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An analysis into the alternative strategies of substantial energy saving for the facilities of University of Jeddah, Khulais branch

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ABSTRACT

The main objective of this study is to develop strategies which aim to improve the energy saving and the sustainability at the University of Jeddah (UJ) - Khulais branch. The energy saving can be improved by reducing -indirectly- the cooling load, while the sustainability can be improved by recycling the sewage water, generating energy from the solar irradiance and improving land-use efficiency. Initially, the main reasons for increasing energy consumption in the buildings were identified. The most important reasons were large heat gain through the flat rooftops and sidewalls, infiltration and exfiltration, partial damage to the insulation materials of walls and ceilings, and thermal mass. To reduce the heat gained through buildings' rooftops, it is proposed to shade the rooftops by tilted and ventilated airgap Building Integrated Photovoltaic (BIPV). BIPV also help to improve the shading efficiency, land use efficiency, natural cooling of the rooftops and PV modules, Energy Efficiency Rating (EER) of the air-cooled ac system, and efficiency of night ventilation system. To reduce heat gained through the sidewalls, it is proposed to shade the walls by planting long-stemmed trees (Eucalyptus) around the buildings. Irrigating the trees by gray water will improve the sustainability and improve Leed Credit Point. Previous studies and current measurements of solar radiation under shaded surfaces have shown that shading the building is an appropriate strategy to reduce solar heat gain. Startup load of air conditioning system is another source of increasing energy use and it forms around 10-20% of the total cooling load due to high indoor temperature at the morning. As the buildings are not occupied after 3:00 PM, and during weekends, it is proposed to use mechanical night ventilation to reduce the indoor temperature and to improve the air quality. Connecting the ventilation system with a separate control system and the BMS at the buildings help to reach to the possible minimum indoor temperature.

1. Introduction

Khulais is a governorate of the region of Holly Makkah in Saudi Arabia. This province is located in the Tihama region, 90 km from Jeddah Province and 100 km from Makkah, and about 30 kilometers from the coast of the Red Sea to the east. Khulais is located at the line of 22 degrees in latitude and 39 degrees longitude. Khulais is renowned for its large agricultural valleys such as

Gran and Qadded Valley [1]. Fig. 1. Shows a satellite image for the Khulais Branch.

Fig. 1. Satellite image for the Khulais branch (Source: Google map)

'Jeddah features an arid climate under Koppen's climate classification, with a tropical temperature range. Jeddah differs from the rest of the Saudi Arabian cities, as the weather remains warm in the winter, and the temperature in the winter ranges between 15°C at dawn to 28 °C in the afternoon while the temperature is high in summer, sometimes exceeding 48 °C in the afternoon and 35 °C in the evening. The weather in summer is generally humid and the dew temperature is about 27 °C. Rain in the Jeddah region is rare, and usually occurs in small amounts, and is accompanied generally by thunderstorms. The most severe thunderstorm was in December 2008, and it was accompanied by precipitation reaching around 80 mm. The lowest temperature recorded in Jeddah was 9.8 °C on February 10, 1993, and the highest temperature was 52 °C on June 22, 2010. Dust storms happen in summer and sometimes in winter, coming from the Arabian Peninsula's deserts or from North Africa [2].

Khulais branch is one of the University of Jeddah campuses and is located northwest of Khulais city. It consists of 8 main buildings, each building has 3 floors, and the total area of each floor is about 2500 m^2, in addition to services' buildings. The main objective of this study is to develop strategies and find technologies (preferable is passive technology) and measures aimed at improving energy savings, sustainability, and indoor environmental quality (IEQ) at the Khulais Campus where the climate in this area is hot and humid most of the year. The energy-saving can be improved by reducing -indirectly- the cooling load and indoor temperature, while the sustainability can be improved by recycling the sewage water, generating energy from the solar irradiance, planting trees, and improving land-use efficiency. However, IEQ can be improved by understanding interactions of local outdoor climate conditions, the building's architecture, and ventilation within the building [3]. Initially, the main reasons for increasing energy use in the buildings due to increasing the cooling load were identified. The most important causes are the large amount of solar heat gained from the rooftops and sidewalls, infiltration and exfiltration due to the cracks in the walls and building's airtightness, partial damage of the thermal insulation, and thermal mass of building material. All of these sources indirectly cause an increase in cooling load as they cause an increase in the internal temperature and/or relative humidity (RH). On the other hand, the interior temperature in the buildings rises after the official working hours end due to the cessation of ventilation and air conditioning systems. This problem appears clearly in the summer as the sunset begins approximately five hours after the end of the official working hours, which causes a significant increase in the temperature of the confined air inside the buildings. Building cracks and poor thermal insulation efficiency reinforce such a problem. The next day, this problem causes an additional load to the conditioning system startup load, as the indoor temperature takes a longer time to reach the desired (setting) temperature. To improve energy savings, maintain sustainability, and improve indoor environmental quality in hot and humid weather, as is the case in Jeddah and its suburbs, designers and buildings' developers consider many techniques, measures and strategies at both design and planning stages. Designers resort to the use of passive techniques as they help create a balance between the thermal comfort inside the buildings and the sustainability of the surrounding environment in addition to the economic advantages. These measures include microclimate, natural ventilation, daylighting, orientation, thermal insulation, shading, construction materials, and so on [4]. Bughio et al. [5] developed a model based on data related directly and indirectly to the energy use of an architectural campus building in Karachi (the climate hot and humid), to study the energy reduction potential by reducing indoor temperature and cooling energy demand. They investigated the impact of passive energy efficiency measures (PEEMs) on the potential reduction of indoor temperature and cooling load. Sadineni et al. [6] reported that PEEMs have a key role in improving energy use and quality of the indoor comfort conditions in buildings. And, Bughio et al. concluded that in a hot and humid climate, high-thermal-mass building with thermal insulation outside has significant potential in reducing indoor temperature and energy demand, but thermal insulation of walls was the best modification measure to reduce cooling energy demand.

