

Condenser – process constant pressure heat dissipation, with a temperature range from 0 to 45 °C.

Heat exchanger – heat transfer process.

Expansion valve – process isenthalpic throttling process in an expansion device.

Evaporator – process constant pressure heat extraction, the

temperature ranges from 0 to -15 °C.

To implement the system using a simulation program coolpack and OpenModelica, as shown in Figure 2, connection editor software, and the modeling of (compressor, condenser, expansion valve, heat exchanger, evaporator). It was formulated by the EES program.

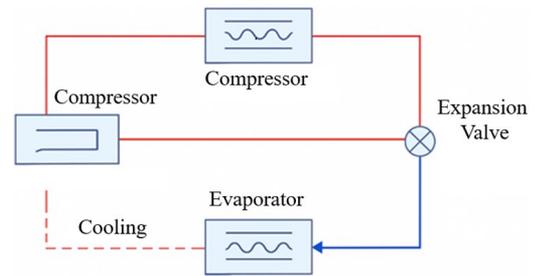


Figure 2. Vapour compression system schematic by OpenModelica software

Modeling of a simple vapour compression system. These detailed assumptions enhance the reproducibility of the model and ensure accurate heat transfer calculations. The total heat transfer (Q) was calculated using [11]:

$$Q = m \cdot c \cdot \Delta T \quad (1)$$

where,

Q : total heat transfer (J)

m : mass of the coolant (kg)

c : specific heat capacity of the coolant (J/kg·K)

ΔT : temperature difference between the coolant and the environment (°C)

The work input to the compressor can be determined as follows:

$$W_{comp} = m \cdot c \cdot \Delta T \quad (2)$$

Given data:

$m = 150$ kg

$c = 4186$ J/kg·K

$W_{input} = 2,000,000$ J (measured experimentally)

The COP of the vapor-compression system is defined as the ratio of the refrigeration effect to the work done by the compressor, and it can be calculated as:

$$COP = \frac{q_{cooling}}{W_{input}} \quad (3)$$

where,

COP: coefficient of performance (dimensionless)

$q_{cooling}$: cooling capacity or refrigeration effect (J)

W_{input} : compressor work input (J)

The system was created using a simulation program OpenModelica as shown in Figure 2. The system consisted of a compressor, condenser, heat exchanger, expansion valve, and evaporator using R22 as a refrigerant. All the temperatures and pressures at the inlet and outlet were calculated to calculate the system's COP. The type of refrigerant was added to the simulation program through a coolpack program that contains all the types of refrigerants that are used. The cooling process was modeled using thermodynamic equations to predict heat transfer efficiency and system performance. Initial

conditions assumed include a steady ambient temperature of 25 °C, a constant coolant flow rate, and insulation to minimize external heat exchange. Boundary conditions were set to ensure the ice cube temperature remains constant at -15 °C during operation, while the external heat load varies based on experimental parameters.

3. EXPERIMENTAL WORK

3.1 System ring

The proposed cooling system is designed based on integrating local techniques with simple engineering principles to achieve high efficiency at minimal cost. Figure 3 shows the flow chart of the system. The system comprises two main components: the freezing unit and the cooling unit. The experiment was conducted in one of the government departments in Baghdad, Iraq, in the spring of March. The experiment started from 12:00 PM to 6:00 PM, when the ambient temperature reached 30 °C.

