

# Solar Cooling Alternatives for Kuwait's Climate

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**Abstract.** Kuwait has a very hot climate; thus, air-conditioning systems are widely used in buildings. In a typical building, 60% of the total energy use goes to the air-conditioning, and it uses up to 70% of the electricity at peak hours. This high demand for energy leads to an increased carbon footprint, which harms the environment, and the rise of the peak load demand, which harms the power grid. Hence, there is an urge to replace the conventional air-conditioning system with a more energy-efficient and eco-friendly one. This study focuses on a comparative study between the two potential solar thermally driven cooling systems: the desiccant cooling system and the absorption cooling system. The numerical model of the systems developed comprises components that are validated empirically or experimentally. Modelling has shown that the absorption chiller refrigeration system provides better results in terms of maintaining the temperature in the building and power consumption. Even though the desiccant evaporative system is more thermally and electrically efficient, the system has to operate for longer periods to maintain a comfortable thermal environment than the absorption chiller system.

**Keywords:** Absorption chiller, Evaporative cooling, HVAC, Solar collector, TRNSYS

## 1. Introduction

Countries in hotter regions face the issue of excessively using air-conditioners to cool indoor spaces. In Kuwait, cooling systems account for as much as 60 percent of the energy used in buildings [1-2]. During peak demand periods, air-conditioning can use roughly 70 percent of the total electricity [3]. The challenge of the heating, ventilating, and air conditioning (HVAC) industry is to reduce energy consumption while providing a comfortable environment and good indoor air quality [4]. Studies have shown that good air quality can positively impact an individual's productivity [5]. In this context, a solar thermal air-conditioning system offers a potential alternative to save energy and improve indoor air quality. Studies have shown its effectiveness in a variety of climates and are a suitable replacement for conventional HVAC systems [6]. This study will compare two potential thermally driven AC systems, the desiccant evaporative cooling system & the absorption chiller cooling system, for Kuwait's climatic conditions.

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Climate conditions at the location of the building will set the design requirements and the factors to improve how efficiently an air conditioner uses energy; hence, the design, selection and operation of the air conditioner need to be based on the location's temperature and relative humidity profile. Based on the Köppen climate system, Kuwait falls under a subtropical desert climate, marked by mild winters and very intense summers. Kuwait's temperature starts to get warm from April, rises to its peak in July, and gradually goes down until November. The maximum temperature in July goes up to 46°C. The relative humidity is around 60% on average all year; however, the lowest is in July [7].

Kuwait has around 3000 hours of sunshine a year, suggesting great potential for using solar systems in this region. Solar energy systems, such as solar thermal systems, will be cost-effective and economically viable in this area. Hence, integrating solar technologies in industries such as HVAC and others would be an attractive option.

Generally, thermal comfort can be achieved if the temperature is maintained between 18–26°C and the humidity kept between 40–70% in the indoor space. The ASHRAE standard [8] presents acceptable indoor conditions for people in conditioned spaces using temperature and humidity ratio charts. In practice, no system can meet every requirement throughout the entire year, especially when outdoor conditions become extreme. The Energy Efficiency Ratio (EER) of conventional air-conditioners is between 3 and 7; this means one unit of electricity is used for every 3-7 units of cooling. This system uses a vapour compression refrigeration cycle to produce cooling by removing heat from the building. An alternative cooling system suitable for dry climates is the evaporative cooler. This system basically humidifies hot and dry air; the way it does that is by simply vaporising water particles in the air, which absorbs the heat from the air, hence providing cooler air. It also provides 100% fresh air in the given space. This method can achieve an EER of 20 and above [9]. However, this system has been proven less effective in humid climates due to the moisture in the ambient air.

