The Effect of Night Ventilation on Covered Sports Halls Energy Conservation

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Abstract:

Recently there was an increasing demand in the field of sports facilities especially in the Middle East region. As a result, more attention is drawn toward reducing energy consumption in such facilities located in hot arid areas. Due to the large number of occupants inside covered sports halls, they work as a heat sink during the occupied periods. This article aims to study the effect of using night ventilation on reducing covered sports halls energy consumption. The methodology includes analyzing literature reviews related to sports facilities to study the effect of envelope modification on enhancing energy performance. DesignBuilder and EnergyPlus softwares are used to build and study a covered sports hall model and investigate the effect of using night ventilation on hall number one of the Cairo sports halls complex. Results show that night ventilation in hall number one positively reduces energy consumption by 18 %.

Keywords: Energy Conservation, Night ventilation, Covered sports halls, DesignBuilder, EnergyPlus.

1- Introduction:

The building envelope serves as a thermal partition between indoor spaces and external surroundings. It controls the indoor microclimate while also acting as an exterior barrier to preserve the indoor environment. Some of the building envelope's roles are containing structural components, creating aesthetic form, and reducing the project's ecological footprint. The envelope design directly affects indoor environmental conditions, it influences the penetration of natural daylight, helping to maintain comfortable indoor temperatures and the amount of energy required to do so. The quantity of energy needed to sustain the building's thermal environment may be primarily determined by the envelope's responsiveness to climatic circumstances. [1].

Since the building envelope acts as a boundary between the indoor spaces and the outside environment, it is subjected to natural variables such as temperature changes, air movement, humidity, rain, and solar radiation. Furthermore, using climatic thermal principles while constructing the building envelope can have a positive impact on thermal performance, which is closely related to energy use. Limiting the quantity of heat absorbed through the building envelope will help to minimize and regulate the amount of cooling energy consumption in hot arid areas [2]. Moreover, covered sports halls suffer from the heat trapped inside due to the internal heat gain that is generated by occupants. In order to enhance athletes' performance and audience satisfaction in Covered Sports Halls, a comfortable indoor environment is needed. Additionally, improving indoor thermal comfort and energy-saving standards must be considered when operating the covered sports halls. One of the methods used to remove the heat from the indoor enclosers and reduce energy consumption is using night ventilation. The effectiveness of night ventilation mainly depends on local climate conditions, building envelope design parameters such as window to wall ratio, and using ventilation systems [3].

2-Main Goal

The main goal of this paper is to prove that scheduled “night ventilation” can reduce energy consumption in covered sports halls.

3-Methodology

First, a quick literature review is conducted to study the methods of reducing energy consumption and analyze the effect of natural and night ventilation on sports halls. Second, an analytical approach is used to study hall number one in Cairo’s sports halls complex through two main stages, the first stage focused on parsing the base case situation while the second stage focused on studying the effect of night ventilation on the same hall using a computational simulation.

4- Literature Review

Anna Dudzińska investigated the methods of reducing solar gains during high outdoor temperatures for a low energy sports hall building located at Slomniki. The model was built using DesignBuilder software. Dudzińska reported that using external shading devices and natural ventilation help to reduce the cumulative excess of solar and internal energy gain by 30% [3]. Alessia Accili examined a zero-energy sports hall located in Barcelona, Spain. Field measurements were used to acquire information about occupation patterns and environmental indoor conditions. The model was built using SketchUp software. Accili reported that using PV cells, solar thermal collectors, installing shading devices, and using natural and night ventilation can positively drive the sports hall towards a nearly zero energy building [4].

4.1- Building envelope elements

Building envelopes may often be divided into two primary categories: opaque and transparent elements. The envelope's transparent components may include windows, skylights, and doors while the opaque components may include walls, roofs, floors, and insulation materials. According to research by Rahul V. Ralegaonkar and Rajiv Gupta, building envelope components that are directly exposed to sunlight and the surrounding environment are responsible for 73% of building heat gain and loss [5].

