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CFD Analysis of Windcatchers

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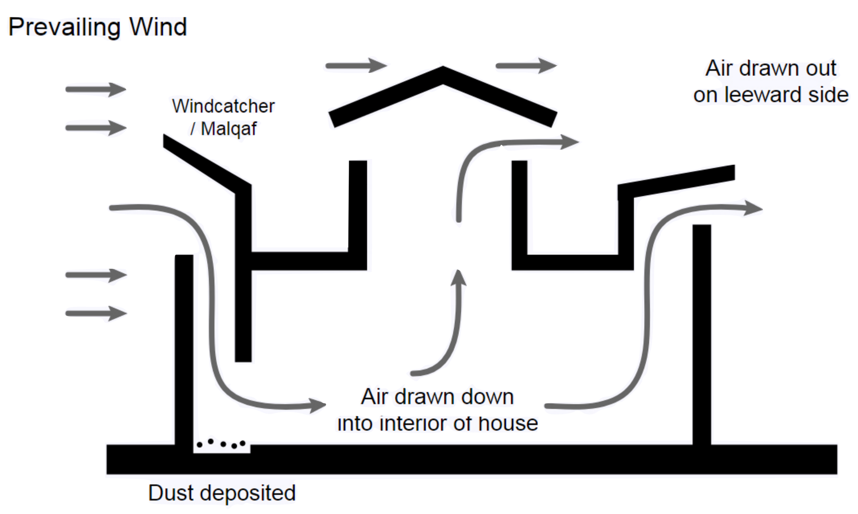
Introduction:

Windcatchers are architectural elements that naturally ventilate and cool indoor spaces by redirecting outside oncoming wind to the interior of a dwelling.

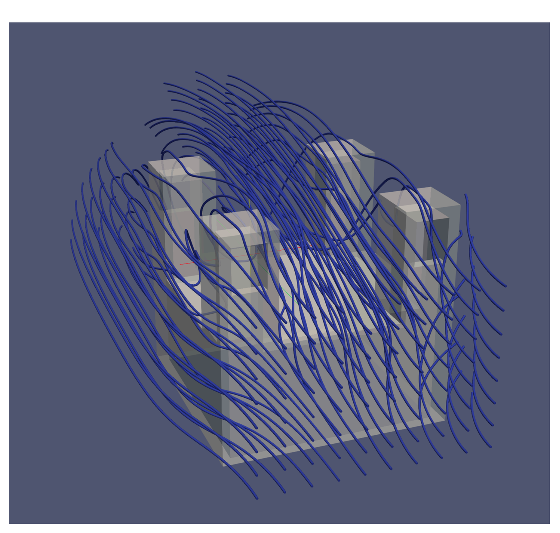


Despite the well-known existence of this architectural element, there isn't a concrete understanding of how they work. This may be the reason for the lack of their use in western architecture.

Gaining an understanding of the principles of windcatcher fluid mechanics will allow for improved designs which may lead to wider use in future infrastructure.

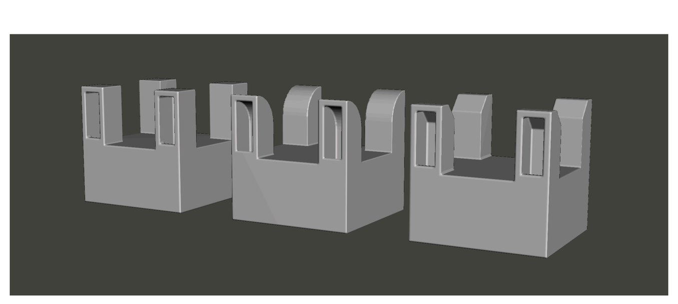
Benchmarking:

The 1st step was to benchmark the performance of the initial model. As expected, the model performed very poorly as the mass flow rate for the model was ≈ 0:



The primary issue is that most of the air is passing around the windows and very little is entering the windows.

To allow more inflow, the size of the windows were increased and various tower shapes were simulated:



The results of the larger window model along with curved and angled tower variations are below:

Tower Shape: (Large Windows)	Mass flow rate: (Squared=1)
Squared	1
Curved	1.132
Angled	1.009

There is little difference between angled and squared tower shapes. Curved is by far the best performer.

A shorter version of large windows + curved towers was tested:

Height of towers/body:	Mass flow rate: (Tall=1)
Tall	1
Short	1.479

Compared to the first tall squared design, the short curved design has 67.5% more mass flow!

To test robustness, the short curved model was tested with tower orientations and varying wind directions:

Angle:	Symmetrical: (0^o Oriented=1)	Oriented: (0^o Oriented=1)
0^o	0.828	1
45^o	0.781	0.877
90^o	0.828	0.088

Objective:

The scope of this project is limited to determining the basic design principles that maximize (1) the flow rate of air and (2) and thermal convection inside of a basic windcatcher.

Method:

First, an initial (simple) model of a windcatcher will be designed to simulate and analyze windcatcher operation.

Then, individual elements of the windcatcher will be modified independently and the change in performance will be recorded.