The walls and roofs of buildings work as interface elements between the interior of the building and the surrounded environment. The thermal characteristics of these elements and the quality of the internal components and nature of their external surfaces determine the degree of thermal interactions between them and surrounded environment. Proper thermal design of these elements affects the indoor thermal comfort and IEQ. However, IEQ affect by other parameters such as type and rate of ventilation, nature of internal activities, quality of the surrounded air and weather changes. A variety of studies have been conducted to show different measures of energy savings in university buildings, office buildings, and others, in regions with hot and humid climates. Bughio et al. [5] found that renovating the building envelope design and construction on a university campus, has reduced heat transfer through walls by 51%, windows by 50%, and roof by 30%. Solar gains were also reduced by 57%. Aktacir et al. [7] calculated the cooling load according to the Radiant Time Series, and they found that the design cooling load of the sample building decreased around 33% due to thermal insulation. Yueer et al. [8] reported that natural ventilation is an effective way to improve thermal comfort e and could help reduce cooling energy demand by 10–30% compared to not using natural ventilation in hot and humid summer zones. Another study conducted by Tetsu and Doris [9], in a hot-humid climate has proved that night ventilation has a better effect than daytime ventilation and all-day ventilation. Alhuwayil et al. [4] proved experimentally that the night ventilation by vertical operable vents lowered the indoor temperature in the next morning by about 2°C and reduced the cooling startup peak, by about 20%. They reported that the indoor temperature can be reduced by both shading and natural ventilation. Freewan [10] reported that shading devices could improve the visual environment and reduce the temperature of the offices, compared to the base case. Alhuwayil et al. [11] incorporated external shading devices with a self-shading envelope for a multi-story hotel building in the hot and humid climate of Saudi Arabia to investigate this technique in annual save consumption. They found that this technique could save about 20.5% of annual energy consumption.

Analysis of IEQ and user perception of IEQ in lecture halls of two Architectural Campus Building (ACBs) in Karachi have been discussed [12, 13]. Degree of IEQ and thermal comfort affect the building occupants' in term of wellbeing, productivity, performance, health, comfort, satisfaction, spirit, and in-between relationship. Bughio et al. [11] investigated the building of indoor environmental conditions using CoolVent Simulation Tool to predicted Mean Vote (PMV). The inputs for PMV included building geometry, air temperature, relative humidity, wind velocity, metabolic rate, and clothing. PMV is a seven-point scale of comfort from cold (-3) to hot (3). According to American Society of Heating Refrigerating and Air Conditioning Engineers [13], the general comfort range of PMV is between -0.85 to +0.85.

Understanding local climate conditions and outdoor thermal comfort is essential to find suitable and applicable strategies to achieve indoor comfortable conditions in case of uncomfortable or even severe outdoor parameters. Bioclimatic Chart help to find the appropriate strategy based on the local climate conditions. For example, Bughio et al. [11] used Olgyay's Bioclimatic Chart (OBC) to discuss the climate conditions of Karachi and to find the appropriate strategy to achieve indoor comfortable conditions. OBC specifies thermal comfort with the relation of dry bulb temperatures and relative humidity. OBC is divided into zones and based on the local outdoor dry bulb temperature and relative humidity you will select the suitable strategy form proposed strategies; which include control of evaporation, shading, solar radiation, air movement, air conditioning, and heating. For instance, when the conditions are hot and dry, it is recommended to use evaporative cooling.

From the above literature review and discussion, the association between local climate conditions, outdoor/indoor thermal comfort, and IEQ are obvious. However, climate change effect on outdoor thermal comfort has been predicted by assessing the outdoor thermal comfort in the long-term, based on the Perceived Temperature index (PT) [14]. The results of both American Society of Heating Refrigerating and Air Conditioning Engineers and Matallah et al. [13, 14] indicate a gradual increase in PT index values for upcoming years. Matallah et al. [14] Assessed (PT) index using simulation software ENVI-met and calculation model RayMan and the results showed a significant elevation on (PT) averages between 2020 and 2050 with a difference of +5.9 °C, (PT) index values also showed a high elevation on heat stress during the hot season when the comfortable thermal zone is decreasing from 25% in 2020 to 1% in 2050 and 0% in 2080. Yau et al. [15] examined the outdoor thermal comfort in the Korean Peninsula in 2007 using (PT) index. They concluded that (PT) is a useful thermal index for assessing thermal comfort and thermal stress through the Korean Peninsula.

In the current study, we will discuss the effect of heat gained from solar irradiation through rooftops and walls, cracks in buildings and the associated problem of infiltration and exfiltration, and the start-up load on total cooling loads at the buildings. We will not consider the impact of the insulation efficiency on cooling load in the current study. Evaluating the impact of insulation efficiency on cooling load requires a specialized study to find out the places where the insulation efficiency has weakened, whether because of the age of the thermal insulation or because the thermal insulation is damaged due to water leakage or other reasons. Thermal mass of buildings mainly depends on the type of materials used in construction and changing or modifying these materials is not possible.

The current study proposed three strategies to reduce the cooling load and to improve energy saving and sustainability. The first two strategies aim to reduce the impact of outdoor climate conditions on cooling load and indoor environmental quality, particularly in severe conditions while the third aim to reduce indoor thermal stresses. The strategies include the following measures:

1.1 Planting Eucalyptus Trees around the Buildings

Planting eucalyptus trees around the buildings has three functions: helping control the moisture in the soil around the buildings, working as heat sink, and providing shade to the buildings' walls.

1.2 Shading the External Surfaces of the Buildings (Rooftops and Sidewalls)

The purpose of shading external surface of the buildings is to reduce the direct solar heat gain and create cooler microclimate around the buildings which consequently reduces the cooling load.

1.3 Apply Night Ventilation

The purpose of night ventilation is to reduce the indoor temperature at nighttime and early morning hours. This strategy could possibly reduce thermal stresses during night and morning hours and thus reducing the startup load of the air-conditioning system.

It is expected that the above strategies will indirectly help reduce the cooling load, improve the efficiency of the buildings and subsequently improve the energy savings and the sustainability. In the next sections we will discuss the effect of each strategy’s measure separately.

2. Planting eucalyptus trees around the buildings

To understand the purpose of planting eucalyptus around buildings and its indirect relationship in reducing the cooling load, we will first discuss the appearance of cracks in the walls of some buildings and the root causes behind them, then we will discuss the relationship between the existence of cracks and the increase in cooling load. At the end we will show the relationship between the planting of the trees and initiating of the cracks and increasing of the cooling load

2.1 Cracks in Buildings Walls

According to the literature many buildings will develop cracks at some point during their service life due to the following causes: poor workmanship, temperature variations, structural design lack of (or) poor maintenance and natural forces [16]. The causes of cracks are reported due to ‘permeability of concrete, corrosion of reinforcement, moisture variation, temperature variation, poor construction practices, poor structural design and specifications, elastic deformation, creep, chemical reaction, foundation movement and settlement of soil, growth of vegetation, and additional alternation of structures [17].