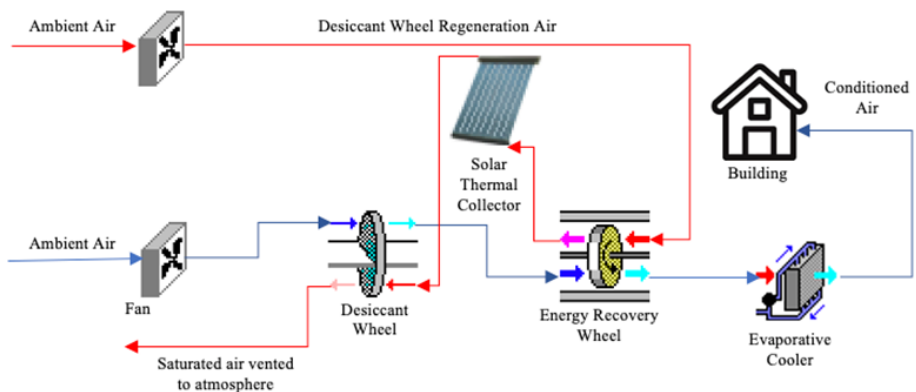
Traditional air-conditioning systems in buildings often struggle to maintain comfortable indoor conditions without using additional energy. In many regions, these systems face one of two problems: (a) they become energy-inefficient when trying to hold the design temperature, or (b) they fail to control humidity at part-load conditions.

Issue (a) is typical of constant air volume systems, which rely on reheating to keep comfort levels when the load drops. Issue (b) appears in variable air volume systems, where the outdoor temperature may fall well below the design point at part load, yet the humidity ratio remains nearly unchanged.

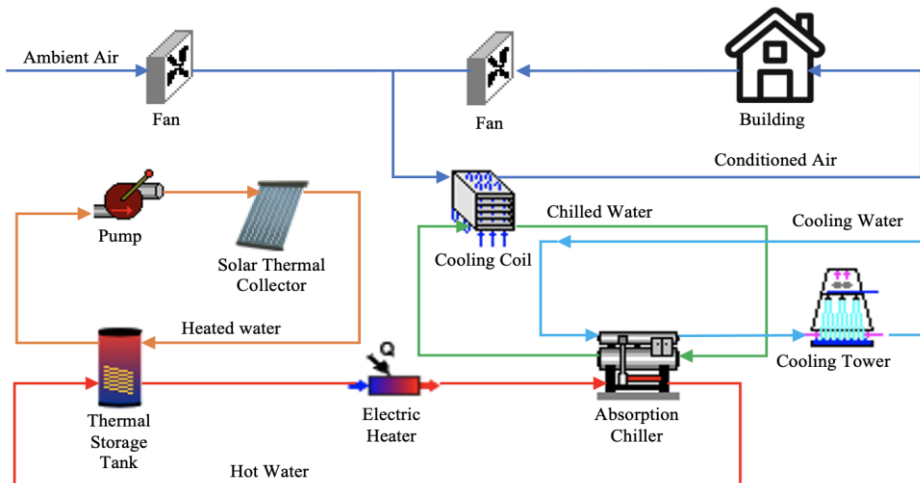
An evaporative cooling system performs well in regions that are both hot and dry, but if the humidity levels are high, the cooling effect produced will fall short of requirements. A desiccant evaporative cooling (DEC) system relies on a desiccant wheel to bring the air's humidity down to very low levels, which makes the evaporative cooling system work more effectively. So, it has good potential to provide an adequate indoor temperature [6]. A solar thermal collector can provide the heat needed to regenerate the air. It is beneficial in this case because cooling is needed the most when the solar supply is at its peak. A DEC setup paired with solar thermal collectors offers a substitute for standard air-conditioning systems. Figure 1 illustrates how a solar-assisted desiccant cooling system is arranged. However, the dehumidification process needs to have higher performance levels.

