Chapter

Post Covid 19: An Innovative System to Supply 100% Treated Fresh Air for Improving City Liveability

Esam Elsarrag and Mohammad Elsarraj

Abstract

Prior to COVID-19, densely occupied areas were already suspected of making employees sick. Post-COVID-19, there is an urgent need to improve air quality and ventilation standards shall change. However, any changes to ventilation must consider other negative consequences including energy and health and well-being impacts from thermal discomfort and exposure to pollutants. The need for moving away from traditional energy sources and to find alternate energy sources is undoubtedly one of the primary objectives for a sustainable progress to humankind. The design and construction of buildings in hot-humid climates requires high energy consumption typically for air conditioning due to higher thermal loads. A further increase in ventilation rates will have intensive impact in energy consumption and infrastructure loads. This chapter presents the performance of an innovative fully integrated smart ventilation system with low energy consumption. It is all in one ventilating and air conditioning system that provides efficient, cost-effective, and sustainable cooled fresh air for open or enclosed spaces whilst achieving thermal comfort. Based on the application, it consists of multistages that can dehumidify and cool the air to the required comfort level. The system has shown 50–60% reduction in energy consumption compared with conventional systems.

Keywords: Covid 19, Ventilation, Comfort, Energy Efficiency, Outdoor Cooling, Comfort

1. Introduction

Higher ventilation rates are dictated both by better comfort requirements and by the most recent standards such as ASHRAE (62-2019) and various CIBSE guides. However, post-COVID 19 pandemics, these ventilation rates require re-consideration. People shall also maintain social distancing regulations, which impact occupied spaces both indoor and outdoor. Eventually, higher fresh air rates are required and researchers will continue to work on the additional fresh air amounts. The more outdoor air is used, the larger the cooling or heating loads required, particularly cooling loads in hot and humid regions. In addition, the uncontrol of the ventilation air physical parameters will impact human comfort and health. For instance, the fresh air must be treated and conditioned to the desired comfort level of humidity and temperature before being supplied to the occupied spaces.

Cooling of outdoor air is usually obtained with refrigeration equipment and often in humid climates and some post-heating is required to heat the air before it is supplied to the rooms. **Figure 1** demonstrates the ventilation air mixing in a typical HVAC system. Conventional energy resources are more depleted and the energy demands of a growing global population continue to increase.

According to Fang et al. [2], individuals spend 90% of their time indoors, resulting in a significant rise in energy consumption to maintain indoor thermal comfort. The characteristics of humid tropical climates are that they are hot and humid. These climates cover a huge portion of the globe and are home to more than 33% of the world's population as stated by Bonell et al. [3]. As a result, achieving thermal comfort outside is also becoming increasingly crucial. For outdoors, however, thermal comfort is difficult to accomplish since humans are directly exposed to the environment, which is influenced by the combination of air temperature, air velocity, relative humidity and radiation fluxes. These are among the environmental parameters. Clothing insulation and metabolic rate are two human personal factors, which are also variables that influence thermal comfort.

Binarti et al. [4] noted that in these hot-humid locations, a pleasant thermal environment is difficult to establish due to the combination of high temperatures and humidity. These variables also vary and are not uniform in large outdoor spaces, which creates difficulty in monitoring and managing them to achieve thermal comfort. Wind speeds will also impair cooling techniques in hot, humid areas.

If outdoor thermal comfort is accomplished, this will increase city liveability whilst simultaneously reducing building heating and air conditioning energy usage by reducing time spent indoors. To correctly analyse the outside thermal environment, it is important to utilise appropriate outdoor thermal comfort models.

Due to the outbreak of COVID-19, it has become increasingly difficult to have many occupants in the same room inside buildings such as restaurants and cafes. Therefore, outdoor spaces must be utilised to accommodate for a larger group of people. However, in hot-humid climates thermal comfort is difficult to achieve outdoors as previously discussed. The presented ventilation system in this chapter achieves outdoor thermal comfort whilst boasting low energy consumption.