4.2- Buildings Energy conservation

Researchers have investigated how to implement energy-saving techniques and arrange them according to various criteria. In 1991, Lechner set up a three-tiered design strategy for developing sustainable buildings. The first tier focuses on the initial and fundamental phases of building design, such as orientation, insulation, and the use of shading devices. The building can easily accomplish around 60% of the heating, cooling, and lighting energy. The second tier is concerned with incorporating passive heating and cooling technologies, such as night cooling, earth coupling, and cooling towers. Making the right choice at this stage can cut energy use by another 20%. The third tire is mainly concerned with designing electrical and mechanical systems which are responsible for the last 20% [6].

4.3- Night Ventilation

One of the most powerful factors influencing the interior atmosphere is night ventilation. It has a significant impact on lowering the cooling demands within enclosed sporting arenas. Based on the temperature difference between indoor spaces and outdoor environment, night ventilation increases the rate of heat exchange between these two zones [7]. Air change per hour (ac/h) is the scale used to indicate the effectiveness of natural ventilation. It specifies the frequency with which a volume of air inside the space will be added, subtracted, or exchanged within an atmosphere air from the outside environment. The recommended outside air ventilation rate (ac/h) for sports facilities ranges from 4 to 8 (ac/h), according to ASHRAE specifications [8].

5- Case Study

5.1- Hall number one general data

One of the primary facilities of the Cairo stadium authority is the covered sports halls complex designed by Magd Massara. It is regarded as the second largest sports halls complex in Africa and the first in Egypt. The building was constructed in September 1991. The halls were constructed to host the fifth African Games. The covered sports halls complex has a total ground floor area of 60,000 square meters and was constructed on an 80,000 square meter plot of land. Up to 23,000 spectators can be handled at the complex. It includes four halls, a primary distribution corridor linking the main hall (hall number 1), a medium hall (hall number 2), two minor halls (halls 3 and 4), and eight service towers [9]. It is made up of four covered athletic arenas that correspond to the Olympic standards. Four chillers are responsible for supplying cooled air, each chiller has a cooling capacity of 900 tons with a combined refrigerant capacity of 3600 tons [9].

Hall number one is selected as the case study because of its large scale in comparison to the other halls. It has an internal diameter of 120 meters and can accommodate up to 20,000 spectators, with an internal height of 38.8 meters between the playground surface and the bottom surface of the dome. Moreover, the playground elevation drops 7 meters below ground level. The hall's envelope is constructed from glass, aluminum, and concrete. Concrete being the main structure material used to build the exterior walls, with a 0.40-meter thickness. The hall has an aluminum dome cover that is supported by a (k) steel truss system as in table [2] and has a circular mechanical vent located at the dome's center.

The hall has a 14,619.84 m^2 ($2 * \pi * 60 * 38.8$) envelope surface area that is exposed to the outside environment. Moreover, an open-air court surrounds the hall's shell, separating the outer surface of the envelope apart from the surrounding elements. This paper presents a study of the effect of a scheduled night ventilation on the hall's envelope to assist in reducing energy consumption.

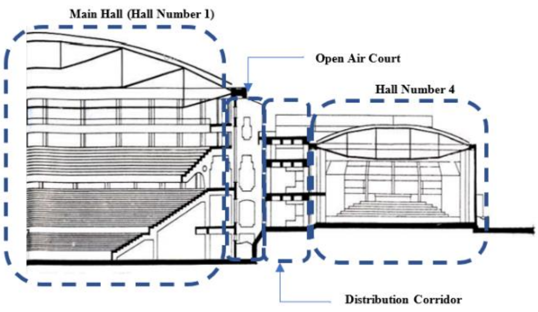

Figure (1): Cross section indicating the relationship between Hall number one, Surrounding Court, Internal Corridor, and Hall number 4.

