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The Potential of Hybrid Cooling Strategies in Office Buildings to Enhance Energy Efficiency

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Abstract: A hybrid cooling system combines both passive and active cooling systems provides energy savings and improves thermal comfort in hot climates. Natural ventilation is combined with mechanical ventilation by switching to mechanical ventilation when natural ventilation is insufficient to maintain indoor thermal comfort. As air conditioning requires a significant amount of energy, this system is limited in hot climates. This paper examines the application of hybrid ventilation modes in office buildings in Saudi Arabia, with the aim of reducing energy consumption without compromising thermal comfort. A dynamic simulation tool, IES-VE, was used to examine the potential energy savings of the hybrid system through a case study approach. The results of this study indicate that hybrid ventilation mode can save up to 13.7% on an annual basis. The hybrid mode achieved higher savings during the underheating period than during the overheating period at 30.4% and 4.4%, respectively.
Keywords: Energy Efficiency, Hybrid mode, Hot climate, Office building, Saudi Arabia

1. Introduction

It is well known that the extreme outdoor temperature in Saudi Arabia contributes to a high risk of overheating (Kaushik et al., 2020). Thus, air conditioning is heavily relied upon to maintain a comfortable indoor environment (Nedhal, 2022). It is estimated that the Saudi building sectors (governmental, residential, and commercial) make up 75% of the total energy consumption to maintain indoor thermal comfort (Abuhussain et al., 2018). Abuhussain (2020) noted that among all types of buildings, the commercial sector, which includes office buildings, accounted for nearly 17% of the total energy consumption. According to Bhatia (2023), the commercial real estate sector in Saudi Arabia is experiencing considerable growth, particularly in major cities such as Jeddah. As indicated by Issa (2023), this has resulted in an increase in demand for new office buildings.

Buildings with high glazing ratios are becoming increasingly popular in Saudi Arabia, especially in major cities like Jeddah. Nevertheless, given the high glazing ratio of such buildings, they are clearly not suitable for the harsh climate of the country due to overheating risks (Ghamdi et al., 2015). In hot climate zones, glazing allows massive heat transmission into buildings, resulting in discomfort and energy waste. Consequently, it is essential to examine various passive design strategies to ensure that indoor thermal comfort is maintained and that energy requirements for cooling can be reduced. Applying passive design strategies to buildings' envelopes can profoundly affect energy requirements for space cooling (Nedhal, 2022).

While it is challenging in modern buildings to maintain thermal comfort without using an air-conditioning system due to the harsh climate of Saudi Arabia, studies such as those by Tenorio (2007), Salcido et al. (2016), Gomis et al. (2021), and Mahgoub and Saber (2022) have highlighted the positive impact of passive cooling systems such as the use of natural ventilation along with the hybrid operational mode on the overall energy consumption instead of the conventional AC mode alone. In addition to increasing shading, by reducing glazing areas on external facades, increasing thermal mass, and providing natural ventilation, when possible, climate-responsive design strategies can significantly improve the thermal performance of buildings (Taleb, 2014, Hung Anh and Pásztory, 2021).

Moreover, natural ventilation's cooling potential is dependent on local climatic conditions, and it cannot be applied everywhere (Fiorentini et al., 2019). Thus, the use of a hybrid mode ventilation system can maximize the use of natural ventilation techniques when necessary. This is true especially in moderate seasons while switching to a mechanical system in the hot season (Ezzeldin and Rees, 2013). Accordingly, this study aims to assess thermal performance and the impact of applying passive design strategies along with the hybrid ventilation system on the overall energy consumption of office buildings within the climate context of Saudi Arabia.

2. Methodology

2.1. Climate Context

Saudi Arabia is situated in the South-west Asian region between 34° and 56° East. The city of Jeddah (the selected case study city) is located on the Red Sea between 21,68° North Latitude and 39,157° East Longitude at an average altitude of 12 meters above sea level. The summer season covers from May to September, with August being the warmest time of the year. During the overheated season, maximum outdoor temperatures are above 35°C with mean lows between 25°C and 28°C. In winter, the air temperature averages between 20°C and 30°C. The relative humidity ranges from 30% in winter to 85% in summer, as shown in Figure 2-1. Over the course of the year, Jeddah has a low precipitation level, with winter being the rainy season.