Another alternative system is the absorption chiller, which consists of a generator/concentrator, condenser, expansion pipe, evaporator and absorber. Absorption chillers are available in several different configurations, including single and double-effect indirect-fired (steam, hot water) and double-effect direct-fired (gas, oil burner) absorption chillers. Single-effect absorption chillers utilise a single generator or concentrator and a

single condenser to condense the entire vaporised refrigerant [10]. Whereas a double-effect absorption chiller operates using two generators/concentrators, and the thermal energy absorbed in the high-temperature generator or concentrator by the vaporised refrigerant is used as the heat supply for the low-temperature generator or concentrator. This process results in a reduction in the amount of cooling required to condense the vaporised refrigerant. The double-effect absorption chiller has the same steps as the single-effect absorption chiller but uses an additional generator/concentrator to improve the efficiency of the absorption chiller [11]. The thermal EER of absorption chillers varies depending on the type of chiller, with single-effect absorption chillers having an EER of between 0.4 and 0.8, while double-effect absorption chillers can have an EER of up to 1.2 [12]. Figure 2 shows the configuration of a solar absorption cooling system.



**Figure 1.** Configuration of the solar desiccant cooling system



**Figure 2.** Configuration of the solar absorption cooling system

According to Almasri and Abu-Hamdehet al. [13], solar-powered sorption cooling systems such as adsorption, absorption, and DEC are gaining traction due to their potential to reduce conventional energy use and environmental impact. Their study highlights solar absorption systems as the most efficient among current technologies, while also noting the growing role of hybrid systems, nanofluids, and phase change materials in enhancing

performance. Altun et al. [14] conducted a dynamic simulation of a solar-driven absorption cooling setup modeled in TRNSYS, analysing its performance across six Turkish cities. The study evaluated various design parameters and introduced a novel boiler control strategy to improve system efficiency. Financial analysis revealed Izmir as the best site option, offering a payback period of about 10.7 years, while Trabzon showed the least economic viability.

The performance of a small-scale single-effect solar absorption cooling system with a capacity of 4.5 kW was evaluated using dynamic simulation and experimental validation. The analysis highlighted the significant influence of heat rejection temperature on overall system efficiency. To address this limitation, a geothermal-based heat rejection method was proposed as an alternative to conventional dry cooling towers, which reduced the system's dependence on ambient conditions and resulted in a noticeable improvement in the coefficient of performance (COP), reaching an increase of up to 0.42. Further investigations into solar-assisted absorption heating and cooling systems examined different system configurations and control strategies aimed at improving performance while limiting additional capital costs. Simulation-based analysis demonstrated that variable-speed pump operation combined with demand-based temperature control significantly increased the solar contribution to the system. In addition, employing a parallel auxiliary heating arrangement instead of a series configuration led to higher solar fraction (SF) and improved collector efficiency. Overall, these optimization strategies achieved close to a 20% improvement in solar energy utilization without substantially increasing system complexity or cost.

## 2. Methodology

To compare the two proposed cooling options, separate TRNSYS models were developed and their performance was assessed. The solar desiccant cooling setup includes a solar thermal system, an evaporative cooler (EC), an energy recovery wheel (ERW), a desiccant dehumidification wheel (DDW), and two fans that move ambient air through the system, the building, and the regeneration pathway. An evacuated tube collector (ETC) provides the thermal input required to heat the regeneration air for the DDW. The model's desiccant wheel output was compared with data from Novel Aire, and the close alignment between them demonstrates that the model is dependable [6].

The second model developed using TRNSYS uses a single-effect absorption chiller to deliver cooled and conditioned air to the building. This type of setup is far more complex than the evaporative cooling system, as it requires additional components for the absorption chiller to function properly. The model developed comprises an absorption chiller, cooling coil, cooling tower, pump, electric heater, thermal storage tank and two fans. An evacuated tube collector supplies the solar heat required to raise the water temperature for the absorption chiller. When the collector cannot meet the demand, an electric heater supplements the system by bringing the hot water to the operating range of 50 to 95°C. The parameters for each of the proposed systems are shown in Table 1.