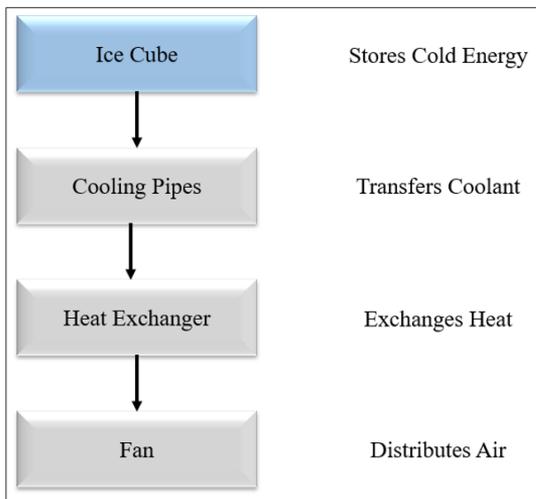


Figure 3. Vapour compression system flow chart by OpenModelica software

3.2 Freezing suction

- (1) Freezing Tank: A thermally insulated tank with a capacity of 300 liters and cooling coils for better heat exchange while producing ice cubes at -15 degrees Celsius.
- (2) Pulley and Condenser: A 2-ton compressor using R22 refrigerant is simulating effective freezing.
- (3) In Operation: Water freezes for 10 hours for the making of a 150-liter-sized cube of ice with the attainment of a steady temperature of -15 °C, as shown in Figure 4.



Figure 4. The cold room in a vapor compression system

3.3 Cooling suction

Cooling pipes: Embedded in the ice cube, there is a flow of that specialized coolant having a freezing point of -50 °C.

Circulating Pump: The circulating pump continuously moves the coolant between the ice cube and the cooling chamber, as shown in Figure 5.

- Power: (30 watts)
- Voltage: 115V, single phase

Coolant: To ensure continuous operation, a refrigerant that does not freeze down to -50 °C is selected.

Evaporator: The assembly, as shown in Figure 6, is composed of tubing through which the cool fluid passes, and a fan that enhances heat transfer between the block evaporator and test chamber.

Heat Exchanger and Fan: Facilitate heat transfer from the coolant to the air surrounding it, reducing the temperature in the room by the indoor split unit, as shown in Figure 7.

Operation: Over six hours, the system reduced the test chamber's temperature from 22 °C to 18 °C.



Figure 5. Circulating pump



Figure 6. Freezing tank



Figure 7. Indoor split unit

3.4 Heat transfer model

The heat transfer model assumes the following coolant properties and environmental conditions to ensure clarity and reproducibility:

Coolant properties as shown in Figure 8:

Specific heat capacity: 4186 J/Kg·K (based on water properties).

Density: 1000 kg/m³.

Thermal conductivity: 0.6 W/m·K.

Initial temperature: -15 °C that recorded by digital temperature measurement as shown in Figure 9.



Figure 8. Antifreeze coolant C12

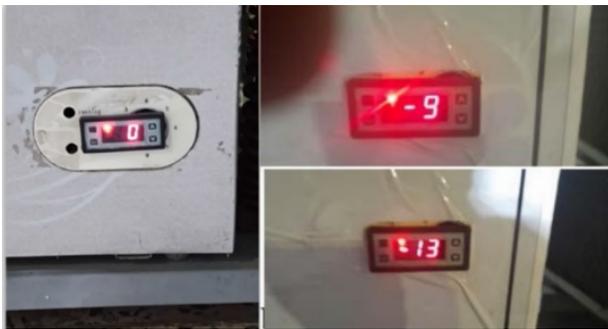


Figure 9. Digital temperature measurement

Environmental conditions:

- Ambient temperature: 25 °C.
- No significant heat losses to the surroundings due to insulation.
- Constant pressure of the system at 1 atm.

Assumptions:

- The specific heat capacity of the coolant remains constant across the operational temperature range.
- The system is well-insulated to minimize heat losses to the surroundings.
- Steady-state operation is assumed for each time interval.

The basic requirement of a system's efficiency is assumed:

- The input work supplied to the system components is measured as a constant, with no variation in the records during the time of measurement.
- The heating effect is the total heat being absorbed by the coolant from the start to the end during operational hours.

3.5 Research approach and innovation

The proposed cooling system was thus assessed on the basis of dual methodologies, i.e., theoretical simulations and experimental validation. It is to be made clear that applying such methodology in cooling system research is, per se, no innovation. The novelty of this work lies in the design of the cooling system, the thermal and dynamic performance enhancement using simulation and experimental results, and the use of an accurate simulation model along with advanced analytical tools for the efficiency evaluation of the cooling system, which together delineate this work from the previous works in the area.

4. RESULTS AND DISCUSSION

The system effectively reduced temperature levels in the controlled environment with stability and reliability in cooling performance. Major findings are:

4.1 Cooling performance

In the course of six hours, a reduction of 4 °C in the test chamber was achieved by the system.