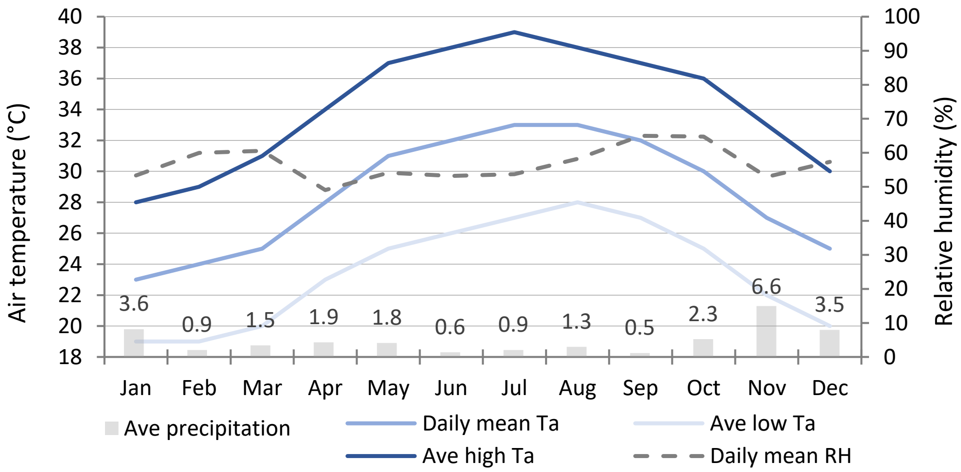

Figure 2-1 Climate data of Jeddah, Saudi Arabia. Reproduced from (Weather Spark, 2016, Climate Consultant 6.0, 2021)

2.2. Case Study Building

The selected office building for this project is the National Commercial Bank (NCB) in Jeddah, Saudi Arabia. It was completed in 1983 (Wood, 2007).The special case study was selected because of its location in a hot and humid climate zone, Jeddah. According to Wood (2007), it was designed with reference to the local climate. The selected building has not been quantitatively evaluated using the assessment method applied in this study.

The triangular building rises 27 stories above its base with three different façades: north, southeast, and southwest. Office spaces were designed in a 'V' shape, with all glazing and openings looking into a central atrium. The floor plan's layout created several voids on the north and southeast facades. Accordingly, two floors will be tested, the 16th floor (F1- with north void) and the 22nd floor (F2 with southeast void), as shown in Figure 2-2 (A-C).

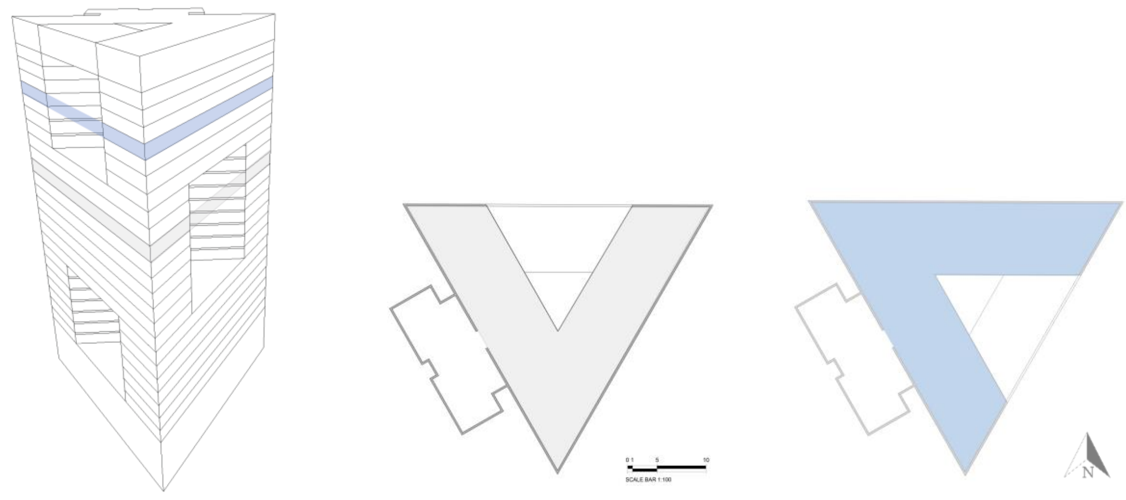
(A) (B) (C)

Figure 2-2 A. 3D view of the NCB building in IES-VE, B. floor 16 (F1- north opening), C. Floor 22 (F2- southeast opening).