The collector area needed to heat the regeneration air for the DDW in the evaporative cooling system is approximately 40 m<sup>2</sup>, whereas, for the absorption chiller, the evacuated tube collector needs a surface area of approximately 50 m<sup>2</sup> to heat the water passing through the evacuated tube solar collector to a similar temperature to that achieved in the evaporative cooler system. The TRNSYS models were simulated for an entire year, from midnight on January 1 to 11 p.m. on December 31 (8760 hours), using Kuwait's weather data to represent the conditions a local building would face. The building in the TRNSYS simulations includes thermal insulation in both its external and internal walls, ceilings, and roofs. All windows are double-glazed, and the layout features three bedrooms, communal

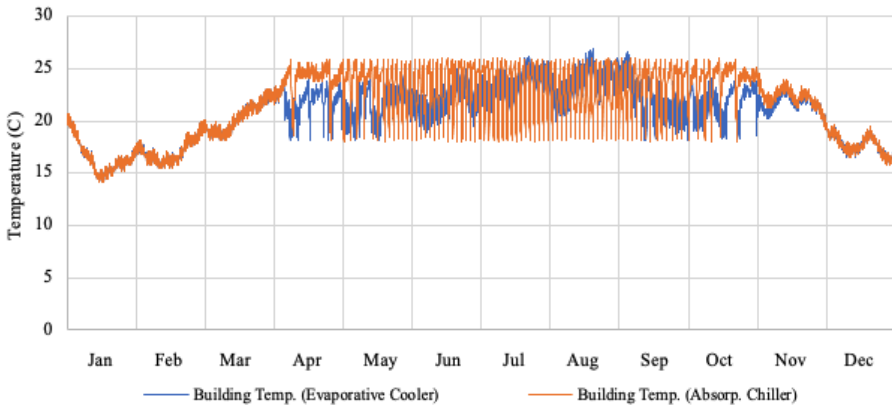
living areas, and general facilities found in all modern-day houses. It covers an area of approximately 297 m<sup>2</sup>.

**Table 1.** System constant parameters for the evaporative cooler and absorption chiller systems.

System Parameters	Evaporative System	Absorption Chiller
Room temp. set point	Min. 18°C . Max. 26°C (+/- 0.5)	Min. 18°C . Max. 26°C (+/- 0.5)
Conditioned spaces	living & bedroom	living & bedroom
Room air mass flowrate	2640 kg/hr	2640 kg/hr
Room conditioning schedule	00:00 - 23:59	00:00 - 23:59
Solar collector size	50 m <sup>2</sup>	50 m <sup>2</sup>
Desiccant wheel size (Dia.)	1220 mm	-
Desiccant wheel power consumption.	200 W	-
Evap. cooler power consumption.	950 W	-
ERW power consumption	100 W	-
Fan power consumption	573 W	573 W
Cooling tower power consumption	-	540 W
Absorption. chiller power consumption.	-	511 W
Pump power consumption	-	105 W
Chilled water flowrate	-	2900 kg/hr
Cooling water flow rate	-	5100 kg/hr
Hot water flow rate	-	2500 kg/hr

### 3. Results

The results indicate that the absorption chiller is more effective than the evaporative cooling system at keeping indoor temperatures within the target range of 18 to 26°C. In the evaporative cooling setup, the evacuated tube collector was able to heat the regeneration air for the DDW to about 100°C during the hottest summer hours. Meanwhile, with the absorption chiller, the data from the modelling shows that the temperature of the water passing through the evacuated tube solar collector when the system is operational would also reach a maximum temperature of 100°C during the hottest parts of the summer periods.