There are challenges related to intensifying energy consumption majorly by the installed air conditioners especially related to hot-humid climates (46°C dry bulb, 31°C wet bulb) due to the fact that evaporative cooling systems will certainly fail to meet the comfort criteria due to the high wet bulb temperature. Despite searing temperatures

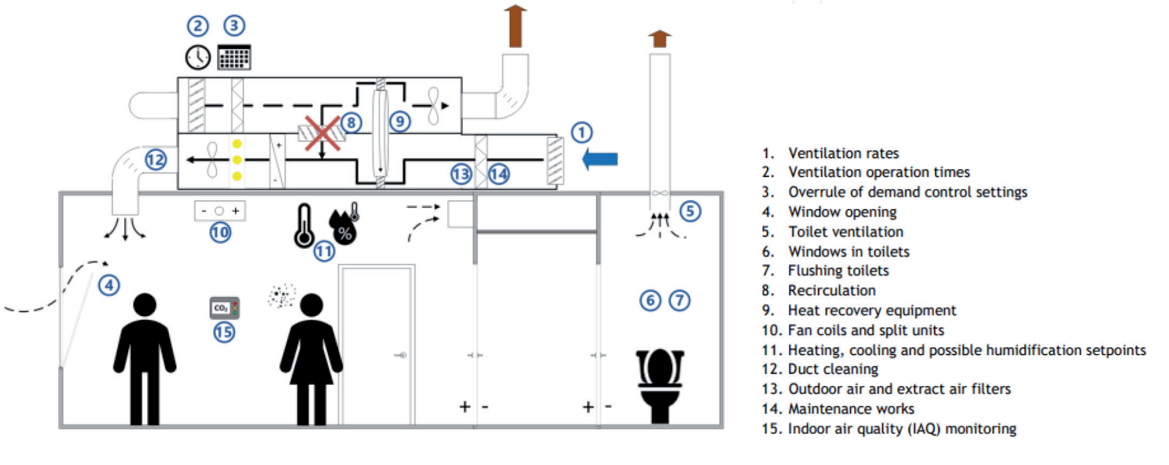

Figure 1.
Main items for building services operation [1].

and high humidity, people will find it interesting to go to places such as markets, cultural venues and other tourist destinations if given a cool and suitable ambiance. Evaporative cooling is often used for outdoors but it will not be enough to relieve people's discomfort with the weather during the hot months. Cooling is usually obtained with refrigeration machinery, and often some post-heating is required to heat the air before it is supplied to the rooms. Conventional air conditioning systems (e.g. vapour compression systems) address these issues by cooling air below its dew point such that water vapour condenses on a cooling coil, thus removing moisture from the air.

Nevertheless, achieving thermal comfort in using fresh air in hot and humid regions is energy intensive. Countries with extreme climatic conditions impose a heavy reliance on cooling, mostly electricity-based, and thus a strong and structural dependency of a high energy resource. In hot-humid climate, the average highest outdoor temperatures during a year is 37.0°C; however, high-temperature values that exceed 46°C could be observed in summer. As illustrated by **Figure 2**, the temperature exceeds the 40°C for more than 300 hours, which anticipated to be doubled when considering hot-humid climate climate change in 2025. Air conditioning counts for more than 60% of the electricity consumption in the Gulf Region as explained by Elsarrag [5]. Moreover, this lack of responsiveness to the local climatic conditions also leads to problems of indoor air quality, user comfort and user productivity. With energy being cheaply available, the incentive for building users to save on their energy consumption is weak.

In hot-humid climates, not only the total annual energy consumption in buildings is very high, but peak demands for electricity also put a heavy burden on the infrastructures needed to respond to such demand pattern. In this context, building energy efficiency strategies can help to realise peak shaving by load reduction and load shifting.

Improving the energy efficiency measures has taken the attention of researchers in hot-humid climate in the Gulf Region. Experimental and theoretical studies were conducted recently to improve building fabric efficiency and promote enhanced indoor air quality in hot-humid climates as conducted by Elsarrag [5]. High-rise building passive design attracted researchers from different parts of the world [6–9]. In hot-humid climate, it is vital to cool and dehumidify the ventilation air