Efficiency was sustained with various external temperatures.

4.2 Energy efficiency

For such a system, the COP tells us how much work gets output by it per unit energy input.

4.3 Sustainability

There are sustainable resources that local and economical designs contribute to in environmental and economic sustainability. The system serves to reduce energy consumption and also maintain conditions of comfort within the space. The system consisted of two steps. The first step is freezing. Here, a heat exchanger of the type shell and tube is used to freeze the ice cube to a temperature of -15 °C. The second step is the cooling; it has a pump, condenser, and evaporator, which reduced the room temperature from 25 °C to 18 °C. This system was theoretically composed from a simulation program, OpenModelica, and CoolPack. In the program, the system was created, and all required components were added. A heat exchanger was integrated to facilitate the freezing of ice cubes, and a pump system was established to circulate the working fluid between the chamber and the tank containing the ice cubes. The inlet and outlet temperatures at each point were fixed to monitor temperature variations over a 360-minute period for the first day, and the same procedure was repeated for the second day.

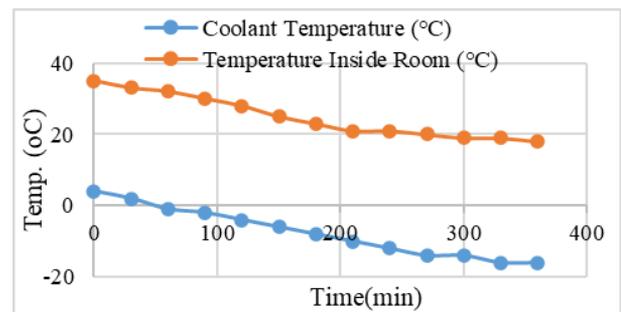


Figure 10. Difference in coolant temperature and temperature inside the room with time on the first day

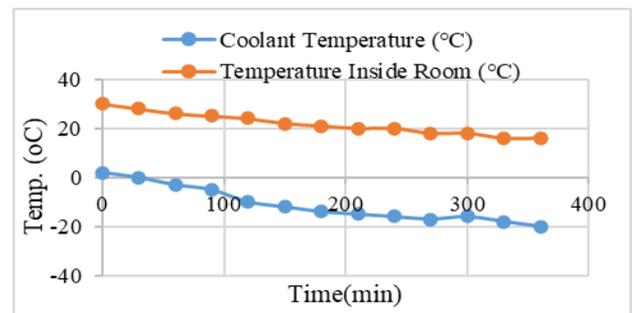


Figure 11. Difference in coolant temperature and temperature inside the room with time on the second day

Figures 10 and 11 illustrate the recorded temperature changes for both days. It can be observed that as the temperature of the working fluid decreases, the chamber temperature also drops — indicating a direct proportional relationship between the two. Experimentally, when the system is operated, the obtained results show close agreement with the theoretical values, with an accuracy of approximately 89%. The deviation of about 11% is mainly attributed to energy losses occurring through the pipes and the surrounding environment.

Figure 12 cleared increase in the COP with time (min) until reaching 360 min. The temperature inside the room become 18 °C the COP reached 11.5 on the first day and 11.2 on the second day.

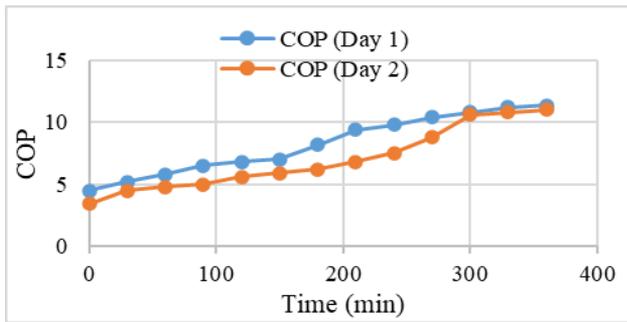


Figure 12. Increase the coefficient of performance (COP) with time in the first and second day