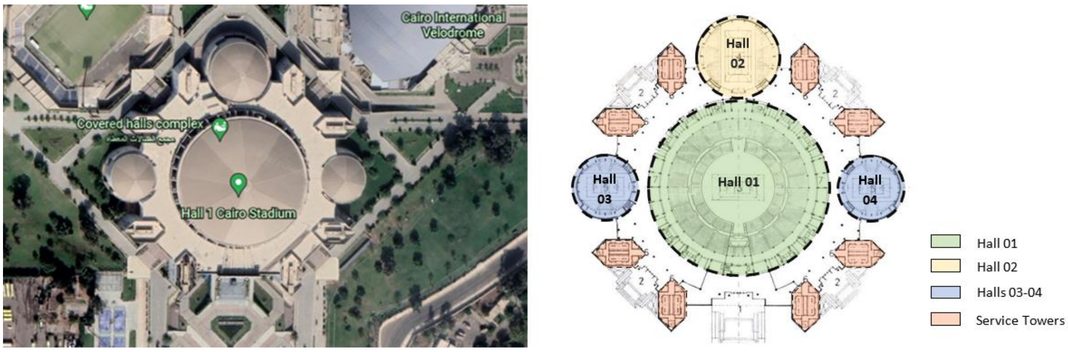

Figure (2): Cairo sports halls complex layout and plan

5.2- Simulation workflow

To study the effect of using night ventilation two main steps were followed. The first step mainly will simulate the existing base case to analyze the indoor temperatures and the amount of energy used to cool the indoor arena. Second, scheduled night ventilation will be performed to evacuate the internal heat trapped inside the sports arena during night-time when the outside temperature drops down. Finally, a comparative analysis will be executed between stages one and two to analyze the amount of energy reduction between the two stages. An EnergyPlus weather file was imported to provide the climatic data for the selected building site. Additionally, it is crucial to set up the occupancy schedule during the covered sports hall operating time. The sports arena will not be fully packed during the whole day's operating period. Therefore, an occupancy schedule is suggested during the hours from 10:00 AM to 12:00 PM, 25% of the entire occupancy would be inside, 50% between 12:00 PM to 2:00 PM, 100% between 2:00 PM to 4:00 PM, 50% between 4:00 PM to 6:00 PM, and 25% between 6:00 PM to 8:00 PM. The following table [1] presents the occupant schedule during the operating period of the hall. Before starting the simulation process, the required data was defined to be used as inputs into the DesignBuilder software as shown in table [2].

Table [1]: Occupancy Schedule:

Duration (Time Span)	Percentage of occupancy	Number of occupants
10:00 AM to 12:00 PM	25 %	5,000
12:00 PM to 2:00 PM	50 %	10,000
2:00 PM to 4:00 PM	100 %	20,000
4:00 PM to 6:00 PM	50 %	10,000
6:00 PM to 8:00 PM	25 %	5,000

Table [2]: The data input into DesignBuilder software:

Data Input	**Cairo covered sports Hall Complex (Hall Number One)**	
	Location	Cairo, Egypt
	Area (m^2)	11,304 m^2
	Height (m)	38.8 m^2
	Number of Spectators	20,000 Spectators
	Envelope Component	
	Walls	Concrete walls 40 cm thick
	Floors	CityBlac Tiles (40 cm × 40 cm) - Epoxy Floors - Tara flex 6 mm thick
	Ceiling Dome	10 mm thick corrugated aluminum sheet supported by a (K) steel truss
	Windows	With no thermal break, a single layer glass system is supported by an aluminum frame. with WWR equal to (15%)
	Doors	Single layer glazing system supported in an aluminum frame with no thermal break (5.4m (3 double leaf doors with width 1.8) × 2.2m)
	Equipment	
	Chairs	Fiber-reinforced thermoset material.
	Screens	Two main screens each one with a dimension of 6×10 m
	Lighting	Arena Vision LED System