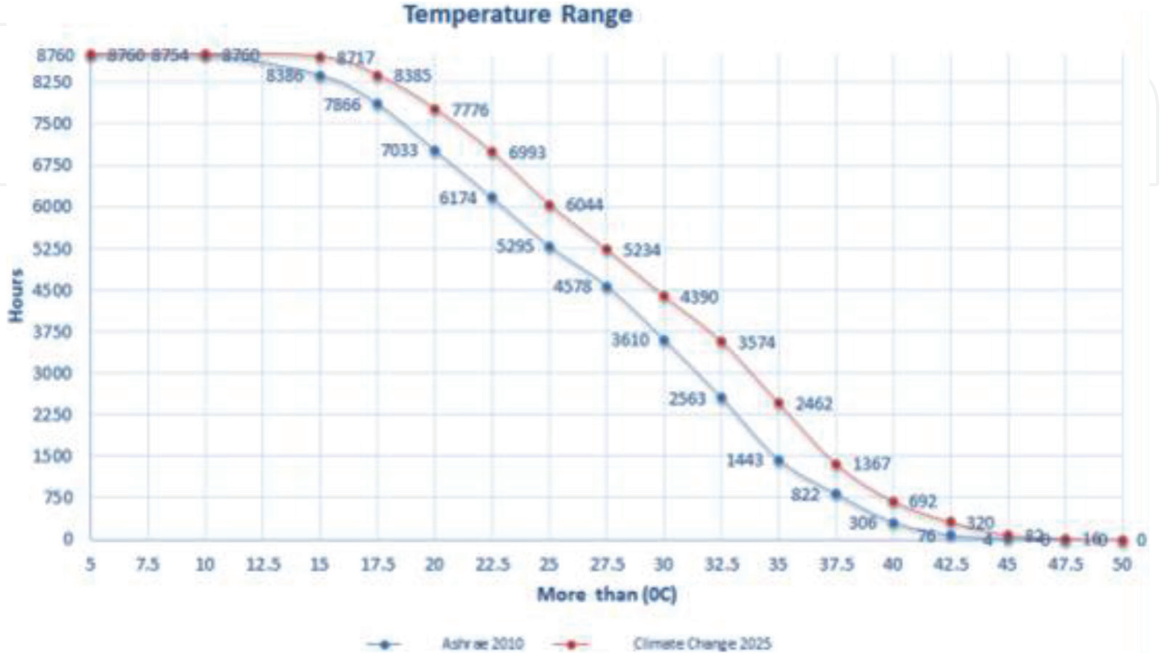

Figure 2.
Temperature range in hot-humid climate in Doha City [5].

before being supplied to the space. Alternative fresh air cooling and dehumidification methods to conventional refrigeration system were presented by Elsarrag [10, 11].

The use of efficient systems and effective means of control is vital to reduce the energy consumption. Several resilience cooling strategies are identified by Zhang et al. [12]. The study by Siroky et al. [13] showed that the energy saving of a building heating system by adopting controls could be reached the range of 15 to 28%. At times when ventilation and daylight cannot alone meet the needs of occupants, the building services should meet the remaining demands as simply and effectively as practicable, in harmony with the occupants and the building as a whole. An essential part of the integrated design is to ensure that the energy supply and monitoring strategy are as coherent and environmentally sustainable as possible.

Figure 3 shows about 83% of the ambient weather conditions are not in the comfort zone; therefore, the following strategies are used to design a high efficient cost effective system. Several strategies can be used to reduce the need of conventional vapour compression systems. Such strategies include the use of desiccants and evaporative cooling (direct and indirect).

In hot climates, it is desirable to reduce the ambient air temperature in order to improve comfort levels; however, in hot and humid climates (as in some Gulf countries), removal of moisture from the air (dehumidification) is almost as important as cooling [15].

Conventional air conditioning systems (e.g. vapour compression systems) address these issues by cooling air below its dew point such that water vapour condenses on a cooling coil, thus removing moisture from the air. The dehumidified air is then reheated to the desired temperature [16]. This process of deep cooling to dew point and reheating consequently leads to higher energy requirement.

This chapter discusses the integration of the innovative and efficient fresh air cooling and filtration system that has been designed, manufactured and tested to reduce the need of vapour compression cycles and provide better liveability for urban environments.