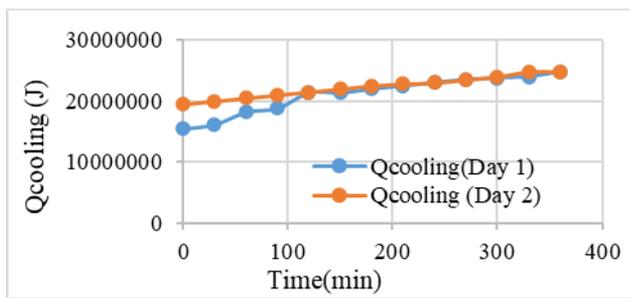


Figure 13. Increase the Q cooling with time on the first and second days

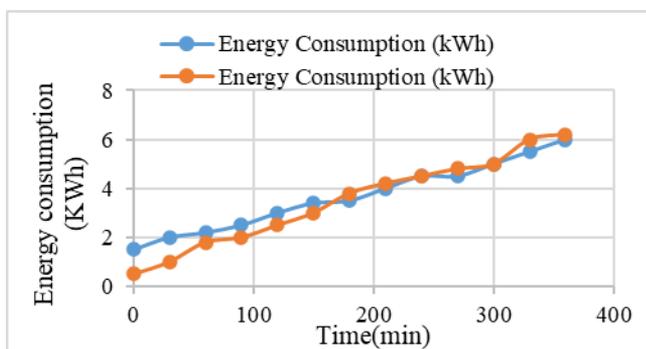


Figure 14. Increase the energy consumption over time on the first and second days

Figures 13 and 14 show the total heat transfer (Q) and energy consumption with time on the first day. The Q cooling increases until reaching 25000000 J at 360 min in the first day a state of fluctuation was recorded from 0 to 200 min. while on the second day, the readings are more stable. While we noticed that the energy consumed increases with the increase in time as a result of the pump working to circulate the coolant

within the system.

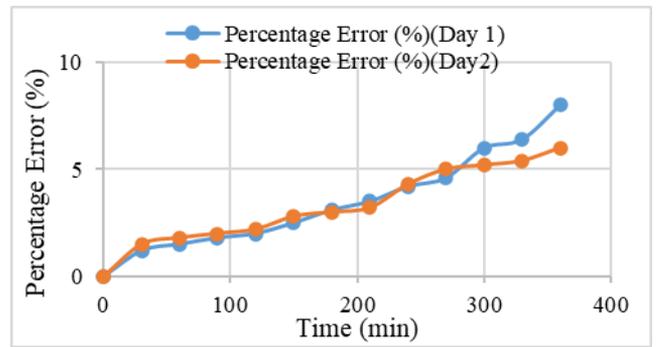


Figure 15. Percentage error (%) on the first and second day

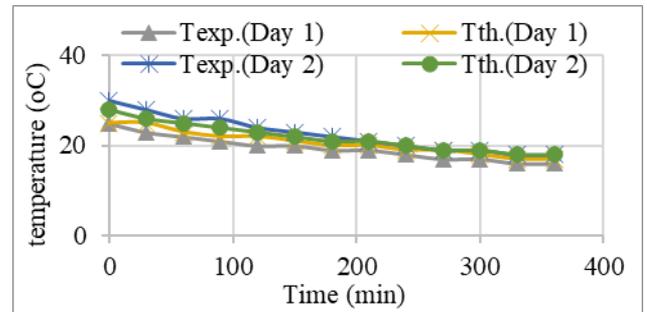


Figure 16. Comparison between the experimental and theoretical temperatures in the Day1 and Day2

Figure 15 shows the percentage error (%) rate in the practical readings obtained during the experiment period. At the start of operation, the error rate is lower and increases with the increase in the operation period the error rate reaches to 8%. Figure 16 illustrates the difference between the theoretical and experimental temperatures inside the room during system operation. The experimental temperature was recorded through actual measurements inside the room while the system was running, whereas the theoretical temperature was obtained from a simulation using OpenModelica. The results show a strong agreement between the theoretical and experimental values, indicating the accuracy of the simulation model.

5. PRACTICAL CONSTRAINTS AND FUTURE WORK

5.1 Practical limitations

Ice cube-based cooling systems have several practical difficulties which limit their efficiency and continuous operation: The short duration between formation and melting of ice limits the effective cooling time; meltwater handling raises questions on contamination and performance reduction. With regard to scalability, larger or industrial applications would require much more storage, better insulation, and automated ice replacement.