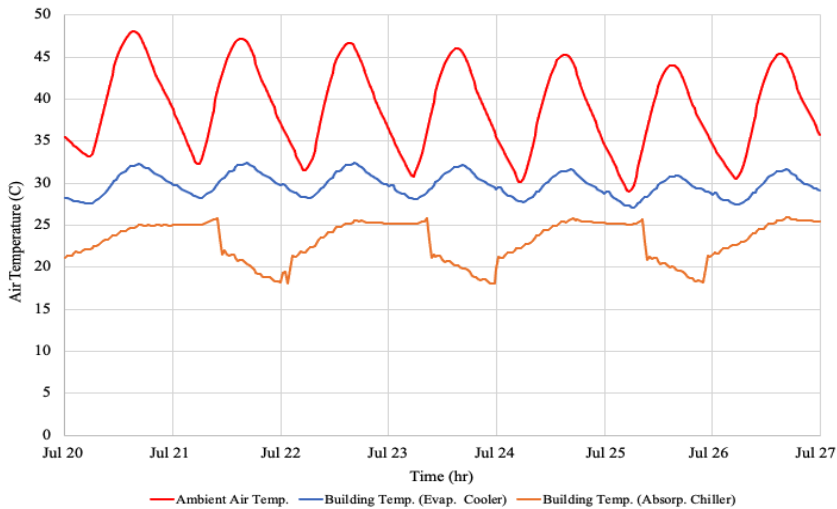


**Figure 3.** Indoor air temperature profiles for both systems.

Both systems kept indoor temperatures within the 18 to 26°C range, but the absorption chiller outperformed the evaporative cooling setup. The simulations show that it could bring the indoor temperature down to 18°C on most days when operating. The evaporative system reached this minimum only occasionally and lacked the same reliability. Temperatures rose above 26°C for about 53 hours, with a peak of 27°C, as seen in Figure 3. This reflects the evaporative system’s limited ability to consistently pull the indoor temperature down to 18°C, where the system would cease operations, resulted in the evaporative system operating continuously for the majority of the span from April to November as the temperature in the building for the majority of this period fluctuates between 20 and 27°C.

To compare how well the two systems cool the indoor space and keep temperatures within the target range, Figure 4 presents the difference in their cooling capacities over a one-week period from July 20 to July 27. Analysis shows that when both systems operate, the absorption chiller system can reduce the temperature in the building within the first 30 minutes of operation during daylight hours. In contrast, the evaporative cooler allowed indoor temperatures to rise during the same time period even though it continued to operate continuously over a one-week period.

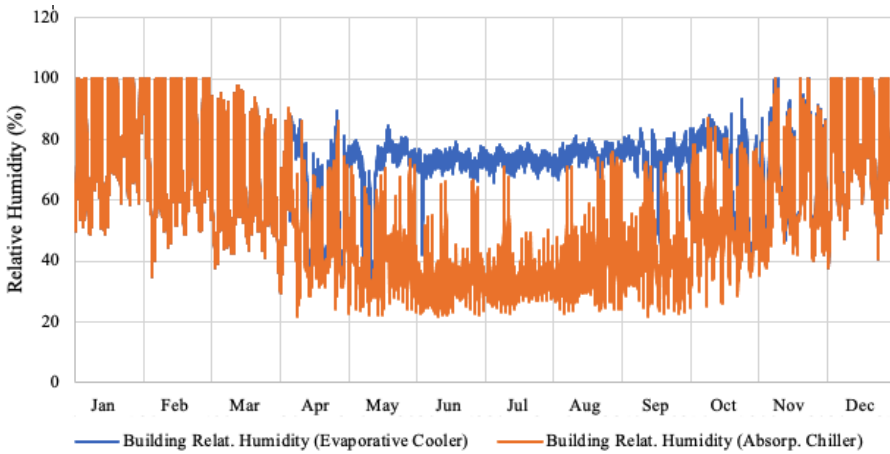
Further analysis shows that the absorption chiller was able to bring the indoor temperature down to 18°C, three times over the 7-day period, resulting in the system ceasing operation for approximately 5 out of the 7 days. The evaporative cooler over the same 7-day period was only able to lower the temperature down to a minimum of 27°C and was unable to maintain this temperature during the daylight period with the temperature reaching a maximum of 32°C, even though the evaporative cooler did not cease operating over the 7 days.



**Figure 4.** Air temperature inside the building over a one-week period for both systems.

The data also shows that the absorption chiller system was able to maintain a lower indoor relative humidity from April to November during system operation compared to the evaporative cooler system (Figure 5). This may be in part due to the absorption chiller system recirculating approximately 80% of the conditioned air, which has undergone some form of dehumidification back through the building with the remaining 20% being fresh air taken from the surrounding environment. Whereas the DEC system takes 100% of the air entering the system from the surrounding environment and dehumidifies it, and then injects water back into the air to absorb the heat to lower the temperature of the air. This result in the indoor air's relative humidity being significantly higher compared to the absorption chiller from May through to October, as highlighted in Figure 5.