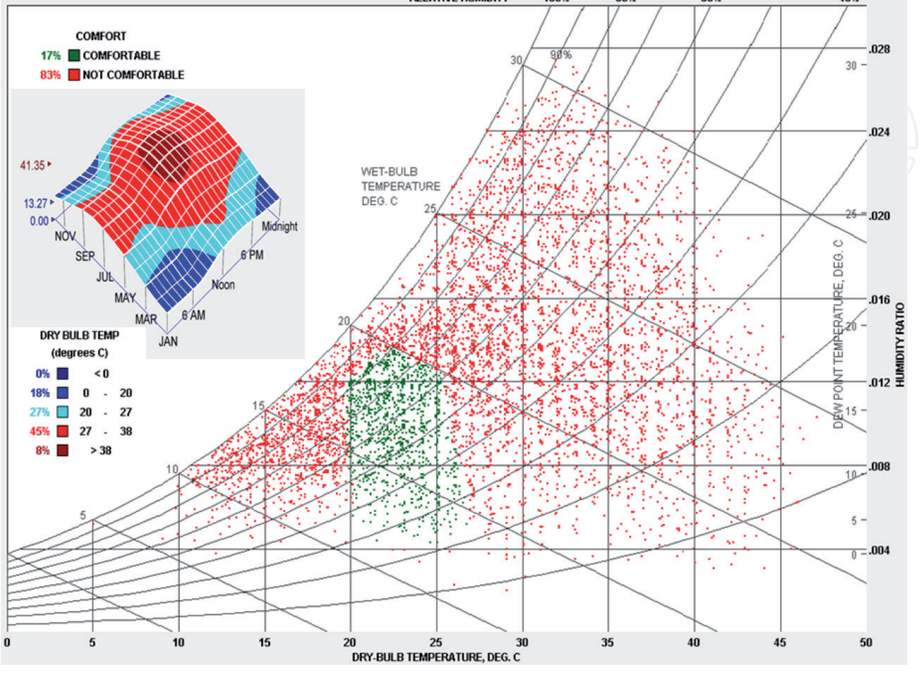

Figure 3.
Extreme weather conditions of hot-humid climate Doha City [14].

2. System description

The innovative smart air conditioning system is a fully integrated and controlled—beCOOL Innovation—ventilating and air conditioning system that provides efficient, cost-effective and sustainable fresh air cooling for open spaces or enclosed spaces in moderate, hot or humid climates. The system can be used tool open spaces such as restaurants, coffee shops, open markets, parks, playgrounds. It can also be used to provide fresh air (ventilation air) to enclosed spaces such as offices, schools, retails. The integrated unit consists of a multistage that can dehumidify and cool the air to the required comfort level. The system utilises the condensate water. The 'all in one' HVAC system can be fully driven by renewable energy. **Figure 4** shows the proposed system that combines air filtration system, and a three-stream water temperature control system, a multistage fresh air cooling heat exchanger and water collection/makeup system. The system is integrated with a variable frequency drives and smart controls. Initially, fresh air is filtered and used to cool three water streams. The scavenging outdoor air is exhausted to the atmosphere again. The innovative heat exchanger is a compact heat exchanger that allows more than one water stream to circulate. The first water stream is so called the high grade as the water temperature is higher than the second water stream (low grade). The supply hot and/or humid air will be initially filtered, precooled by the first stage in the heat exchanger, dehumidified in the second stage and cooling enhanced in the third stage. Dry cold fresh air is then supplied to spaces. The system is installed at different facilities for testing in a coffee shop, residential external sitting area and industrial workshop in Doha, Qatar. The tests were conducted during the months of June and July where temperature exceeds 47°C in the afternoon and humidity exceeds the 75% at night. Several temperature and humidity sensors are used to verify the readings. At the air intake and outlet, two type of sensors were incorporated, the first is directly integrated with the beCOOL-Innovation control system and the second is connected to the cloud for monitoring and verification.

The system was placed at a coffee shop—an open sitting area as shown in **Figure 5**. The system was placed 2.5 m away from the sitting area. To maintain effective outdoor cooling, the use of beCOOL-Innovation must be aligned with outdoor energy efficiency strategies to improve resilience to extreme heat in order to maintain comfortable outdoor thermal conditions during heat waves, such as the use of solar shading and wind barriers. Here, the system was placed between buildings that have shading and act as wind barriers for most of the day.