2.3. Base Case Assumptions

To predict the thermal comfort and energy consumption of the existing building condition and test different solutions to promote the thermal performance of the building, a 3D model was constructed in IES-VE. The input data and thermal properties of the base case model are shown in Table 2-1. A cooling set point temperature of 24°C was set based on SEEC (2022) recommendations. The default system provided by IES was considered during the occupancy period, with a tolerance of 1.5°C to increase the system's efficiency. In AC mode, cooling was provided throughout the year (i.e., without natural ventilation). The profile schedules for people, lighting, and computers were set at 50% during off-occupancy hours (08:00-09:00 and 17:00-06:00) and 100% during occupancy periods (09:00-17:00 Sunday to Thursday).

Table 2-1 Simulation inputs for building's properties

Building properties	**Values**	**Unit**
Floor area	1,638	m^2
Concrete wall with external insulation	1.04	$W/m^2\ K$
Roof with insulation	0.96	$W/m^2\ K$
Glazing	Double glazed- 2.5	$W/m^2\ K$
People	90	W/person
Lighting	16	W/m^2
Computers	15	W/m^2
Infiltration	0.5	ac/h

2.4. Parametric Study Cases

A variety of scenarios were assessed using the IES simulation tool on the case study office building (NCB). Different floors with different orientations were analyzed to assess the impact of the orientation on the energy. As illustrated in Table 2-2, different case scenarios were developed to assess different parameters and solutions to optimize thermal performance.

Table 2-2 Parametric study cases developed by the author.

Category	Cases	Design Modifications
A: Existing condition	Base case	Base case scenario
	2	Increase the external insulation to 50%
	3	Placing the insulation on the inside
B: 40% window-to-wall ratio on the external façade.	4	40% of window-to-wall ratio on the external facades
	5	Window type changed to low-e with a U-value of 1.6W/m^{2}K
	6	Louvres to block 70% of insolation
C: 100% window-to-wall ratio on the external façade	7	100% of window-to-wall ratio on the external facades
	8	Window type changed to low-e with a U-value of 1.6W/m^{2}K
	9	Louvres to block 70% of insolation

2.5. Hybrid Control Scheme

The hybrid mode scenario was compared to the AC scenario for all the developed models to assess its impact on energy consumption. To prevent excessive energy consumption, the developed operational control system allows windows to open when indoor temperatures are higher than 24°C and lower than outdoor temperatures. This system allows AC to switch on only when the indoor temperature exceeds 29°C and the outdoor temperature is greater than the indoor temperature.

3. Results and Discussion

The predicted monthly energy consumption of the base case model for F1 and F2 are shown in Figure 3-1 and Figure 3-2, respectively, considering both operational modes (AC and hybrid) in each graph. The results indicate that energy consumption peaks during the summer season (between May and September), with the average consumption ranging from between 28MWh to 33MWh. However, the lowest monthly consumption was reported in the winter season, with energy consumption ranging between 18MWh and 26MWh in October and April, respectively. Thus, the local climate conditions contribute significantly to the overall energy consumption pattern of the building since summer temperatures increase the amount of cooling required to maintain indoor thermal comfort.

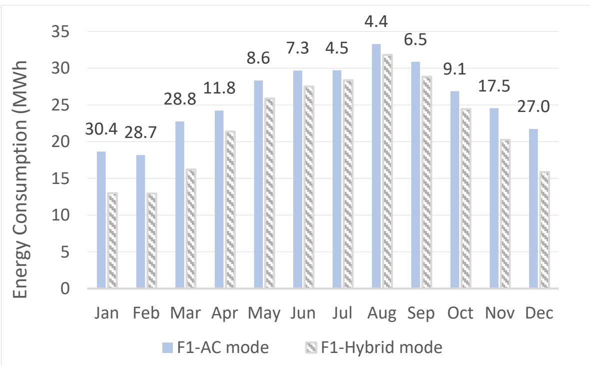

Figure 3-1 Base case monthly energy consumption and savings for F1.

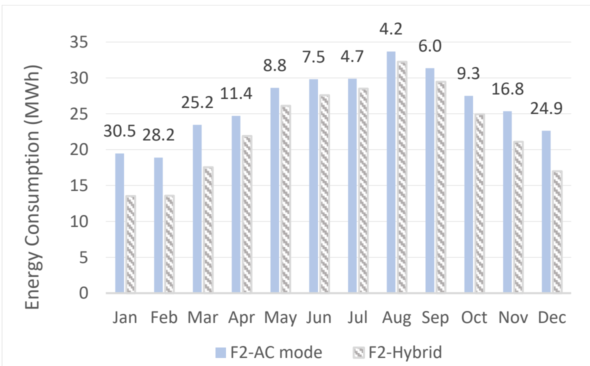

Figure 3-2 Base case monthly energy consumption and savings for F2.