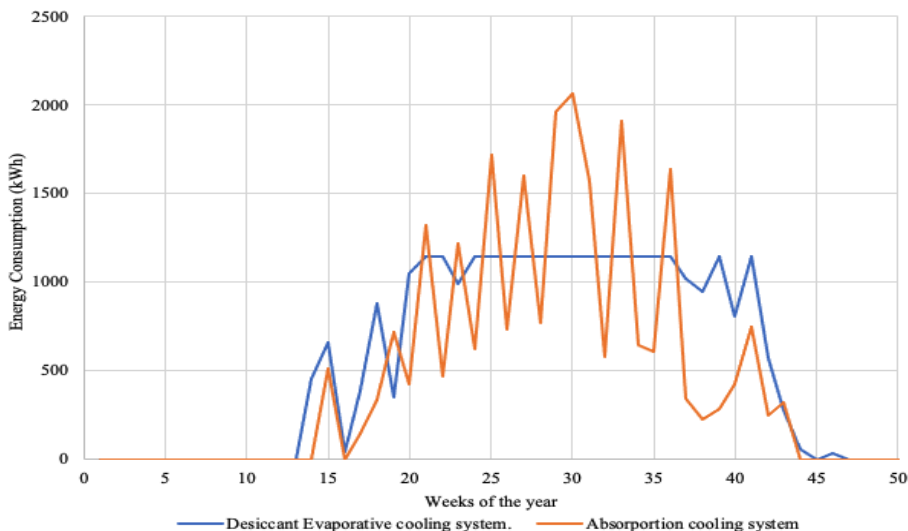
The modelling indicates that using a DEC system would lead to indoor air humidity levels fluctuating between a minimum of 34% at a temperature of 22°C in the month of April, through to a maximum of 91% also at a temperature of 22°C during the month of October when the evaporative cooling system would be used to provide conditioned air to the building. By contrast, when the absorption chiller provides conditioned air, the modelling shows that indoor humidity levels fluctuate more regularly between a minimum of 21% and 59% and reach a maximum of 84% within the 18 to 26°C temperature range when the system is operational from April until late October. Further analysis of the data shows that for the majority of the time that the proposed systems are operational; the relative humidity in the building would mostly fluctuate between 64% and 82% when an evaporative cooler is used. Compared to the absorption chiller where the modelling shows that the relative humidity will mainly fluctuate between 21 and 59% from May through to October. The data shows that the moisture level inside the building when an evaporative cooler is used can be more than three times higher than when an absorption chiller is used. The elevated indoor humidity produced by the evaporative cooler can affect occupant comfort, even when the indoor temperature remains within the desired 18 to 26°C range during the hottest hours of the day.



**Figure 5.** Indoor humidity ratio for both systems

When the systems are operational, the data shows that over the course of the year, the evaporative cooling system will consume more power overall than the absorption chiller. The modelling shows that when both systems commence operating at the start of April, the evaporative cooling system will on average; consume more power on a weekly basis than the absorption chiller system for the first three months. As the ambient temperature in Kuwait increases with the onset of summer, the modelling shows that the absorption chiller will consume significantly more power from July through to late August than the evaporative cooler in trying to keep indoor temperatures within the target range. But from late August through to the end of November, the evaporative cooler will again consume more power than the absorption chiller as highlighted in Figure 6. The analysis suggests that the absorption chiller system would consume approximately 13.6% less power than the evaporative cooling system over the same operating period.

This is due to the absorption chiller system being able to cool the building's interior at a faster rate to the minimum temperature for thermal comfort of 18°C, where the system ceases operating until the building reaches its peak temperature for thermal comfort of 26°C. The main reason why the evaporative cooler consumes more power than the absorption chiller is its inability to consistently lower the temperature down to 18°C during the peak heat from April to November. This results in the evaporative system not ceasing operations for a period of time and instead continuing to operate continuously for extended periods to maintain the temperature within the required temperature range. The modelling shows that the evaporative cooling system would operate for approximately 4266 hrs compared to only 1496 hrs for the absorption chiller system. The results indicate that the evaporative cooling system would operate 2.85 times longer than the absorption chiller system, but only consumes 13.6% more power, highlighting that the evaporative cooling system is more energy efficient in delivering conditioned cooling to a residential space.