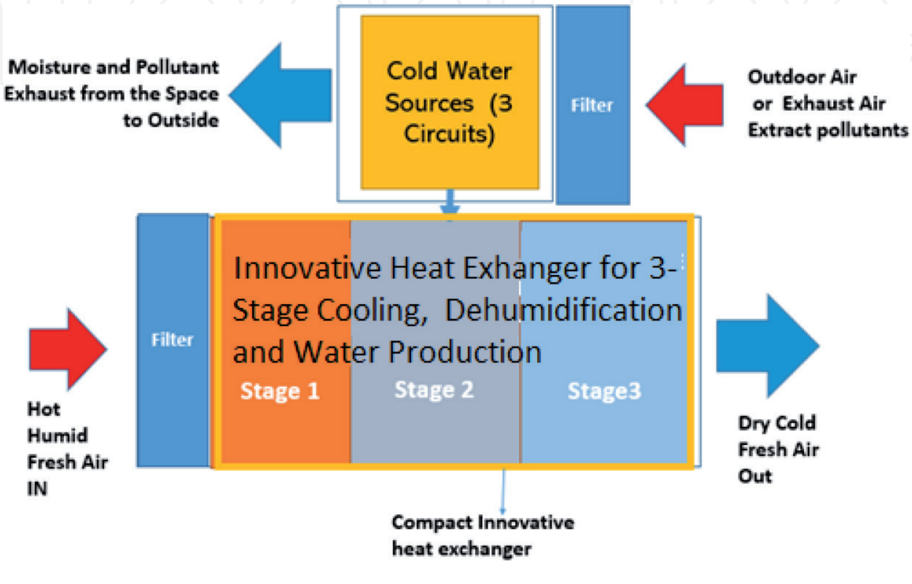

Figure 4.
The innovative system schematics.

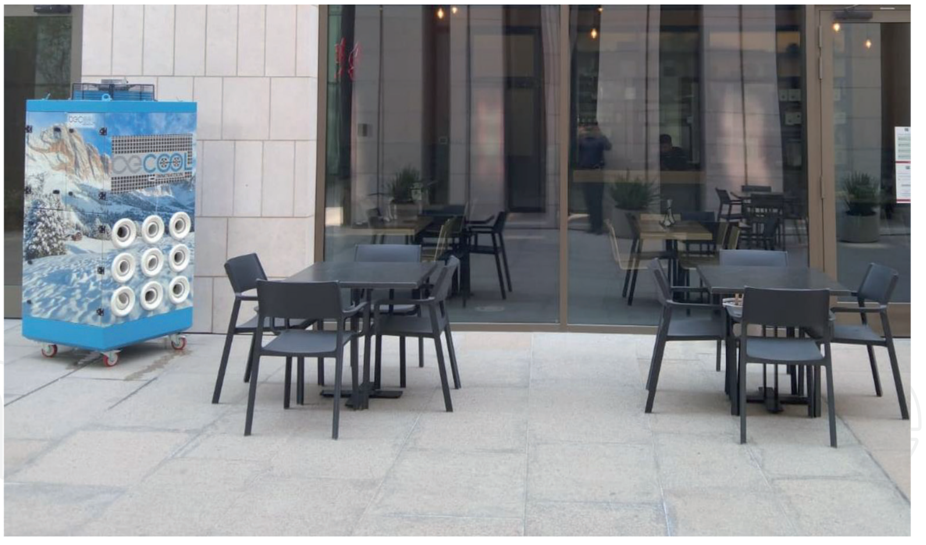

Figure 5.
beCOOL-innovation outdoor testing setup.

Temperature and humidity sensors were placed at the air intake of the unit (behind the unit), and the supply temperature and humidity are measured at the diffuser outlet. Air flow is measured using anemometer. The measured data were used to obtain the enthalpy of the entering and exit air, hence calculating the total cooling energy of the unit. A multimetre was used to measure the voltage and current to calculate the electrical energy. The coefficient of performance (COP) of the system is equal to the cooling energy divided by the electrical energy. Typical COP of conventional air conditioning in hot-humid climate varies between 2 and 2.5 for air-cooled direct expansion units. In this study, the COP for conventional system is considered the highest value (COP = 2.5) to ensure that energy savings are compared with the best practices for similar systems.

The temperature metre accuracy is 0.1°C and the humidity metre is 1%. Energy is measured *via* multimetre to measure both the voltage and current. The objective of the setup is to verify the theoretical performance.

Figure 6.
The actual beCOOL-innovation system.

Figure 6 shows the beCOOL-Innovation actual system. Jet diffusers are used to supply air to far distances.