Some cracks at walls of some buildings have been noted by the employees of maintenance department, but no action has been taken to stop or repair the cracks. Unfortunately, the cracks grew up and extended in different directions and showed different profiles. Fig. 2 shows that cracks developed at different locations inside the buildings. They have taken different patterns; some of these cracks are horizontal while the others vertical or diagonal.

2.2 Preliminary Investigation

Before launching the investigations with help of the state department and local laboratory, we started a preliminary site investigation to understand the case. Reviewing the cracked buildings’ drawing show that the buildings have been constructed according to the original designs and no significant change was found at the site. After several visits to the site to check the severity of the reported cracks, it was found that the cracks have taken different shapes and patterns. According to site investigations some of these cracks appeared in the last three years at different locations inside the building.

The cracks photographed and numbered in one building. The width of some cracks has been measured and it was around 2-8 cm. No tilting in the wall has been noticed, however signs of corrosion appear at some buildings. Some of the cracks seems dead where the other cracks seem live. Primary investigation showed that there is a sign of water leakage near cracked buildings. Diggings around the cracked buildings showed that sand at different depths from the surface has a content of moisture.

Fig. 2. Shows cracked wall at one of university buildings

2.3 Laboratory Investigations

To find out the root cause of the cracks, a group of samples has been taken from the soil around cracked buildings and all tests were conducted by a local laboratory. According to the laboratory reports and site investigations, the main cause of the cracks is the decline in the south corner because of the leakage of water from the lines of extensions and manholes neighboring the building. Based on the laboratory tests, we recommend the state department to monitor the level in the sewage tank using level sensors and connect them with Building Management System (BMS).

2.4 Do the Cracks Increase the Cooling Load in Buildings that are Cooled by Mechanical System?

In General, cooling / heating load at cracked-walled buildings are increased due to infiltration and exfiltration defects. Both of the two defects cause an effect on IEQ, rate of heat transfer from / to buildings, latent and sensible cooling load.

Air conditioning systems are used to add or remove heat from a building interior. However, air leakage into building interiors has a considerable impact on the energy demand of the building [18]. Infiltration also affects the indoor air quality because it introduces pollutants, allergens, and microbes into the building [19].

Air infiltration is the movement of air into a building, whereas air exfiltration is the movement of air out of a building. Infiltration cause moisture intrusion into building envelop both liquid and vapor. The basic causes of moisture intrusion are groundwater and moist outside air [19].

Cooling load due to Infiltration is divided into two categories: sensible heat (Q sensible) and latent heat (Q latent) and they can be calculated by Eqs. 1, 2 and 3.

$$Q_{sensible} = 1.08 \times CFM \times (T_o - T_i) \quad (1)$$

$$Q_{latent} = 4850 \times CFM \times (H_{Ro} - T_{Ri}) \quad (2)$$

$$Q_{total} = 4.5 \times CFM \times (h_o - h_i) \quad (3)$$

Where *CFM* is infiltration air flow rate, T_o and T_i are outside / inside dry bulb temperature in °F, H_{Ro} and H_{Ri} are outside / inside humidity ratio, lb of water / lb of dry air, h_o and h_i are outside / inside air enthalpy in Btu per lb dry air.

From the above equations it is obvious that the infiltration and exfiltration cause an increase to cooling/heating load. For example, to maintain a 15 °C temperature in a certain dwelling about 3.0 kW of heating is required at 0 ACPH (no heat loss due to warmed air leaving the dwelling, instead heat is lost due to conduction or radiation), 3.8 kW at 1 ACPH and 4.5 kW are required at 2 ACPH [20]. Where ACPH is number of air changes per hour, and higher values correspond to better ventilation.

To control the moisture level at areas surrounded the cracked buildings which was the main cause of the cracks, it is proposed to plant a long stem tress around the buildings at area where moisture level was recorded high. Planting the trees around the buildings has three functions: helping control the moisture in the soil around the buildings, working as heat sink, and providing shade to the buildings' walls. Proper planting procedures and selecting a species adaptable to the site are the best means for dealing with excessive moisture that cannot be corrected without drainage techniques [21]. The effect of shading the buildings on cooling load reduction will be discussed in the following sections. Eucalyptus trees, are single-stemmed and the tallest known flowering plant on Earth. Tree sizes follow the convention of: small: up to 10 m in height, medium-sized: 10–30 m, Tall: 30–60 m, and very tall: over 60 m [22].

In many countries, they are planting eucalyptus around cesspits to solve sewage problems in the fact that this tree has a high water-absorbing capacity, as it forms a large vegetative group in a short time and is a repellent of harmful insects [22]. I have planted a eucalyptus tree in Jeddah, in an area that suffers from high groundwater levels and infiltration of sewage water. Fig. 3 shows the eucalyptus tree planted in Jeddah. The tree has proven a high ability to live in the environment of the city of Jeddah (humid and hot). The tree was growing fast and every time some branches were cut, it was noticed that it was growing again quickly.

The tree has reached more than 4 m in length in less than one year, and the tree has resisted pollution and harsh environmental conditions with unparalleled success, which made me suggest planting the tree to solve the problem of wastewater leakage in the Khulais branch.

Fig. 3. Eucalyptus tree planted in Jeddah in 2019

The tree has proven a high ability to live in the environment of the city of Jeddah (humid and hot). The tree was growing fast and every time some branches were cut, it was noticed that it was growing again quickly. The tree has reached more than 4 m in length in less than one year, and the tree has resisted pollution and harsh environmental conditions with unparalleled success, which made me suggest planting the tree to solve the problem of wastewater leakage in the Khulais branch.

Unfortunately, it is expected that the leakage problem will be repeated in the campus because the sewer lines in the college are not connected to the public sewage network. Therefore, we will dedicate a study in the future to benefit from wastewater for irrigation of eucalyptus trees.

Preliminary measurements showed that most of the wastewater in the college is gray water, so we will suggest separating the gray water from the wastewater for later use in irrigating trees. This will improve the environmental situation in the campus and in the surrounding areas. Site observations showed that eucalyptus is a good solution to get rid of water in the soil, and its great height and permanent green color make it ideal also for shading the buildings.

We conclude from the above reviews and investigations, that in addition to the laboratory and state department recommendations, planting eucalyptus trees around the cracked buildings helps to reduce and may control the moisture level in the soil by absorbing the sewage water and rain water in case of leakage. It is expected that if the above recommendations applied properly, the problem of the cracks will stop growing and the problem of the infiltration and exfiltration will become insignificant after repairing the cracks.

