Evaluating the Performance of a Passive Architectural Element in a Hot-Dry Climate through Natural Ventilation and Thermal Impact Analysis

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Summary

This study aims to mitigate the lack of integrating passive design ideas from local architectural elements such as windcatchers, used as climate systems in hot climates to provide occupants comfort in modern housing designs. The study investigated various windcatcher types in different room designs (single zone) that is expected to be included in a single-family home proposal. The analysis used CFD tools to see the potential variation in thermal profiles and air speed distribution. The conducted CFD simulations found reductions in air temperature from 2°C to 7°C for different wind speed conditions. The indoor air velocity was kept in the comfort range from November to March, particularly in the daytime.

Introduction

- A key aspect of increasing the energy consumption of cooling new houses is neglecting passive local architectural element techniques to cool spaces. Such techniques should be developed with modern architecture to avoid energy consumption and provide occupants more control over natural ventilation [1].
- The Residential sector accounted for 21% of the total U.S. energy consumption and 55% of the energy used for heating and cooling; in comparison, residential in Saudi Arabia uses 50% of the country's total electricity, and 70% of that is used for air conditioning only [2,3].

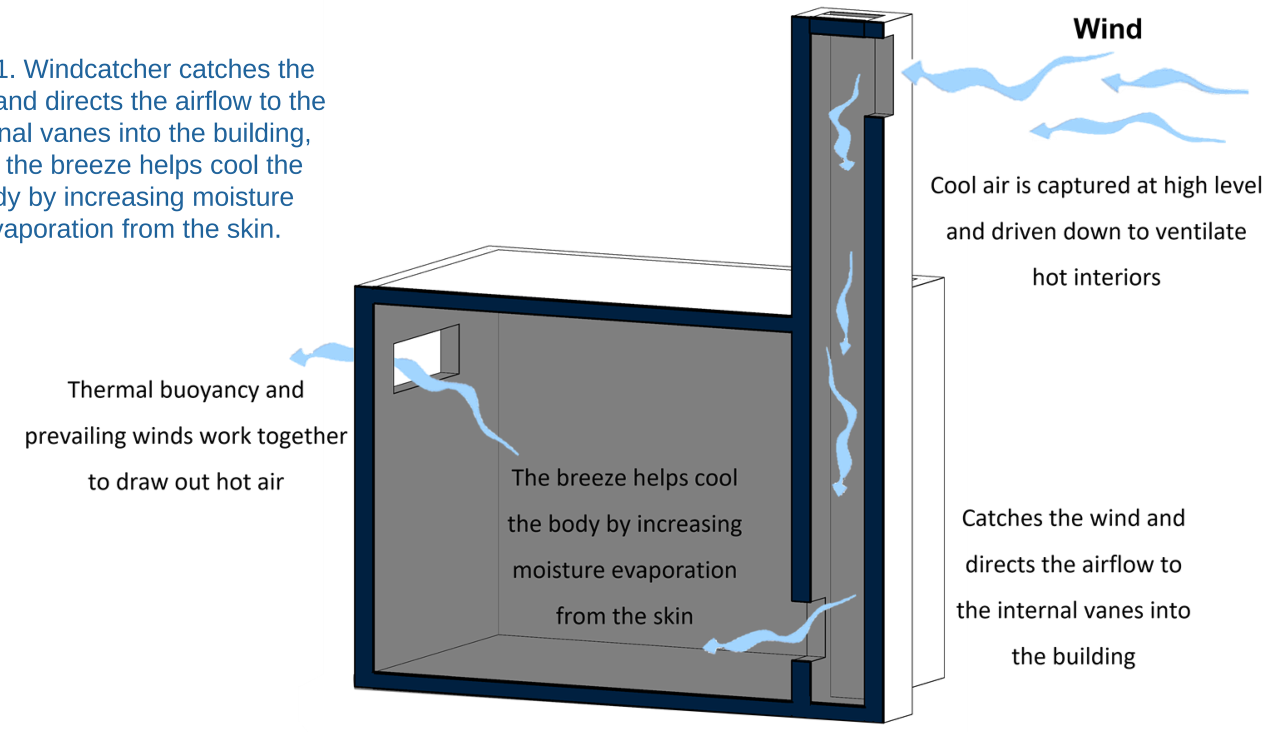


Fig. 1. Windcatcher catches the wind and directs the airflow to the building, internal vanes into the building, and the breeze helps cool the body by increasing moisture evaporation from the skin.