3. Results and discussion

Figure 7 compares the theoretical monthly cooling coil load of the conventional fresh air handling unit and the beCOOL-Innovation cooling load. beCOOL-Innovation supplies 2500–3400 m3/h of treated fresh air with a considerable reduction in the cooling coil load compared with conventional. The system is designed to provide fresh air supply without assistant of any mechanical refrigeration in dry season and to provide cooling and dehumidification in humid season. The theoretical analysis showed that it will correspond to an annual cooling load reduction (cooling capacity reduction) of around 60% as shown in **Figure 8**. The overall predicted monthly and annual system electricity consumption is compared with system cooled *via* direct expansion (conventional refrigeration machine) system in **Figures 9** and **10**. beCOOL-Innovation can reduce the total annual electricity

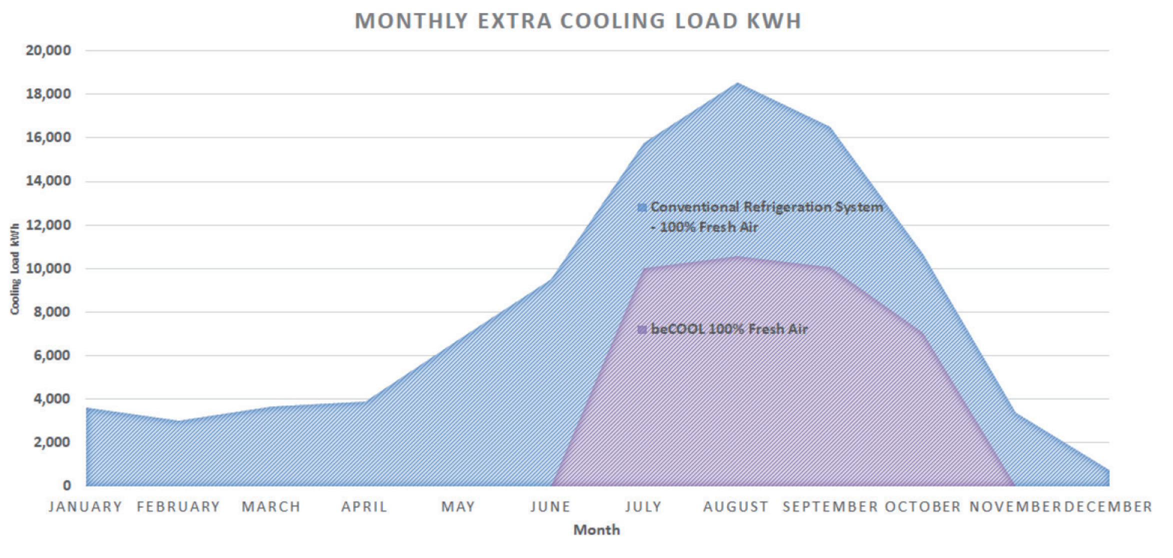

Figure 7.
Monthly cooling coil load (kWh).

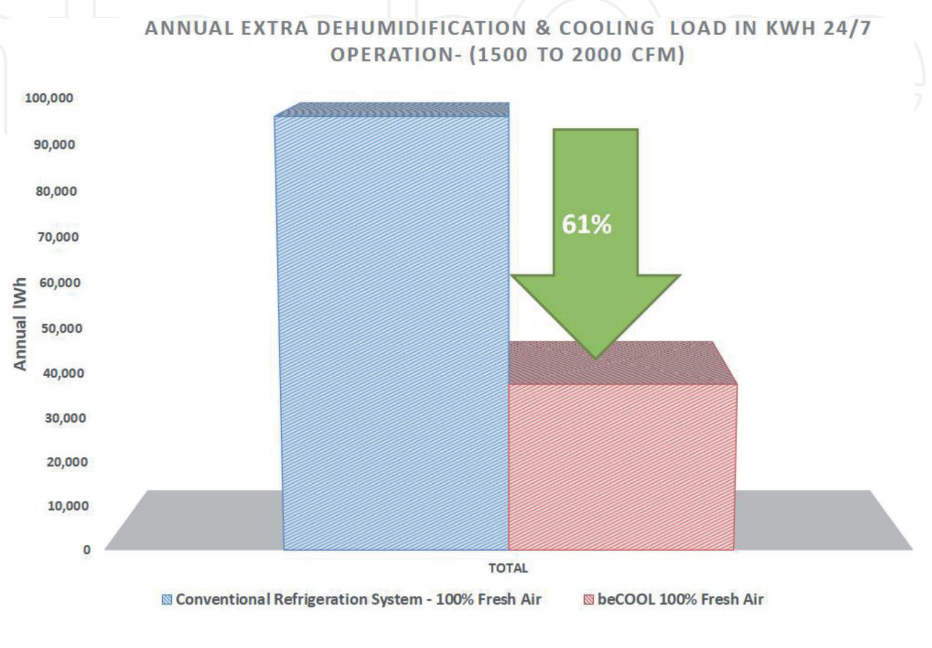

Figure 8.
Annual cooling coil load (kWh).