Choosing the cooling set point temperatures in the activity tab of DesignBuilder software is crucial for regulating the interior climate. The HVAC system's supplied air temperature of 23ºC was chosen as the cooling temperature during the occupied period. The temperature setback was maintained at 26°C. Therefore, the HVAC system will operate automatically to reduce the temperature to 26º C during the unoccupied time when it exceeds 26º C. Therefore, when the spectators begin to arrive, the mechanical HVAC system will only need to drop the inside air temperature by 3°C to achieve indoor temperature of 23°C. Since, four chillers, each with a 900-tons refrigerant, were utilized to cool the complex's indoor areas. So, a water-cooled chiller was used as an HVAC system template in DesignBuilder. Additionally, the HVAC operating schedule was adjusted to fit with the spectator’s schedule, allowing the HVAC system to start operating concurrently with the spectator timetable and closed down during unoccupied times. Night ventilation was evaluated using the existing (WWR) of 15% with windows fully opened from 9:00 PM to 9:00 AM to allow night ventilation to remove the heat out from the indoor arena. In the DesignBuilder model, a scheduled mixed mode was used to turn on the HVAC system during the period between 9:00 AM to 9:00 PM

6-Results and Discussion

6.1- Stage one: Existing base case simulation results

It was found that the operative temperature between June and August considered the highest during the annual simulation. it was discovered that: The mean operative temperature inside the hall in January equals to 17.6°C; it starts increasing to reach the maximum of 29.07°C in August; then it decreases until it reaches 19.29°C in December as presented in figure (3). It was found that the yearly cooling load equals -479.7 kWh/m^2. Moreover, the zone sensible cooling load changes in response to the changing of the operating temperature following the operative temperature curve. Additionally, figure (4) illustrates a heat balance curve indicating that the heat within the hall was mostly generated by the occupants, which ranges between 35.5 kWh/m^2 and 39.3 kWh/m^2.