By switching to the hybrid mode, the monthly energy consumptions for F1 and F2 range between 13MWh and 31.8MWh and between 13.5MWh and 32.2MWh, respectively. The energy savings achieved varied through the course of the year, ranging from about 4% in the summer to 30.5% in the winter (i.e., higher savings were achieved in the winter than in the summer). Thus, it is evident that, without considering any changes in the existing condition of the building, construction, material or equipment, the hybrid mode alone can significantly reduce energy consumption in hot climates without compromising thermal comfort.

The annual energy consumption results of F1 and F2 for the nine developed cases considering both AC and hybrid modes are shown in Figure 3-3. Among all cases, Case 6 performed better than the other cases in both operational modes, achieving the lowest annual consumption. Compared with the base case model (AC mode), Case 6 (AC mode) achieved 7% energy savings in F1 and 8% in F2, respectively. However, when considering the hybrid, Case 6 achieved 20% and 21.7% energy savings in F1 and F2, respectively, compared with the AC mode of the base case. By comparing Case 6 with Case 2, it noticeable that increasing WWR with proper shading and low-e glazing is more desirable than increasing the thermal insulation of the external walls alone. Nevertheless, Case 7 performed the worst, with annual consumption reaching 350MWh, followed by Case 4, with an annual consumption of 320 MWh. This means that in such a climate, increasing WWR is proven to be inefficient unless shading devices are applied with the use of highly efficient glazing types.

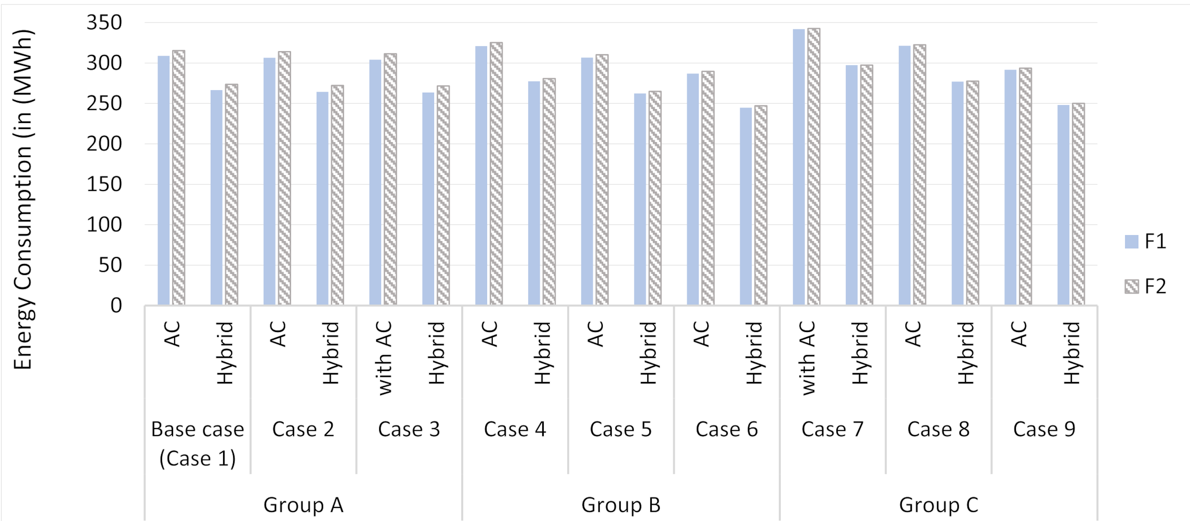

Figure 3-3 Annual energy results of the AC and hybrid mode for the nine cases for F1 and F2.

4. Conclusion

This study assessed the application of hybrid ventilation modes in an existing office building in Saudi Arabia, with the aim of reducing energy consumption without compromising indoor thermal comfort. A case study simulation approach was used to examine the potential energy savings of the hybrid system using the IES-VE simulation tool. The findings indicate that applying some design strategies on the building envelope resulted in a significant reduction in annual energy consumption. Under the hot climate conditions of Saudi Arabia, the hybrid mode shows more energy savings in the wintertime than in the summer period.

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