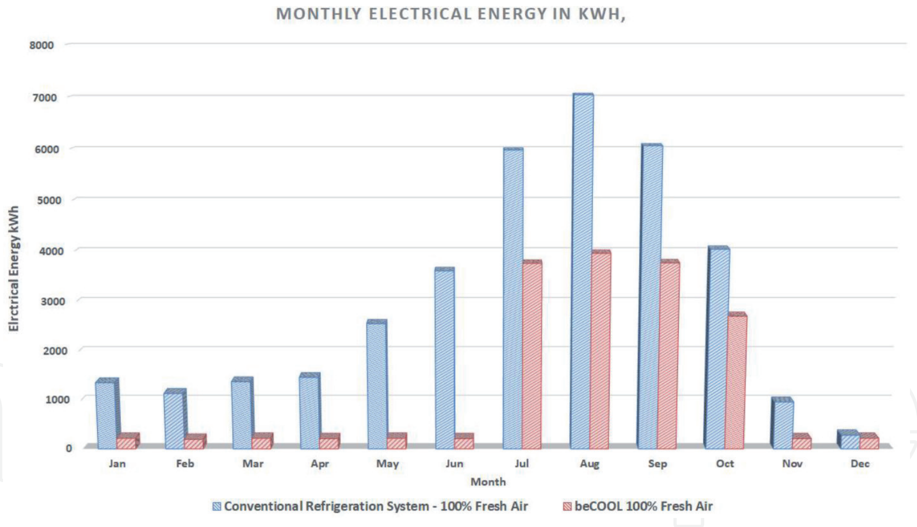

Figure 9.
Monthly system electrical energy (kWh).

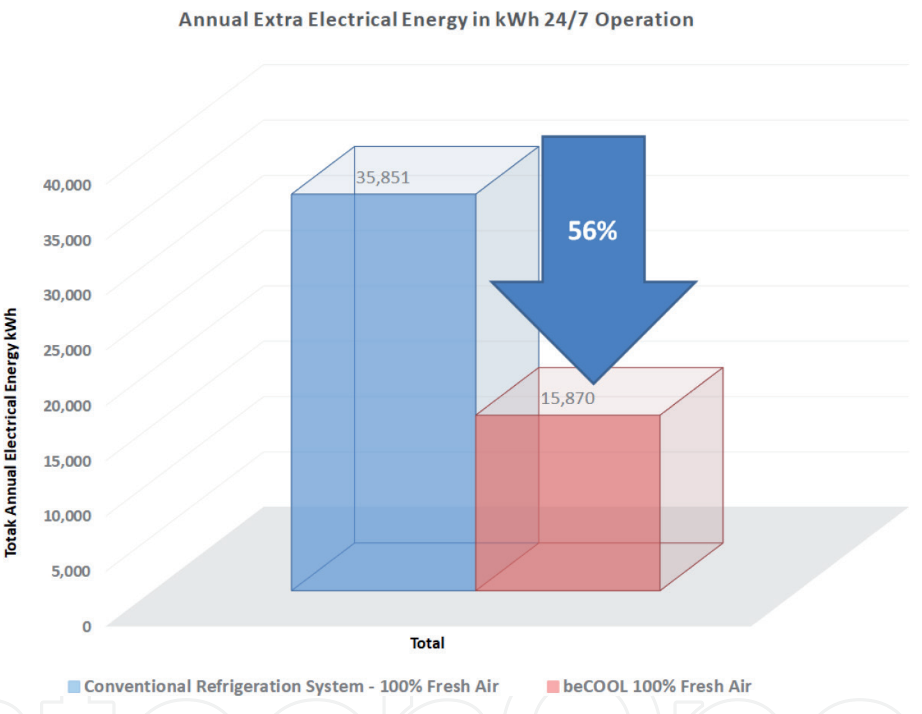

Figure 10.
Annual system electrical energy (kWh).

consumption by 55%. The system electricity consumption includes all power associated with unit including fans, pimps, compressors and electronics. The experimental setup results showed consistency with the theoretical analysis.