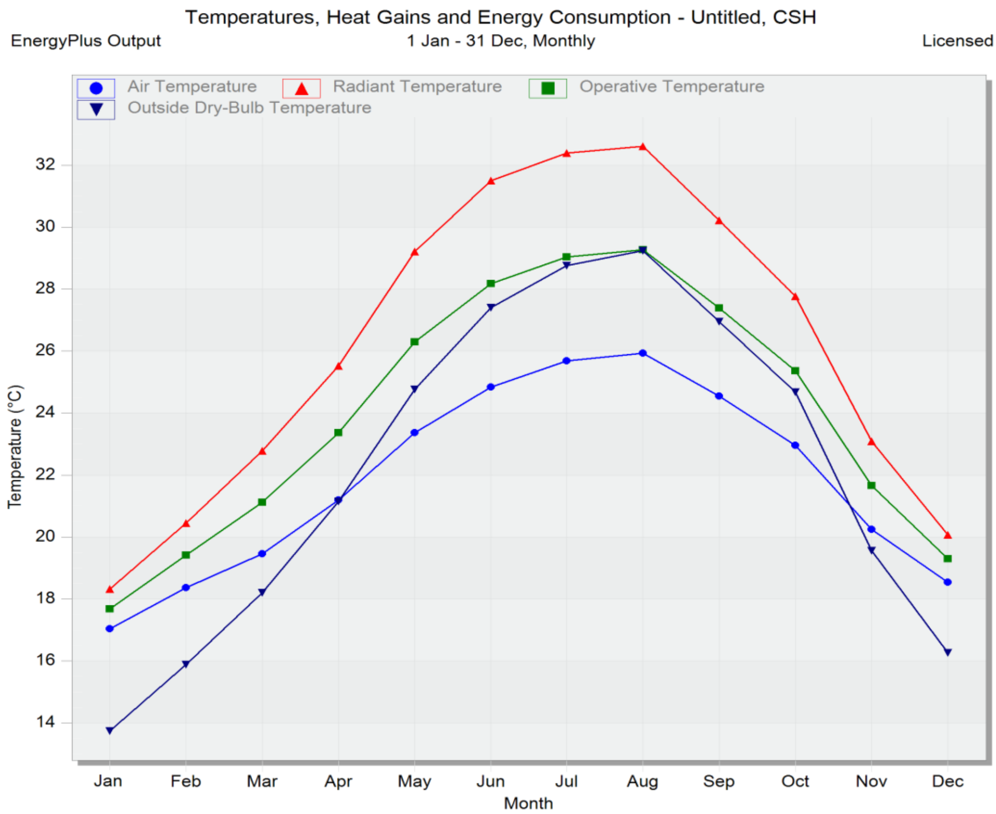

Figure (3): The Hall Annual Indoor Temperature curve

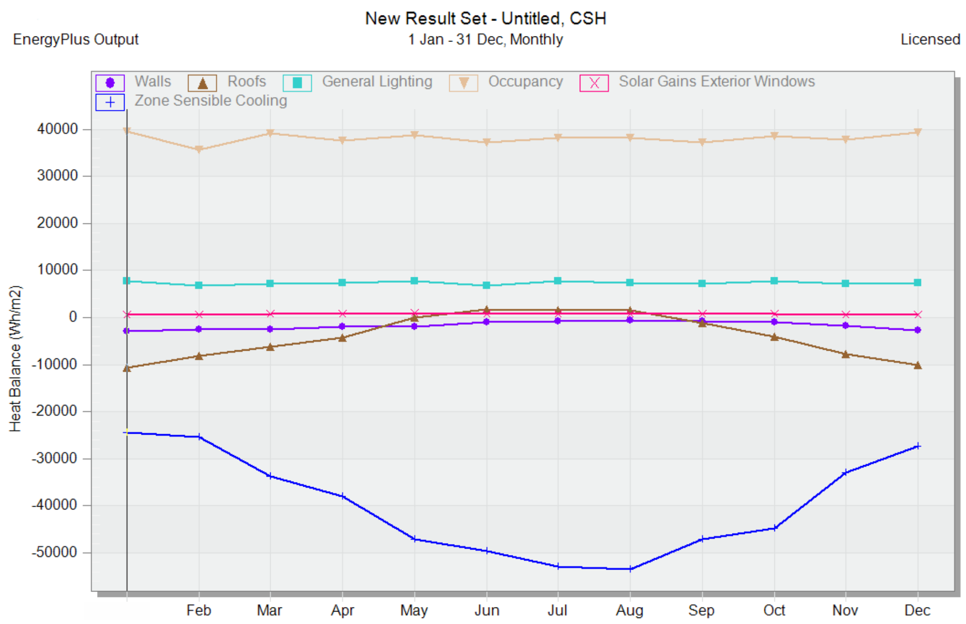

Figure (4): Annual Heat Balance Curve

6.2- Stage two: Night ventilation simulation results

Figure (5) presents zone sensible cooling rate for one year simulation period. The red curve shows the effect of using night ventilation. While the blue curve shows the existing case sensible cooling rate. Moreover, using night ventilation drops the annual zone sensible cooling from -476.49 kWh/m^2 to -390.25 kWh/m^2 by 18% as shown in figure (6).