- Evaluating the efficiency of a natural ventilation system can be achieved by measuring local mean age of air (LMA), a parameter to measure the relationship between changing old air to new air in the space for early design decision; better indoor quality has a lower age of air.
- Traditional buildings techniques are a sustainable passive strategy for cooling many building types, will reduce energy use and lead to mitigate environmental problems by reducing the dependence on fossil fuels and being more climate-responsive [1,4,5].
- According to the Adaptive Comfort Model, the comfort zone area for that hot-dry location ranges between 23°C to 31°C [6].

Methodology

- This research investigated detailed impact of a passive local architectural element in new single-family homes, namely the windcatcher, in a hot-dry climate like Jeddah.
- The study used CFD tool to explore the element's potential through natural ventilation, within rooms faced north based on the most dominant wind direction
- The detailed thermal analyses can be listed as follows:

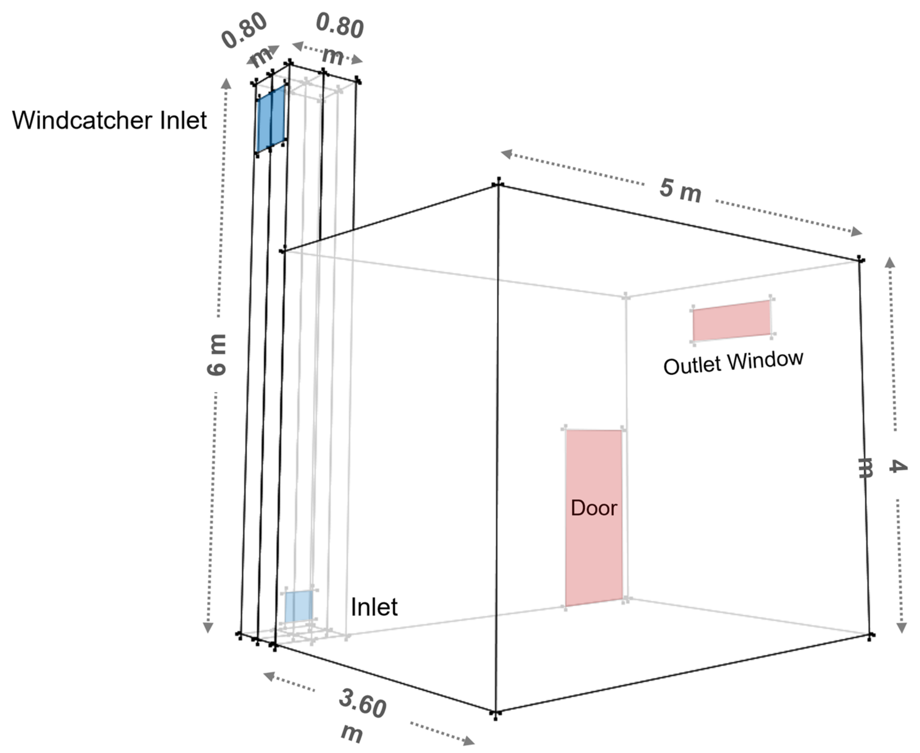
(1) evaluating the performance of a windcatcher in hot-dry climate through natural ventilation/wind potential data;

(2) evaluating the potential variation in the thermals and air profile distribution, air temperature and airflow, and air volume;

(3) evaluating the efficiency of the natural ventilation through measuring the LMA;

(4) evaluating the potential of windcatcher for one-zone and multizone/floors.