Table 1 shows the theoretical and measured results for average summer days. It can be clearly noticed that the discrepancy between the theoretical and experimental is below 8%, which provides confidence to the system design. For thermal comfort comparison, the apparent temperature analysis is used. The apparent temperature (AT) is the temperature perceived by the human body from the combined effects of ambient temperature, wind speed, humidity and solar radiation more objectively reflecting the thermal sensations experienced by the human body than temperature alone, especially in highly humid environments [17, 18].

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Ambient air temperature °C	Ambient air humidity %	Measured supply air temperature °C	Theoretical supply air temperature °C	Discrepancy
44.8	26.8%	22.4	21.4	4.7%
44.1	16.2%	15.8	14.7	7.5%
44	22.0%	18.1	17.1	5.8%
42.8	31.6%	21.8	21.5	1.4%
41.5	43.2%	23.6	23.3	1.3%
37.6	65.2%	26.8	26.3	1.9%
36.1	74.8%	28	27.5	1.8%

Table 1.
System measured vs. theoretical supply air temperature.

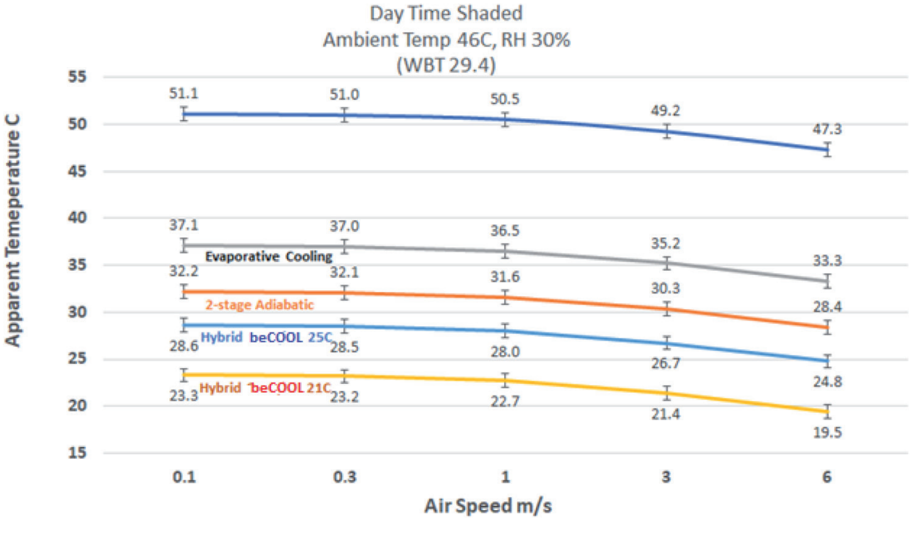

Figure 11.
Comparison of different systems on thermal comfort.

The apparent temperature (AT) is a suitable comfort index for climates with high temperatures and humidity. As shown in **Figure 11**, the apparent temperature at air speed for afternoon shaded is at 1 m/s air speed 50°C. If evaporative cooling is used, AT is reduced to 36.5°C. A two-stage indirect direct evaporative cooling system will reduce AT to 31.6°C. beCOOL-Innovation can reduce AT to 22.7°C at the same speed (1 m/s), which will have good impact on human comfort compared with traditional technologies.

The beCOOL-Innovation is a 100% fresh air system; therefore, the water consumption is directly related to the weather conditions. The average hourly water is found to be 10 litres/hour; however, the system produces 17.5 kW of cooling and consumes 3.4 kW electricity.

4. Conclusion

This chapter presented the drivers, challenges and the beCOOL-Innovation technology to provide efficient treated fresh air for outdoor comfort whilst reducing energy consumption especially for hot or humid climates. Outdoor comfort is vital to improve urban liveability. The system has shown 50–62% reduction in energy consumption compared with conventional refrigeration systems. The efficient cooling system can shrink clients' carbon footprints using cost-effective means. In addition to enclosed spaces, typical applications include open spaces such as stadiums and walkways, hospitals, health centres, laboratories, and greenhouses that would reduce food imports and strengthen national and regional food security. The testing results have shown less than 8% discrepancy between the theoretical and actual air supply temperatures.

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