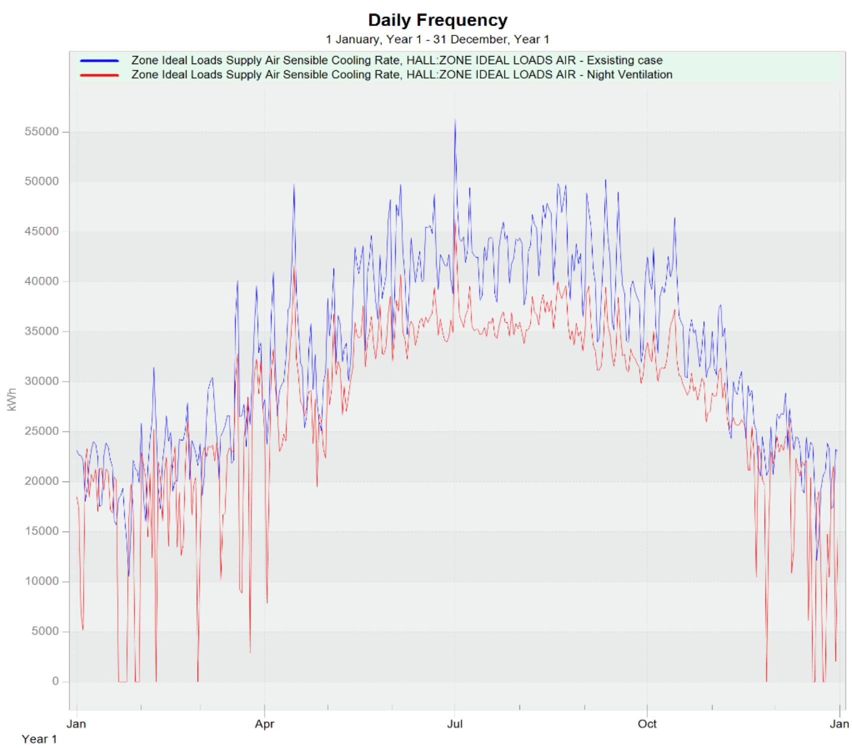

Figure (5): Monthly zone sensible cooling

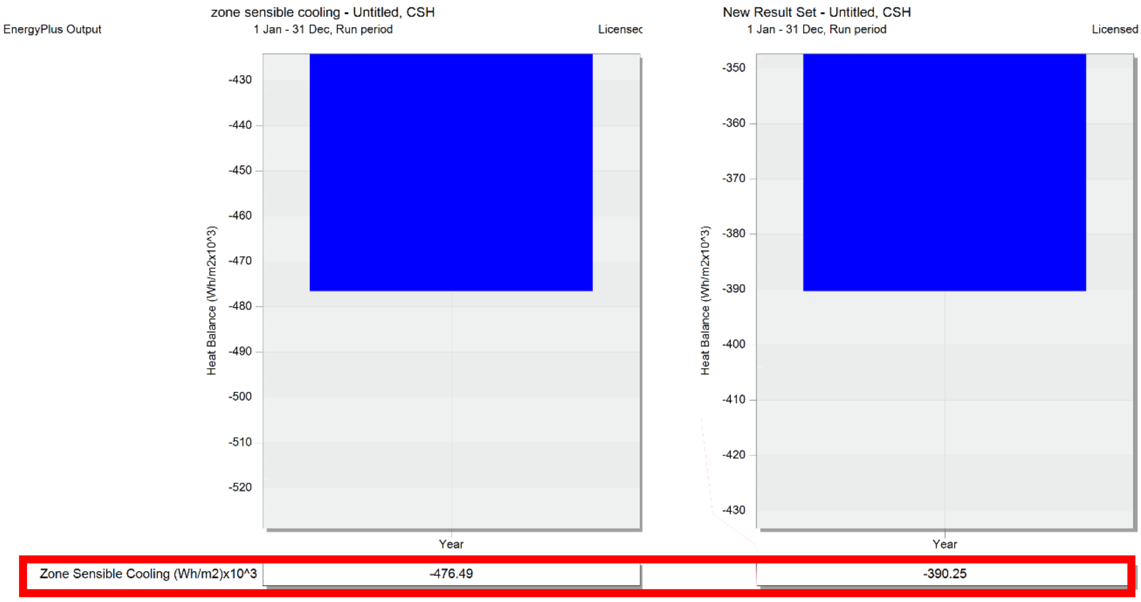

Figure (6) Annual zone sensible cooling (the values are presented in the negative direction of the Y axis)