Fig. 2. Visuals of the simulated room model with a one-sided windcatcher and four small cross-sections 0.4m×0.4m-Right Door (RM-1S-SC-RD).



Results and Discussion

- From November to March, the winter has warm weather ranging from 24°C to 28°C, including constant seaside wind with an average speed of 3.5 m/s (7.8 mph), demonstrating high natural ventilation potential. Jeddah's annual average wind speed is higher than Houston at 3.2 m/s (7.2 mph) and less than Miami at 3.9 m/s (8.5 mph).
- The annual outdoor temperature is indeed high, but the wind speed is also high, so, when outdoor temperature falls in winter, the high wind speed provides comfort to occupants.
- Jeddah's wind speed are high, ensuring indoor air velocity of less than 0.6 m/s, helps to reduce the amount of hot outdoor air entering the indoor space in the hot-dry location.
- Keeping low air volume and air velocity within a suitable range leads to better indoor ventilation with the capability of lowering the daytime temperature in winter by 2°C and 9°C in summer, keeps the room temperature within comfort zone ranges of 23°C to 31°C.

CFD analysis results for winter and summer at noon for opened/closed room door for the case of a room model with one-sided windcatcher and small cross-section 0.4m×0.4m-right room (RM-1S-SC-RD)

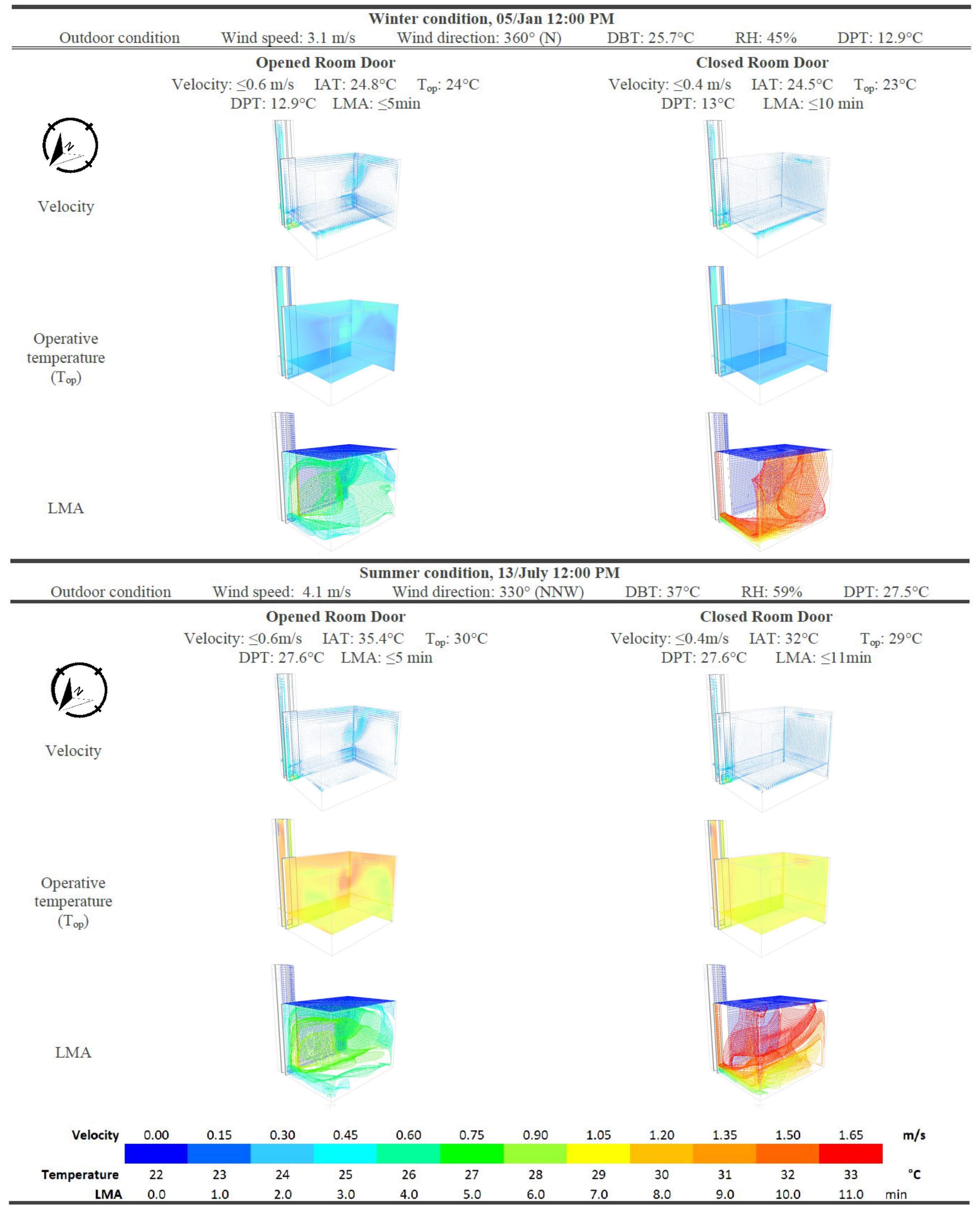


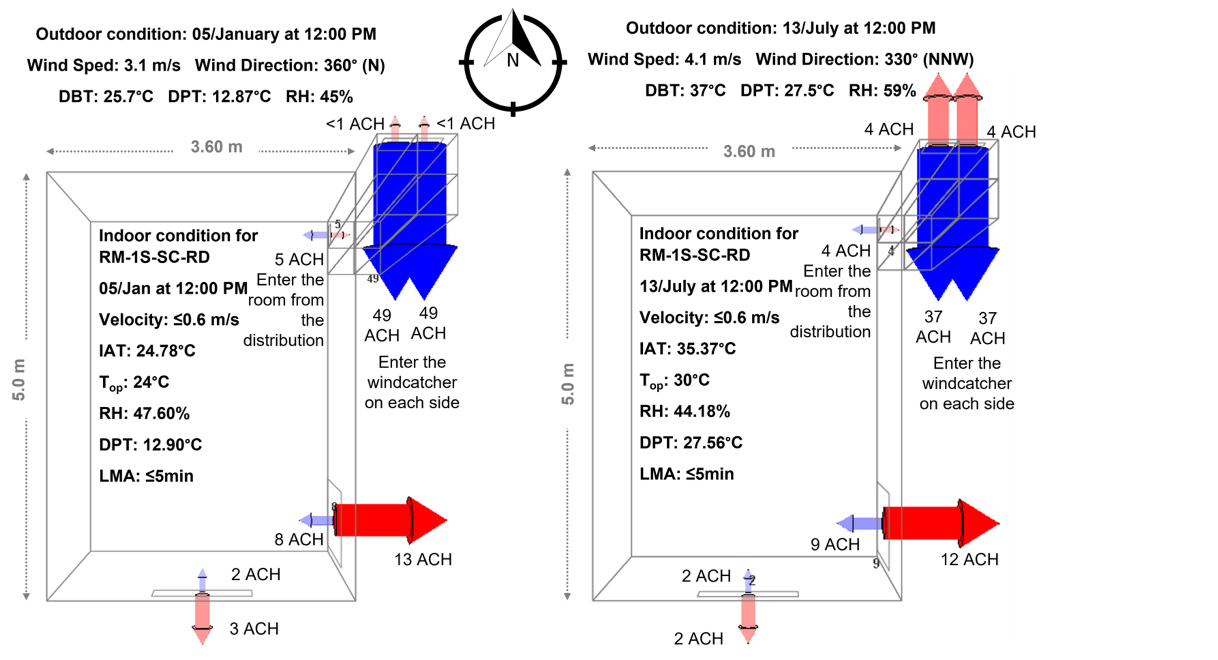
Table showing outdoor conditions and summarizes the CFD results data for the indoor conditions during winter and summer for four different models with different scenarios.