Other inefficiencies manifest as heat loss, uneven temperature distribution, or dependence on ambient conditions, which prevent on-site performance from matching theoretical predictions.

5.2 Recommendations for future research

The future aspect of development is for the introduction of

concentric reinforcement to provide a better cooling period and waste energy reduction with progressive insulation upgrade, phase change materials (PCMs). And those developments would turn into great efficiencies, cost effectiveness, and sustainability itself as systems are developed to automatically recycle melting water and use local natural materials from their sources.

Thereby facilitating the construction of the system into a more practical, scalable, and effective cooling option for engineering applications.

6. CONCLUSION

The ice cube cooling system provides an affordable and green approach compared to conventional ways of temperature control. It was experimentally observed that an 18 °C temperature decrease can be achieved, equivalent to of 11.5% enhancement on operating performance conditions compared with conventional ones. The effectiveness of cooling is realized with locally available materials, making this system more appropriate for use in rural or poor communities. Although not confirmed, it is estimated that the system consumes about 20% less energy than a similar capacity small-scale vapor compression loop, implying its potential for energy-saving operation.

Future studies should focus on:

- Investigating advanced thermal storage materials that can be effective in prolonging the cooling duration.
- Integrating renewable energy sources into the system for improved energy savings.
- Testing the system under varying environmental conditions and scaling up design optimization for bigger applications.

The study therefore demonstrates that cost-effective and energy-efficient cooling effects may be obtained through local resource mobilization combined with innovative engineering approaches to solve practical setbacks in sustainable refrigeration.

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REFERENCES

[1] Wang, T., Lv, M., Jin, Y., Alam, F. (2025). Integration of vapor compression and thermoelectric cooling systems for enhanced refrigeration performance. *Sustainability*, 17(3): 902. <https://doi.org/10.3390/su17030902>

[2] Kılıç, M. (2022). Evaluation of combined thermal-mechanical compression systems: A review for energy efficient sustainable cooling. *Sustainability*, 14(21): 13724. <https://doi.org/10.3390/su142113724>

[3] Mahan, H.M., Katawy, A., Shabeeb, O.A., Alrubaiy, A.A.A.G. (2025). Analyzing thermal insulation of

concrete polymer by adding mineral wool. *Advances in Science and Technology Research Journal*, 19(5): 430-439. <https://doi.org/10.12913/22998624/202766>

[4] Banjo, S., Bolaji, B.O., Oyelaran, O.A., Babalola, P.O., Afolalu, A.S., Salawu, E.Y., Emeteri, M.E. (2024). Performance assessment of a refrigeration system with an integrated condenser under different environmental conditions. *Heliyon*, 10(7): e29226. <https://doi.org/10.1016/j.heliyon.2024.e29226>

[5] Nwasuka, N.C., Nwaiwu, U., Nwadinobi, C.P., Echidebe, C., Ikeh, V.C. (2020). Design and performance evaluation of a condenser for refrigeration and air-conditioning system using R134a. *International Journal of Mechanical and Production Engineering Research and Development*, 10(3): 6435-6450.

[6] Luthfi, L. (2025). Thermal behavior of reusable ice cubes: Cooling efficiency and performance analysis. *Jurnal Polimesin*, 23(1): 1-10. <https://doi.org/10.30811/jpl.v23i1.5521>

[7] Prajapati, P., Raja, B.D., Savaliya, H., Patel, V., Jouhara, H. (2024). Thermodynamic evaluation of shell and tube heat exchanger through advanced exergy analysis. *Energy*, 292: 130421. <https://doi.org/10.1016/j.energy.2024.130421>

[8] Barale, D.D. (2020). Performance analysis of VCRS for multipurpose application by using shell and tube type condenser. In *2nd International Conference on Recent Innovations in Engineering & Technology*, Pune, India, pp. 740-743.