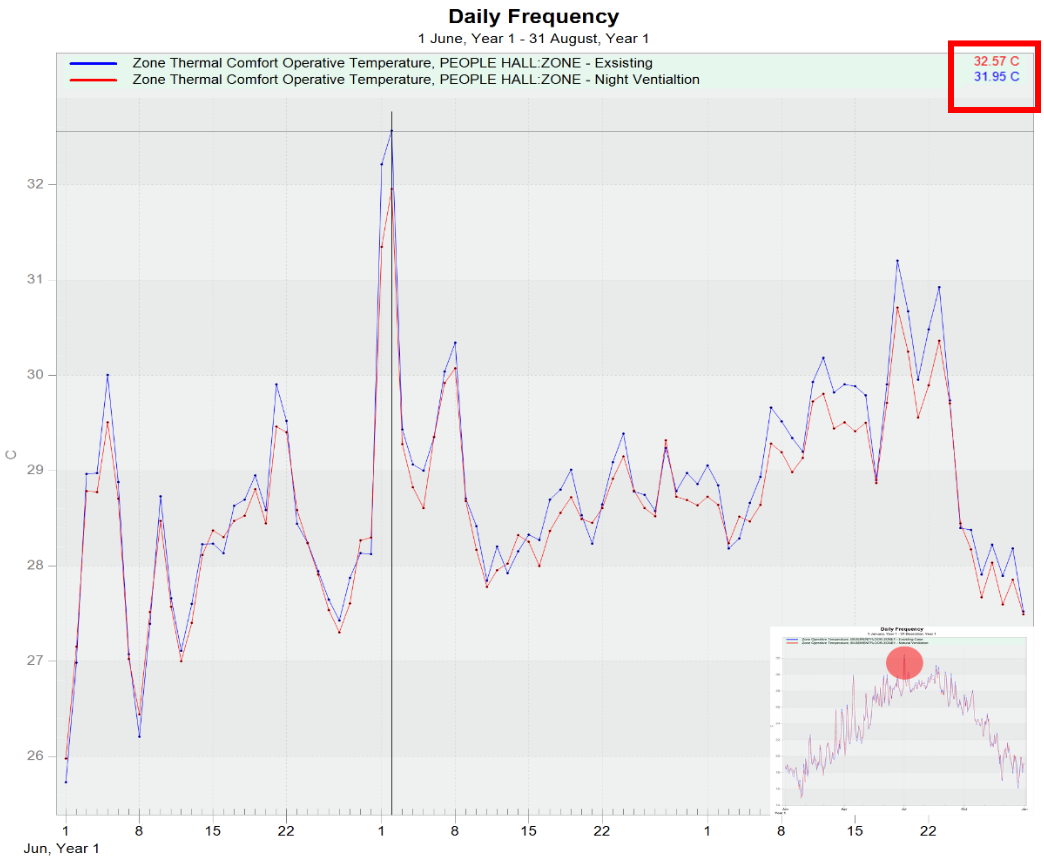

Figure (7): Differences between the operative temperature for the two cases during the period between June and August (highest operative temperature during the year), the key indicates a zoomed-out vision for the curve during the year.

When studying the effect of night ventilation on the indoor operative temperature. It was found that night ventilation reduces the indoor operative temperature (from 32.57ºC to 31.95ºC) by 0.62ºC at the highest indoor operative temperature period during the entire year as presented in figure (7). Furthermore, night ventilation affected the PPD (Predicted percentage of dissatisfaction) for the occupants inside the sports arena as presented in figure (8). It reduced the percentage of dissatisfied occupants by 4.25 % during July and annually by 3 %.