**Figure 6.** Weekly electricity consumption rate of for both proposed air conditioning systems

The data indicates a marked difference in the performance of the two systems. The overall effectiveness of the evaporative cooling system is significantly better as the modelling shows that the EER of the overall system is approximately 6.06. This indicates that the evaporative cooling system removes more thermal energy from the air than the system's overall electricity consumption when it is operational. In contrast, the modelling shows that the absorption chiller has a significantly lower EER than that of the evaporative system, indicating that more energy is being consumed by the electrical components used in the system than the thermal energy extracted from the air when the absorption chiller system is operational. The thermal performance of each of the systems also differs significantly as the data shows that the evaporative cooling unit has an average thermal EER of 0.91 depending on the air temperature at the cooler's inlet. In comparison, the absorption chiller was able to achieve a thermal EER of 0.61. This again indicates that the evaporative cooling process used in the evaporative cooler is a more efficient process at removing thermal energy from the air than the absorption chiller process.

A possible alternative to the evaporative cooler is an advanced indirect evaporative cooler. A study carried out in South Australia [15] examined the use of an indirect, or dew point, evaporative cooler to supply conditioned air to a home in Roxby Downs. The system was able to lower ambient air temperatures of more than 40°C to about 15°C in a house with a conditioned area of roughly 140 m<sup>2</sup>. During operation, outdoor temperatures averaged between 27.5°C and 40.4°C, while relative humidity ranged from 12.8 to 32.2 percent. The air leaving the cooler averaged about 14.9°C. The study demonstrates that indirect evaporative cooling can perform well in hot climates and may serve as an alternative to standard evaporative cooling systems. If this type of evaporative cooler is able to consistently lower the temperature in the residential building in Kuwait down to 18°C during the summer period, the amount of time that the evaporative system would operate may be similar to that of the absorption chiller. This would see a significant reduction in the amount of power consumed by the evaporative cooling system and lower peak load demand on the electricity grid in Kuwait. But for this to be achieved, the system must be tailored to the specific climate where the building is located.

## 4. Conclusions

The TRNSYS simulations showed that, for most of its operating period, the evaporative cooler could keep indoor temperatures within the target range of 18 to 26°C. Its inability to lower the temperature down to 18°C where the evaporative system would cease operating results in the evaporative system operating continuously. As the residential building is situated in Kuwait where the ambient air temperature can reach into the high 40s during the summer period. It is more than likely that the system would be left to run continuously, even when the residential building is not occupied, to keep the space comfortable when occupants return. The simulations show that the evaporative system would operate for 2770 hrs longer than the absorption chiller, as the absorption chiller is able to lower the temperature in the building down to the cut-off temperature of 18°C almost on a daily basis. This results in the absorption chiller system only operating for approximately a third of the time of that of the evaporative cooling system.

The increased amount of time that the desiccant evaporative cooler operates results in this cooling system consuming more power than the absorption chiller, even though it is more thermally and electrically offers better efficiency compared to the absorption chiller. The absorption chiller is a far more complex system than the evaporative cooling system and may require more maintenance to ensure the system functions properly compared to the evaporative system, which requires fewer components to ensure a comfortable indoor climate. Another drawback of the evaporative cooler is the rise in indoor humidity levels due to water being used in the evaporation process in the evaporative cooler to reduce the temperature of the air entering the building. The relative humidity is up to two to three times higher during the summer period compared to the absorption chiller, and this may have an effect on the thermal environment in the building and make it less comfortable for the building's occupants during the summer months.