Date/Time	Wind Speed	Wind Direction	DBT	DPT	RH
05/January at 12:00	3.1m/s	360°(N)	25.7°C	12.9°C	45%
13/July at 12:00	4.1m/s	330°(NNW)	37°C	27.5°C	59%

Room Model	Parameter	Scenario: 05/Jan at 12:00, Opened Room Door	Scenario: 05/Jan at 12:00, Closed Room Door	Scenario: 13/July at 12:00, Opened Room Door	Scenario: 13/July at 12:00, Closed Room Door
RM-1S-SC-RD[1]	Velocity	≤0.6m/s	≤0.4m/s	≤0.6m/s	≤0.4m/s
	T_{op}	24°C	23°C	30°C	29°C
	DPT	12.9°C	13°C	27.6°C	27.6°C
	LMA	≤5min	≤10min	≤5min	≤11min
RM-1S-SC-RD-ER[2]	Velocity	≤0.6m/s	≤0.4m/s	≤ 0.5m/s	≤0.3m/s
	T_{op}	24.2°C	23°C	29°C	28°C
	DPT	12.9°C	13°C	27.6°C	27.6°C
	LMA	≤8min	≤11min	≤9min	≤11min
RM-1S-SC-RD-ER-MF[3]	Velocity	≤ 0.5m/s	≤0.5m/s	≤0.5m/s	≤0.5m/s
	T_{op}	23°C, 23°C	22°C, 22°C	27°C, 28°C	26°C, 27°C
	DPT	12.9°C, 12.9°C	13°C, 13°C	27.6°C, 27.6°C	27.6°C, 27.6°C
	LMA	≤9min, ≤6min	≤11min, ≤7min	≤8min, ≤6min	≤11min, ≤8min
RM-1S-SC-RD-1.5m[4]	Velocity	≤ 0.5m/s	≤0.5m/s	≤0.5m/s	≤0.5m/s
	T_{op}	24°C	24°C	30°C	29°C
	DPT	12.9°C	13°C	27.6°C	27.6°C
	LMA	≤6min	≤11min	≤6min	≤11min

[1] Room model with one-sided windcatcher (RM-1S) and small cross-section 0.4m×0.4m (SC) Right Door (RM-1S-SC-RD)
[2] RM-1S-SC - Right Door–Extra Rooms (RM-1S-SC-RD-ER)
[3] RM-1S-SC - Right Door–Extra Rooms-Multiple Floors (RM-1S-SC-RD-ER-MF)
[4] RM-1S-SC - Right Door–High inlet distribution of 1.5 m (RM-1S-SC-RD-1.5m)

Fig. 3. shows the data result from the simulation and proves that the wind enters the windcatcher through its openings, creating an LMA value of less than or equal to 5 minutes.



Conclusion

- This study investigated the thermal impact with the performance details of integrating windcatchers in modern house designs in a hot-dry climate, like Jeddah, in Saudi Arabia.
- One-sided windcatcher with a small cross-section of less than 3% of the total floor area is more effective in reducing indoor temperature than a large cross-section. The main finding can be summarized as follow:

(1) no differences in indoor temperature reduction between 6 or 8 meters height of windcatcher.

(2) no differences between a simple/straightforward windcatcher design and a windcatcher with an earth tube 3 meters below ground and around the room boundary.

- Therefore, the simple windcatcher design was selected to continue the study because simplicity is appreciated in construction, with lower temperatures than the maximum outdoor by 6.1°C for open rooms and 10°C for closed door models.
- the windcatcher has more potential with multiple floors than with one single floor. For example, the indoor temperature reduction in winter/summer with one single floor ranges from 2°C to 4°C, but for multiple floors ranges from 5°C to 7°C.
- Overall, reducing the indoor temperature and providing thermal comfort through the natural ventilation potential effect help minimize the use of AC systems to save energy.
- This findings can serve as a base for future studies or include it on building codes/guidelines for integrating windcatchers in new houses, to provide thermal comfort.

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