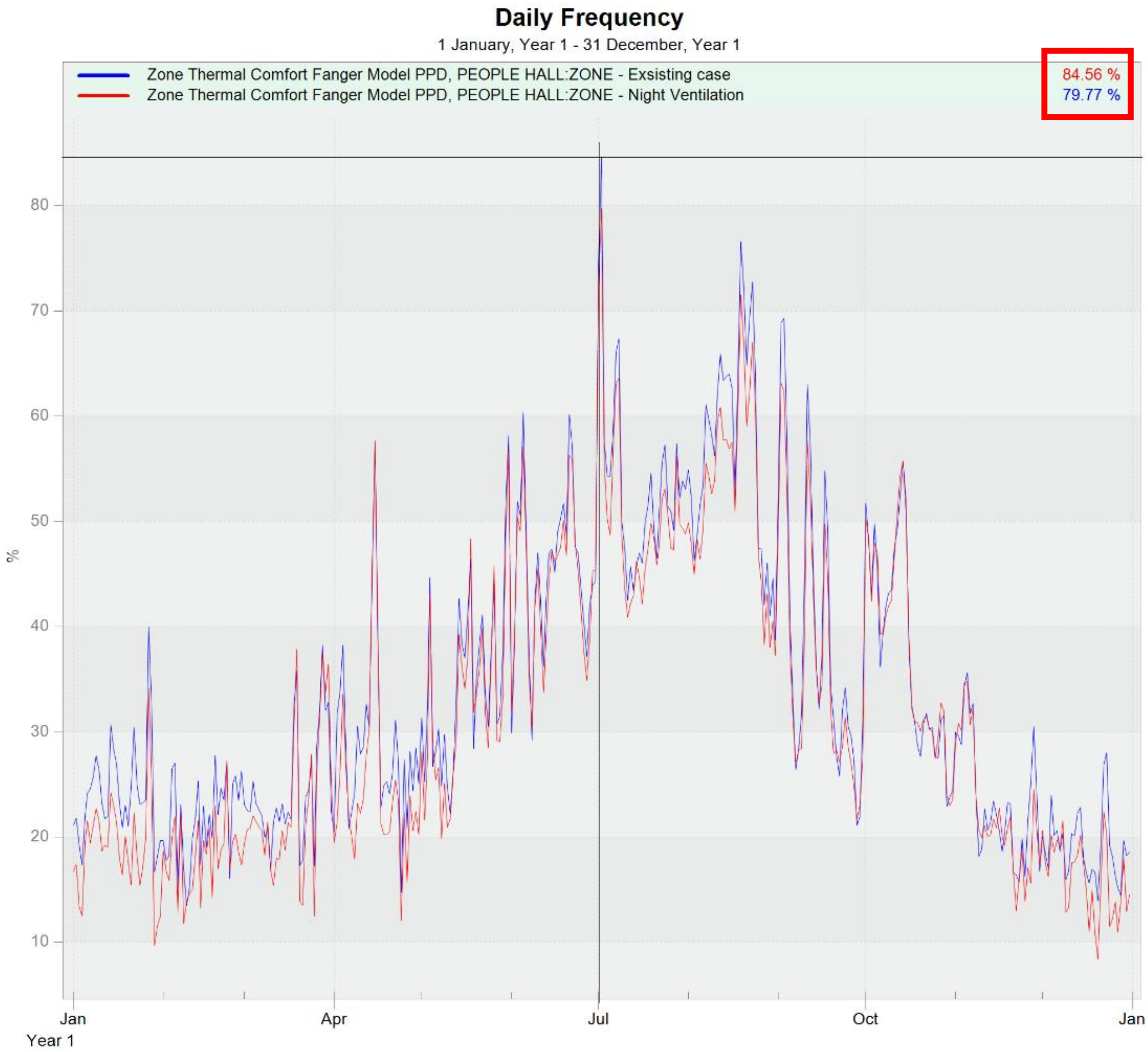

Figure (8): PPD for the existing case and night ventilated case

7-Conclusion

The simulations carried out regarding the impact of night ventilation on energy consumption in the interior of the largest sports hall in Cairo sports halls complex allowed the formulation of the following conclusions:

- Night ventilation is considered an effective method to minimize overheating in covered sports halls during extreme summer hot days
- It is recommended to use natural ventilation during periods of low outside dry-bulb temperatures from early night, till morning.
- Night ventilation has a positive impact on reducing the percentage of occupants' dissatisfaction.
- Night ventilation may reduce the amount of covered sports hall zone sensible cooling by 18%.
- Night ventilation evacuates the heat trapped inside the covered sports hall which reduces the HVAC setback temperature.

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