Modelling indicates that of the two systems; the absorption chiller system will reduce peak load demand even though it is not thermal or electrically more efficient than the evaporative system. Its key advantage in a residential setting is how quickly it can bring the indoor temperature down to the 18°C cut-off, where it ceases operating, and therefore reducing pressure on the Kuwait electricity grid for longer periods from April through to the end of November compared to the evaporative system. Although it is recommended that the absorption chiller system be used in residential buildings in Kuwait, more investigation into indirect evaporative cooling systems as a possible alternative to evaporative coolers needs to be conducted to determine its suitability. Research conducted in South Australia [15] shows that it may be a possible alternative to conventional evaporative coolers that may be able to provide a thermal environment similar to that of the absorption chiller while also possibly reducing power consumption further.

## Abbreviations

HVAC - Heating, ventilating, and air conditioning

EER - Energy Efficiency Ratio

DEC - Desiccant evaporative cooling

COP - Coefficient of performance

SF - Solar fraction

ETC - Evacuated tube collector

DDW - Dehumidification wheel

ERW - Energy recovery wheel

EC - Evaporative cooler

## References

- [1] A. Al-Otaibi, A. Al-Qatta, F. Fairouz, and A. Al-Mulla, Performance Evaluation of photovoltaic systems on Kuwaiti School's rooftop, *Energy Conversion Management* **95**, pp.110-119(2015).<https://doi.org/10.1016/j.enconman.2015.02.039>.
- [2] K. J. Chua, S.K. Chou, W.M. Yang, and J. Yan, Achieving better energy-efficient air-conditioning – A review of technologies and strategies. *Applied Energy*, **104(0)**, pp.87-104(2013).<https://doi.org/10.1016/j.apenergy.2012.10.037>.
- [3] S. Alotaibi, Energy Consumption in Kuwait: Prospects and Future, *Energy Policy*, **39**, pp.637- 643(2011).<https://doi.org/10.1016/j.enpol.2010.10.036>.
- [4] Green Guide – Design, Construction and Operation of Sustainable Building. 2010, ASHRAE.
- [5] A. M. Omer, Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews*, **12(9)**, pp.2265-2300(2008).<https://doi.org/10.1016/j.rser.2007.05.001>.
- [6] H. M. Henning, *Solar Assisted Air-conditioning of Buildings: A Handbook for Planners*, (Springer, New York, 2004).
- [7] World weather and climate info, climate and average monthly weather in Kuwait, (2018), <https://weather-and-climate.com/average-monthly-Humidity-perc,Kuwait>.
- [8] A.A. Halabi, A. Al-Qattan and A. Al-Otaibi, Application of solar energy in the oil industry – Current status and future prospects, *Renewable and Sustainable Energy Reviews*,**43**, pp.296–314(2015).<https://doi.org/10.1016/j.rser.2014.11.030>.
- [9] ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy, ASHRAE Inc., Atlanta, 2010.
- [10] ASHRAE Handbook–Fundamentals, 2009: American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE).
- [11] Jayadeep Kumar J., and James Varghese. Area Optimization of a Flat Plate Collector for Meeting the Air Conditioning Load of an Office Building Using a Solar Vapor Absorption System. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*,**92(1)**, pp.134-148 (2022). <https://doi.org/10.37934/arfmts.92.1.134148>.
- [12] V. Sakraida, 2009, Basics for Absorption Chillers, Engineered Systems, viewed January 2022.
- [13] R.A. Almasri, N.H. Abu-Hamdeh, K.K. Esmacil, S. Suyambazhahan, Thermal solar sorption cooling systems - A review of principle, technology, and applications, *Alexandria Engineering Journal*,**61**, pp.367–402(2020). <https://doi.org/10.1016/j.aej.2021.06.005>.
- [14] A.F. Altun, M. Kilic, Economic feasibility analysis with the parametric dynamic simulation of a single effect solar absorption cooling system for various climatic regions in Turkey, *Renewable Energy*,**152**,pp.75–93(2020). <https://doi.org/10.1016/j.renene.2020.01.055>.
- [15] F. Bruno, On-site experimental testing of a novel dew point evaporative cooler, *Energy and Buildings*, **43(12)**, pp.3475-3483 (2011).<https://doi.org/10.1016/j.enbuild.2011.09.013>.