3. Night Ventilation

The second proposed strategy to reduce start up load of ac system is night ventilation. Night ventilation is the process of ventilating the buildings during the nighttime, naturally or mechanically. HVAC power load is account for 70 to 80% of electric power load at Khulais campus [9]. Startup load of HVAC system forms around 10-20% of the total cooling load due to high indoor temperature at nighttime and morning [23].

The reasons for the increase in the indoor temperature of buildings located in relatively hot areas are due to several indoor and outdoor factors, including, for example, the thermal insulation efficiency, outdoor temperature, solar irradiation, thermal mass, external and internal convective heat transfer coefficient, type of external of walls and rooftops surfaces, building orientation, nature of internal thermal loads, number of hours of operation of the cooling system, method of ventilation of buildings and others. Night ventilation is one of the solutions in reducing indoor temperatures in buildings, especially for buildings that are not occupied during the night. However, the efficiency of night ventilation is greatly affected by the thermal mass of the building and extent of diurnal temperature swings, if the diurnal variation of ambient temperatures exceeds 10 K, the indoor temperature swing of 2.5 K [24].

Natural ventilation is a passive cooling method and suitable solution for cooling small buildings during the nighttime so that the internal temperatures can be significantly reduced [24]. But passive cooling is not suitable for relatively large buildings and in places that are sometimes exposed to dust storms, as the dust affects the air quality and comfort level inside the building. In this case, mechanical ventilation would be a suitable solution. Air ventilation process enhances convective heat losses from mass elements and dissipates the released heat to the lower temperature outdoor heat sink [25]. However, mechanical ventilation will add additional enhancement to convective heat losses due to increase of air flow. Ceiling fans, for example, raises the convective heat transfer coefficient, which facilitates the process of rejecting heat from massive walls at night [26].

Mechanical ventilation is a suitable alternative solution for relatively large buildings for the following reasons.

1. Air can be distributed to all parts of the building evenly.
2. Air filters remove dust and other pollutants from the intake air, so it can be used in dusty weathers.
3. It has the ability to control the air flow rate (cooling rate).
4. It improves the internal convective heat transfer coefficient.

However, the mechanical ventilation system consumes electrical energy, so it is necessary to design a night ventilation system so that the resulting reduction in cooling loads, and then saving in electrical energy, is significantly greater than the energy consumed in operating the system.

At Khulais Campus, the buildings operators run the cooling system around 1-2 hours before the beginning of official working hours to reach to setting temperature by 8 AM particularly after weekend and long vacations. The official working hours and days at Khulais campus is 8:00 AM – 14:30 PM, Sunday to Thursday. Shuangping [27] built a model to study the effect of external thermal mass and nighttime ventilation on cooling load reduction and indoor air fluctuation at night. He showed that night ventilation flow at suitable time with an appropriate thermal mass reduce the cooling load at daytime and has an effect on indoor temperature fluctuation at nighttime. Fig. 4, shows the effect of night ventilation on cooling load from 8 am to 8 pm for different wall materials.

According to Shuangping, cooling load decreases at early time in morning because heat is released from thermal mass at nighttime and carried off by night ventilation. This study confirms the importance of night ventilation on reduction ac startup load. The night ventilation depends strongly on ventilation flow and thermal mass. Thermal mass is defined as the thermal materials that can absorb heat, store it and release it later.

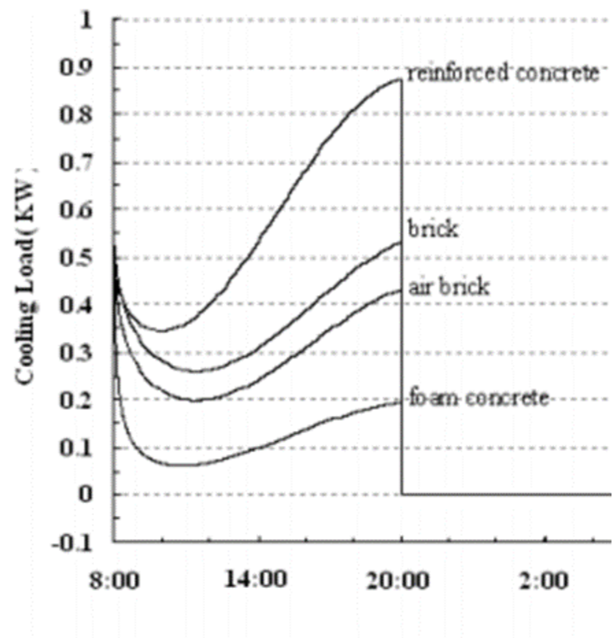

Fig. 4. Effect of night ventilation on cooling load from 8 AM to 8 BM for different wall materials (Source: [27]).

Larger savings occur by nighttime ventilation in heavyweight compared to lightweight by 27 to 36%, depending on the wall construction of the building [24]. Thicker walls, up to 25 cm, may provide longer periods of thermal storage than thinner walls [25].

The buildings in Khulais Campus are constructed of heavy concrete structures and control layers: water control layer, air control layer, vapor control layer and thermal control layer. The walls are supported by steel studs. The walls thickness is 40 cm. The walls are constructed as typical walls to prevent water, air, vapor and heat to transfer through the walls. The main problem in the walls is the discontinuity of the installation layers due to the water leakage which make the wall imperfect in term of heat resistance. On other hand the steel studs are made of high conductivity. Highly conductive material is configured to give the maximum absorption on one end and maximum emissive on another end.

In this case the amount of heat stored in the walls will be greater, which will negatively affect the indoor temperature during the evening and at night. To study the effect of night ventilation and thermal mass on cooling load, Yang and Li [28] introduce a parameter of cooling load ratio, $\xi = Q_{cl}/Q_{cl0}$. ξ is defined by them to represent the ratio of cooling load in building with thermal mass to the load in building without thermal mass at daytime. The cooling load ratio is a timedependent parameter. The smaller the ratio, the more energy saved. Negative value of cooling ratio indicates that the indoor air temperature was below the setting temperature of 24 °C due to night ventilation.

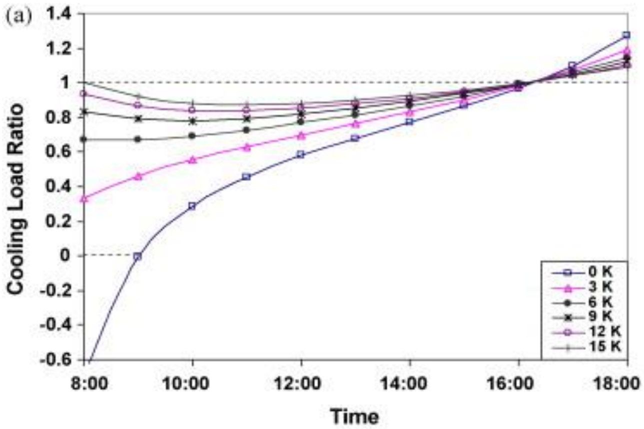

Fig. 5. Profiles of cooling load ratio as a function of the temperature differences between indoor and outdoor air (Sources: [28]).