[9] Zhou, W.H., Li, A. (2024). Experimental study on the performance of the vertical shell-tube indirect evaporative cooler with inner grooved tubes. *Scientific Reports*, 14(1): 20952. <https://doi.org/10.1038/s41598-024-72111-w>

[10] Rifaldo, Z., Hafid, B., Husin, Z., Wijayanto, E.H., Idris, M. (2024). Analysis of heat transfer in shell and tube type condensers. *Journal of Mechanical Engineering Manufactures Materials and Energy*, 8(1): 67-74. <https://doi.org/10.31289/jmemme.v8i1.6238>

[11] Puri, D.B., Naik, B.N., Mane, P.A. (2024). Heat transfer enhancement in evaporators: Nanofluid application in shell-and-tube and plate heat exchangers. <http://doi.org/10.2139/ssrn.5000558>

[12] Memet, F. (2023). Analysis of a vapour compression refrigeration system working with R22. *International Journal of Modern Manufacturing Technologies*, 15(1): 131-140. <https://doi.org/10.54684/ijmmt.2023.15.1.131>

[13] Nogueira, É. (2022). Efficiency and effectiveness method versus ϵ -NTU method with application in finned flat tube compact heat exchanger with water-ethylene Glycol as nanofluid base of iron oxide nanoparticles. *Journal of Materials Science and Chemical Engineering*, 10(2): 1-17. <https://doi.org/10.4236/msce.2022.102001>

[14] Nogueira, É. (2020). Theoretical analysis of a shell and tubes condenser with r134a working refrigerant and water-based oxide of aluminum nanofluid (Al₂O₃). *Journal of Materials Science and Chemical Engineering*, 8(11): 1-22. <https://doi.org/10.4236/msce.2020.811001>

[15] Ma, X., Zhao, H., Zhao, X., Li, G., Shittu, S. (2019). Building integrated thermoelectric air conditioners—A potentially fully environmentally friendly solution in building services. *Future Cities & Environment*, 5(1): 12. <https://doi.org/10.5334/fce.76>

- [16] Nogueira, É. (2020). Efficiency and effectiveness concepts applied in shell and tube heat exchanger using ethylene Glycol-water based fluid in the shell with nanoparticles of Copper Oxide (CuO). *Journal of Materials Science and Chemical Engineering*, 8(8): 1-12. <https://doi.org/10.4236/msce.2020.88001>
- [17] Youssif, S.S., Shabeeb, O.A., Mahan, H.M., Konovalov, S.V., Ismael, A.A.A. (2025). Experimental study of vapor compression refrigeration system using mixing refrigerant (R290/R600a) compare with nano refrigerant (R600a/Al₂O₃). *Advances in Science and Technology. Research Journal*, 19(8): 177-189. <https://doi.org/10.12913/22998624/205278>
- [18] Chel, A., Kaushik, G. (2018). Renewable energy technologies for sustainable development of energy efficient building. *Alexandria Engineering Journal*, 57(2): 655-669. <https://doi.org/10.1016/j.aej.2017.02.027>
- [19] Mastrucci, A., Byers, E., Pachauri, S., Rao, N.D. (2019). Improving the SDG energy poverty targets: Residential cooling needs in the Global South. *Energy and Buildings*, 186: 405-415. <https://doi.org/10.1016/j.enbuild.2019.01.015>
- [20] Pavanello, F., De Cian, E., Davide, M., Mistry, M., et al. (2021). Air-conditioning and the adaptation cooling deficit in emerging economies. *Nature Communications*, 12(1): 6460. <https://doi.org/10.1038/s41467-021-26592-2>
- [21] Al-Rashed, A.A. (2011). Effect of evaporator temperature on vapor compression refrigeration system. *Alexandria Engineering Journal*, 50(4): 283-290. <https://doi.org/10.1016/j.aej.2010.08.003>
- [22] Younus, Z.K., Younus, K.K., Abbas, L.K., Hussein, A.K. (2023). A study of cracked nano composite plates under mechanical buckling load. *AIP Conference Proceedings*, 2830: 070011. <https://doi.org/10.1063/5.0158072>
- [23] Usri, N.A., Azmi, W.H., Mamat, R., Hamid, K.A., Najafi, G. (2015). Thermal conductivity enhancement of Al₂O₃ nanofluid in ethylene glycol and water mixture. *Energy Procedia*, 79: 397-402. <https://doi.org/10.1016/j.egypro.2015.11.509>