As shown in Fig. 5, as the indoor temperature approaches the outdoor temperature, the cooling load ratio takes lower values and thus achieves more energy savings. This study also confirms the advantage of night ventilation on cooling load. According to Yang and Li [28], the cooling load ratio decrease as the temperature fluctuation during the night increases and time constant increases.

From the above studies, it is obvious that nighttime ventilation helps in maximizing the building thermal transmittance during the nighttime if diurnal variation of ambient temperatures is enough to cool down the indoor temperature. Energy savings due to nighttime ventilation vary between 18 to 20%, compared to a base case [29].

The difference between the air temperature at nighttime and daytime at Jeddah district varies from 5 – 12 °C during the year. Night mechanical ventilation with different flow rates at suitable times will help in reducing the startup cooling load and improve air quality; the trapped and relatively hot indoor air will be replaced by with relatively low temperature fresh air. The difference between the indoor and outdoor temperature at nighttime and temperature fluctuations vary from one night to another. To reach to the optimum indoor temperature (when the indoor air temperature almost coincides with the outdoor air temperature), it is suggested using mechanical ventilation with variable fan speed connected with appropriate control system. In addition to temperature difference and ventilation rate, weather state such as relative humidity and dust should be considered. At high values of RH, the nighttime temperature approaches approximately daytime temperature.

The proposed system is shown in Fig. 6, and consists of mechanical ventilation system with variable fan seed, control system and BMS. The system will work to control duration of running the ventilation system, ventilation flow rate and time of ventilation to achieve the possible minimum indoor temperature with a minimum power consumption.

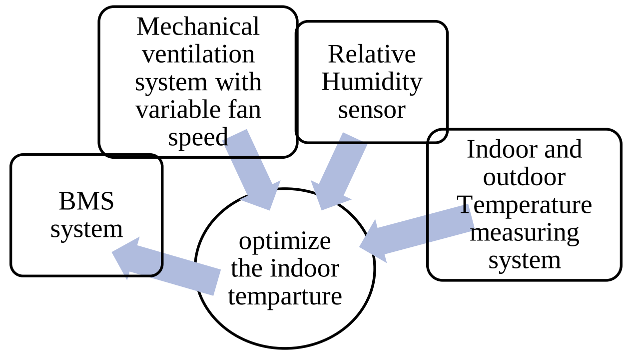

Fig. 6. Proposed night ventilation system

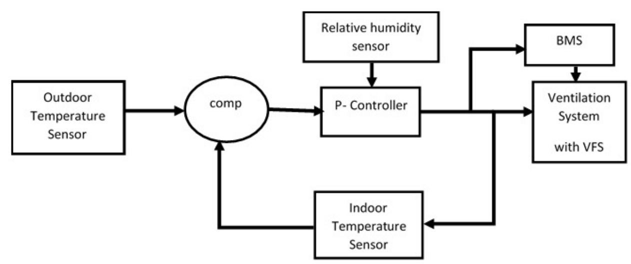

Fig. 7. Block diagram shows the working principle of the proposed night ventilation system

Fig. 7 shows a block diagram for the proposed night ventilation system. The function(s) of each components is/are described below.

1. *Outdoor temperature sensor*: It is to measure the outdoor air temperature
2. *Indoor temperature sensor*: It is to measure the Indoor air temperature
3. *Proportional (P) controller*: It is to control the fan speed and ventilation flow. Controller output signal is proportional with the size of the error (the difference between the indoor temperature and outdoor temperature). Low difference may require high ventilation rate to cool down the indoor temperature. High ventilation flow (higher convection heat transfer coefficient) causes a reduction in the indoor air temperature.
4. *RH sensor*: It is to measure the relative humidity. When RH exceeds a setting value, the controller

output becomes zero and stops the ventilation system even the temperature difference still exists.

5. *Comparator (Comp)*: It is to compare between the indoor temperature and outdoor temperature.
6. *Building Management system (BMS)*: BMS helps to manage the operation hours of night ventilation during the days, weeks, months and year.
7. *Variable Fan Speed (VFS)*: The fan speed and therefore the ventilation flow are controlled based the size of the controller output signal.

The suggested system will run automatically based on the indoor and outdoor air conditions. The fan speed and night ventilation flow will change continuously according to the indoor/outdoor temperature difference and relative humidity mainly. The system will help in optimizing the indoor air temperature (the indoor temperature approximately coincident with outdoor temperature) at nighttime.

The effectiveness of the suggested system in reducing the cooling load should be tested under laboratory or/and real field conditions. The most important parameters that should be considered are indoor and outdoor air temperatures, relative humidity, cooling load and cooling load ratio. The relationship between the cooling load ratio versus temperature difference and ventilation flow should be reviewed to find out the minimum temperature difference that causes a sensible reduction in cooling load.

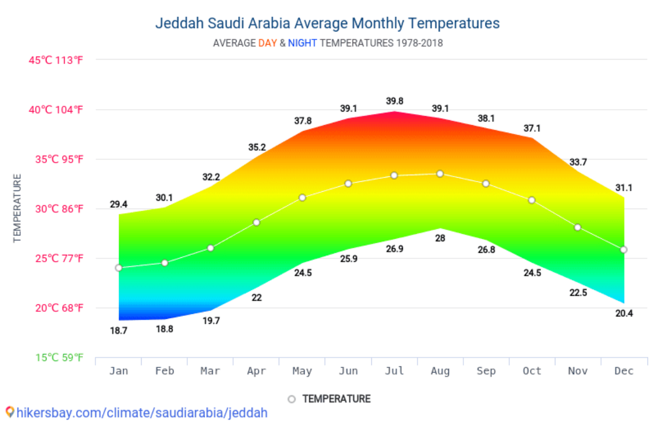

Fig. 8. Jeddah Saudi Arabia average monthly temperature, 1978-2018 (Source: [30])

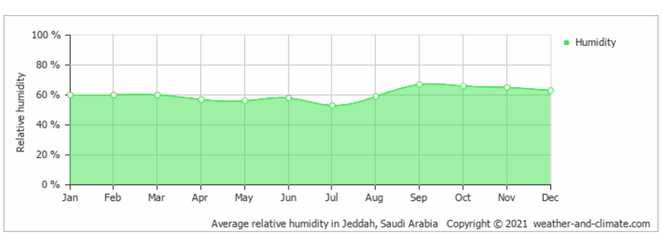

Fig. 9. Jeddah Saudi Arabia Average monthly relative humidity in one year (Source: [31])

Nighttime ventilation will be a suitable strategy for reducing cooling load as the campus buildings are unoccupied during the night and weekends. Connecting the proposed system with the existing BMS will improve the efficiency of the system as it will help in managing the operating hours of the system after the end of official working hours and during weekends and official holidays. Fig. 8 shows the average monthly temperature in Jeddah city from 1978 to 2018, and Fig. 9 shows the average monthly relative humidity in one year.

4. Shading the building

4.1 Shading the Building Rooftops by Rooftop Building Integrated Photo Voltaic (BIPV)

The net rate of radiation heat transfer to a surface exposed to solar and atmospheric radiation is determined from an energy balance Eqs. 4-6. Fig. 10 shows a simple model shows radiation interactions of a rooftop surface exposed to solar and atmospheric radiation, [32].

$$\dot{q}_{net\ rad\ (1)} = \sum Solar\ absorbed + \sum Sky\ absorbed - \sum Emitted \quad (4)$$

$$\dot{q}_{net\ rad\ (1)} = \alpha_s\, G_{DNI} + \alpha G_{DIF} - \varepsilon\sigma T_s^4 \quad \mathrm{W/\,m^2} \quad (5)$$

$$\dot{q}_{net\ rad\ (1)} = \alpha_s\, G_{DNI} + \varepsilon\sigma T_{Sky}^4 - \varepsilon\sigma T_s^4 \quad \mathrm{W/\,m^2} \quad (6)$$

Where, G_{DNI}, the radiation emission from the sun to the rooftop directly and DNI Direct Normal Irradiance, G_{DIF} the radiation emission from the atmosphere and surrounding surfaces to the roof and DIF, Diffuse Horizontal Irradiance, T_{sky}. Effective sky temperature, and it depends on the atmospheric conditions, α_s, is surface solar absorptivity (the fraction of the radiation energy incident on a surface that is absorbed by the surface). The net rate of radiation heat transfer for a shaded rooftop is determined from an energy balance Eqs. 4-6.

Fig. 11 is a simple model shows radiation interactions of a shaded rooftop. In this case the direct effect of radiation emission from the sun, G_{DNI} becomes insignificant, and its value depends on rooftop surface solar absorptivity, α_{ss}. Wang et al. [33] found that peak heat-gain of the rooftop covered by ventilated PV arrays, has the same value as the reflective roof with an absorptivity of about 0.4. When the shading surface is fixed at a sufficient height from the rooftop to allow people to pass freely, the roof of the building will be exposed mainly to radiation coming from the surrounding surfaces and sky G_{DIF}.

$$\dot{q}_{net\ rad\ (2)} = \sum Solar\ absorbed - \sum Sky\ absorbed - \sum Emitted \quad (7)$$

$$\dot{q}_{net\ rad\ (2)} = \alpha_{ss}\ G_{DIN} + \alpha G_{Sky} \quad W/m^2 \qquad (8)$$

$$\dot{q}_{net\ rad\ (2)} = \alpha_{ss}\ G_{DIF} + \varepsilon\ \sigma T_{sky}^4 - \varepsilon\sigma T_s^4\ \ W/\ m^2 \quad (9)$$

Where α_{ss} is solar absorptivity of the shaded surface. ε is the emissivity of the sky, and T_s is rooftop surface temperature.

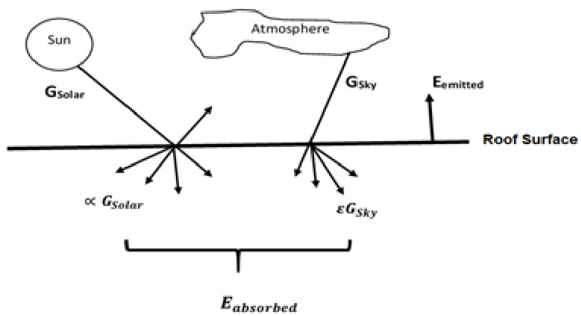

Fig. 10. Radiation interactions of a surface exposed to solar and atmospheric conditions

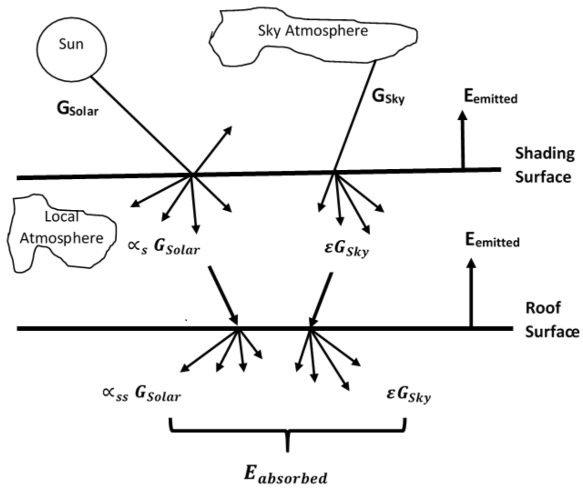

Fig. 11. Radiation interactions of surface exposed to atmospheric radiation and shaded by a shading means

Proper choosing rooftop shading materials that have a low absorptivity will result in neglecting the direct effect of sunlight (G_{DNI}), which will have the effect of reducing the rate of heat transfer into the building. Absorptivity of material depends strongly on the temperature of the source at which the incident radiation is originating. For example, the absorptivity of the concrete roof of a house is about 0.6 for solar radiation (source temperature: 5780 K) and 0.9 for radiation originating from the surrounding trees and buildings source temperature: 300 K [32]. The heat transfer to the interior of the building is mainly occurs through the rooftops, windows, doors, and sidewalls.

To reduce the heat transfer to the interior of the buildings, it is proposed to shade the rooftops by rooftop BIPV and side walls by planting long stem trees around the buildings as possible.

BIPV can help reduce thermal summer load of roofs due to direct solar irradiance [34]. BIPV has significant influence on the heat transfer through the building envelope and its consequent effect on the buildings cooling and heating loads [33]. The reduction in cooling load due shading the roof by air-gap PV is around 65% [35]. Wang et al. [33] used one dimensional transient model to assess the impacts of BIPV on the buildings daily heat gain, peak cooling loads, daily PV power, time lag and decrement factor. Four different roofs were used; ventilated airgap BIPV (A), non-ventilated airgap BIPV (B), close-roof mounted BIPV (C), and conventional roof with no PV and no air gap (D). The simulation results are listed in Table (1). The time lag and decrement factor are defined by Duffin and Knowless [36] as, ‘the time it takes for a heat wave to propagate from the outer surface to the inner surface’, and ‘the decreasing ratio of its amplitude during this process is the decrement factor’. According to Asan [37], buildings ‘with high time-lags and small decrement-factors give comfortable inside temperatures even if the outside is very hot’.

Ventilated airgap BIPV was the most efficient solution; the reduction in cooling load was around 52% and in heat gain was around 46%. This system also was the most efficient solution in term of the produced output power and comfortability.

Table 1

Simulation Results of thermal analysis for rooftop shaded by PV modules

	A	B	C	D
Daily Solar Energy MJ/m^2	27.359	27.359	27.359	27.359
Daily heat gain MJ/m^2	0.569	1.047	1.117	1.072
Peak cooling load W/m^2	8.019	15.256	16.928	16.625
Reduction in peak cooling load/ heat gain	52%/ 46%	8%/ 2%	-1.8%/ <-1%	–
Daily PV power MJ/m^2	1.915	1.809	1.812	–
Time lag h	7	7	5	6
Decrement Factor	0.0154	0.025	0.031	0.0295

Another study was conducted by Dominguez et al. [34] to assess the impact of BIPV on rooftop heat transfer. They shaded the rooftop by air-gap tilted PV and flat PV without air-gap. They found that ceiling temperatures under the tilted PV arrays were up to 2.5 K cooler than under the exposed roof, the reduction in annual cooling load was 38%, and the reduction in heat flux was 63%, and thus enhancing the annual net energy balance of PV by 4% during the year while it was 10% in July (the warm and sunny month). Also, significant reduction in thermal stresses of the roof structure under the PV arrays as the daily variability in rooftop surface temperature was less. Fig. 12 shows the interior ceiling temperature under exposed, flat PV and tilted PV. The most relevant parameter to a building cooling load is the heat flux. Fig. 13, shows conductive heat flux from bottom roof layer to ceiling surface for the exposed roof and the tilted PV array.

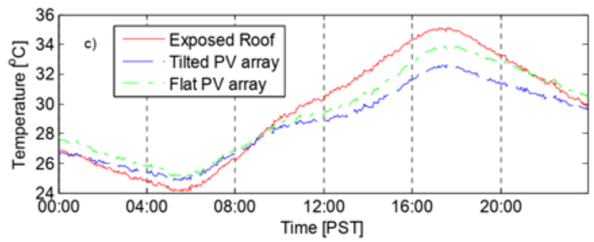

Fig. 12. Conductive heat flux from bottom roof layer to ceiling surface for the exposed roof and the tilted PV array (Source: [34])

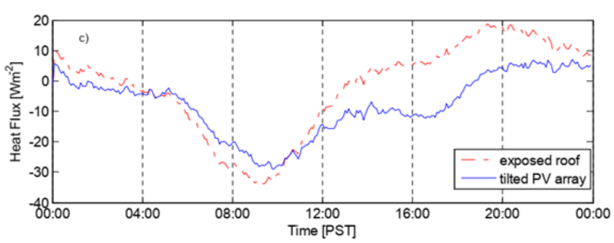

Fig. 13. Interior ceiling temperature under exposed, flat PV and tilted (Source: [34])

Based on the literature the efficient rooftop BIPV, is the airgap, BIPV. To shield the buildings' rooftop at Khulais campus, following two rooftops BIPV are proposed and the main function of them is to reduce the heat flux from the rooftop to the interior of the buildings.

1. Installing an airgap, tilted PV on the building's roofs directly at standard height (around 1 meter from the rooftop surface)

2. Installing air-gap, tilted PV. IBPV at 5 m height from the rooftop surface

BIPV performs the same function of classical roofs but also provides electrical power. The first method does not seem to be the best method for the buildings which are subjected to the current study (flat roof) for the following two reasons.

1. The rooftops are surrounded by 1-meter height sidewalls.
2. The buildings are conditioned using roof-top package units.

The shade created by the sidewalls affects the conversion efficiency of the PV and installing the PV arrays directly on the rooftops is disturbing source for the maintenance and operation works. Also, it may affect the flow of the cooling air of the roof-top units.

The second scenario seems as a practical and beneficial solution for the following reasons:

1. *High shading efficiency*: PV arrays could prevent most of the direct solar irradiance (G_{DIN}) from reaching the rooftop, particularly if the PV arrays are extended beyond the rooftop edges, so extra shading efficiency can be achieved.

2. *High land-use (rooftop-use) efficiency*: The roof can be used for several purposes. In some commercial buildings, the rooftops of the building have been converted into gardens, some for into gyms, and other uses. Solar panels prevent rain from reaching the roof and provide shade, and the rooftop of the building is made from strong concrete, which makes it bear significant loads and is suitable for many uses. In the case of the Khulais campus buildings, we suggest using the roofs of the buildings to be a gym for students and faculty members, and some of them are suitable as centers for agricultural research for house plants and other university activities that require natural ventilation and protection from direct sunlight.

3. *Improving PV conversion efficiency*: The distance between the surface of the rooftop and the back surface of the PV is sufficient to prevent the heat generated from the solar panels from reaching the roof surface, and it facilitates the natural cooling of the solar panels and the rooftops. Combination of PV and ventilated roof improve PV conversion efficiency and reduce cooling load [34, 38].

4. *Improving the air-conditioning efficiency*: Improving the air-conditioning efficiency by creating a cooler microclimate zone beneath the PV arrays and by preventing the effect of direct normal irradiance (G_{DNI}) on the outdoor unit of the ac. Air-cooled air conditioning systems are sensitive to ambient temperature. In general, it is recommended by the ac manufacturers to install the outdoor units in the shaded area if it is possible. US Department of Energy confidently states that 'shading the outside unit can increase its efficiency by up to 10' and 'Shading your air conditioner can reduce energy costs by as much as 50%' [39]. According to Yin et al. [40], shading the outdoor of the ac unit helps reduce local air temperature for the condenser. They found that a 20° F increase in outdoor ambient temperature resulted in 25% rise a compressor power

consumption, a more than 13% decrease in total capacity and finally a 28% decline in EER and sensible EER. Faramarzi [41] conducted experimental research to study the effect of the ambient temperature on the performance of rooftop air conditioning unit, and reported that, EER dropped from 10.2 at 29.44 °C to 6.3 at 54.44 °C, gross cooling capacity (BTU/h) decreased from 63000 at 29.44 °C to 49000 at 54.44 °C, power use increased from 5.9 kW at 29.44 °C to 7.5 kW at 54.44 °C. He found that directly shading the air conditioner can increase the efficiency by up to 10% during the warmest period.

5. *Maintenance and operational efficiencies*: The PV arrays will not interrupt the installing, operating, and maintenance tasks of the roof-top air conditioning units. Also, the shade created by the solar arrays provides a safe and comfortable working environment for the maintenance and operational teams while they are working during daylight hours.

6. *Improving night-ventilation efficiency*: The PV arrays provide air passages that could improve the local wind speed and thus increase the value of the heat transfer coefficient (h). Also, BIPV helps to create a cooler microclimate zone beneath the PV arrays. Improving h value and creating a cooler microclimate helps to improve night-ventilation efficiency particularly when the outside air temperature drops down.

However, there are a couple of following drawbacks to installing solar panels at specific heights from the roof of the building.

1. The cost of the metal structure that will support the solar panels will be relatively high. The metal structure should be strong enough to balance the load creating by the wind and the load due to the panels' weight.

2. The cost of maintaining solar panels could be high due to the difficulty of accessing the faulty parts, and due to the need of an independent cleaning system such as a spraying system or robotics to clean the PV modules to maintain the PV conversion efficiency at optimal rate.

To clarify the effect of shading on blocking the effect of direct solar irradiance, the intensity of solar radiation was measured during daylight hours, a special device in a shaded car park and in an open area inside the campus. Solar power meter TES 1333R was used to measure the solar irradiance. Fig. 14 shows solar irradiance under shade by special cloth and in open area (without shade). Shading approximately blocks 90% of direct solar irradiance G_{DIN}. However, all measurements in the parking were taken in the shade. Returning to Eqs. 7-9, the net rate of radiation heat transfer to a shaded rooftop will drop significantly as G_{DIN} decreases by 90%.

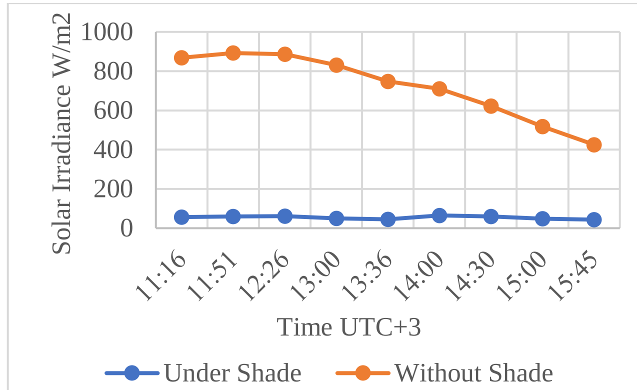

Fig. 14. Solar irradiance under a shade (car parking) and open area

4.2 Shading the sidewalls by long stem trees (creates a cooler microclimate)

In the previous section, the thermal benefits of shading the roof of buildings were discussed. The sidewalls of buildings and windows are among the main parts that cause heat transfer to the interior of the building and thus increase the cooling load. Shading the walls is expected to achieve the same benefits as shading the roofs, in addition to the expected benefits in helping to solve the problem of cracks in buildings, which were discussed in section 2. Solar irradiance according to Akbari et al. [35], tree shade reduces cooling energy used inside a building in three ways: helps prevent direct solar radiation from entering the structure, keeps the walls and windows from getting hot and thereby reducing the amount of heat reaching the interior, keeps the soil around a building cool, which then can act as a heat sink for the building. They have shaded three houses by planting a number of trees around the houses in different directions to calculate the effect of shading on cooling efficiency. They found that the energy savings used in cooling were 40%, 30% and 10%, respectively. The main reason for this discrepancy is due to the difference in local microclimate from one location to another. Another study conducted by Akbari et al. [42] at two houses and they found that shade trees at the two monitored houses yielded seasonal cooling energy savings of 30%, and peak demand savings for the same houses about 27% savings in one house and 42% in the other. According to Akbari et al. [38], deciduous trees absorb around 70 – 85% and transmit around 15 – 30% of solar irradiance in summer, while in winter absorb

35 – 45% and transmit 55 – 65% of solar irradiance trees.

5. Conclusion

Different measures aimed at improving energy savings, sustainability, and indoor environmental quality (IEQ) at the Khulais Campus were reviewed and analyzed. The energy-saving can be improved by shading the rooftops and walls, night ventilation, and reducing the effect of exfiltration and infiltration. All of these measures reduce the indoor temperature and thus the cooling load. The sustainability can be improved by recycling the sewage water, generating energy from the solar irradiance, planting trees, and improving land-use efficiency. However, IEQ can be improved by understanding interactions of local outdoor climate conditions, the building's architecture, and ventilation within the building.

Airgap BIPV will improve the energy saving and the overall efficiency of the buildings by reducing significantly the direct solar irradiances. If the airgap is around normal height of the ceiling at the buildings (around 4 m), it will add many advantages to the buildings, such as improvement in the PV conversion efficiency, land-use efficiency, shading efficiency, EER of the rooftop ac units and night ventilation efficiency. But additional cost will be added to the normal PV arrays due to cost of supporting steel structure and cost of PV maintenance.

Planting eucalyptus trees around the buildings has many advantages; it will help in improving the energy saving by reducing the effect of direct solar irradiance on cooling load, work as heat sink, and create cooler microclimate. As eucalyptus tree has a high water-absorbing capacity, it will help in preventing the root cause of the cracks at the buildings.

Previous studies showed an increase in 'PT index values for upcoming years, and the outdoor comfortable thermal zone is decreasing from 25% in 2020 to 1% in 2050 and 0% in 2080'. These results confirm the importance of selecting eucalyptus trees and BIPV modules as shading elements; the lifecycle of eucalyptus tree exceeds two hundred years and PV modules around twenty-five years.

To reach to the optimal efficiency of night ventilation system during the year's days, it is recommended to connect the system with a separate control system and with the local BMS. It is further recommended to run a thorough investigation to find out the causes of damaging the thermal insulation and to evaluate its insulation efficiency using thermal camera.

The strategies discussed during the current study were built on the basis of previous studies, basic measurements and understanding the outdoor thermal stresses. Subsequently, It is recommended to conduct special studies whether by experimental or modeling methods in order to quantify the impact of each strategy on energy saving and the sustainability at the campus facilities.

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