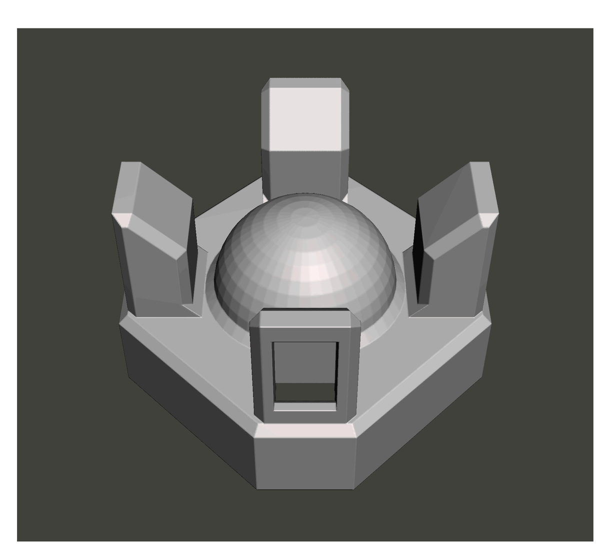
A new design will be created with elements that showed to best results and the performance will be compared to the original design.

Conclusions will be made regarding which elements had the the biggest impact on windcatcher performance.

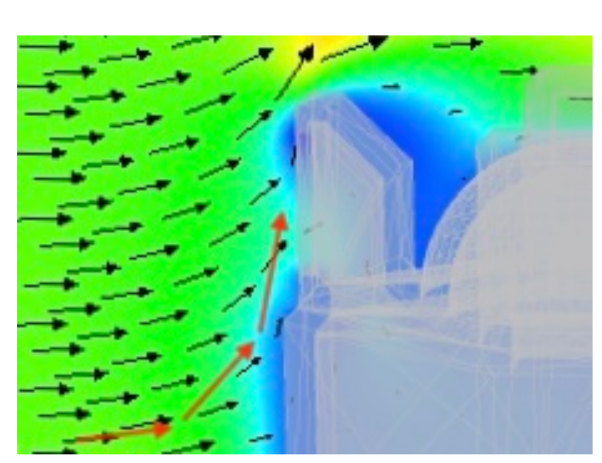
Iterative Model:

The results thus far show that the volume of the windcatcher has the largest impact on the mass flow rate of air. In comparison, the shape of the towers are close to negligible. The towers should also be oriented symmetrically for robustness.

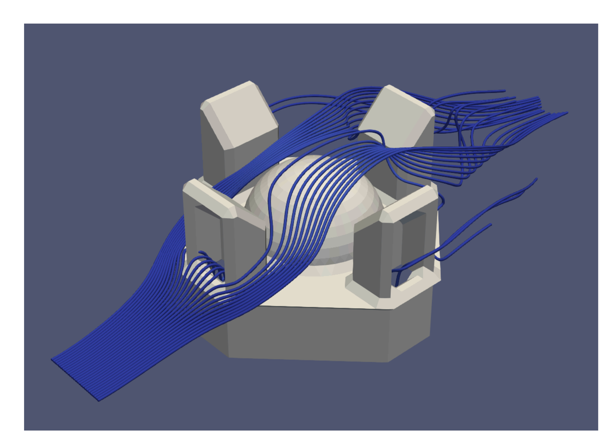
Using this information, a more traditional and realistic design was created with more features including chamfered edges for a more streamlined design and a dome:



A partial velocity flow is below:



The red arrows show an issue with having a body-tower offset. The upward airflow from the body limits the amount of air entering into the window. To solve this issue the body-tower offset was removed and a lip was added:



The flow is smooth and there is outflow from all windows.

The last element to test is the presence of a dome. Since removing the dome will reduce the volume, the mass flow rate will increase.

However in the case of thermal convection, a dome is a good mechanism for "trapping" and "storing" warm air. Therefore, a reduction in mass flow rate is indicative of better thermal convection.

No Convection = 1	Dome:	No Dome:
No Convection	1	1
Convection	1	0.912

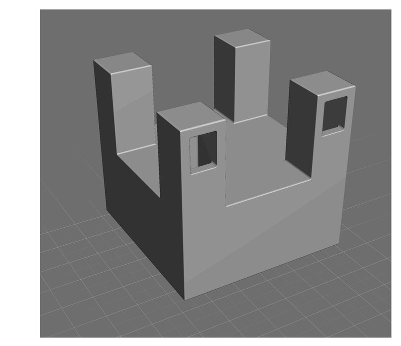
Performance Criteria:

The primary indicators of good performance are:

- Mass flow rate of air inside the windcatcher
- Robustness with respect to wind direction and thermal convection

Initial Model:

This refers to the first iteration design which will undergo many modifications:

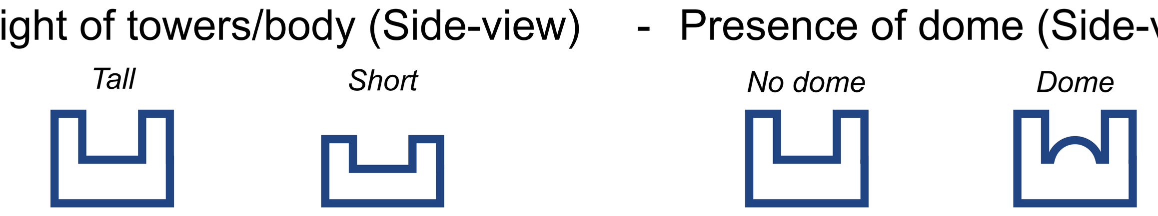


Element Modifications:

- Shape of towers (Cross-section)
- Size of windows (Front-view)

- Orientation of towers (Top-view)
- Body-tower offset (Side-view)

- Height of towers/body (Side-view)
- Presence of dome (Side-view)



Conclusions:

The testing shows that the design elements that maximize the mass flow rate of the air inside the windcatcher are the following:

- Large windows
- Curved or angled tower shapes
- Lowest possible volume of windcatcher

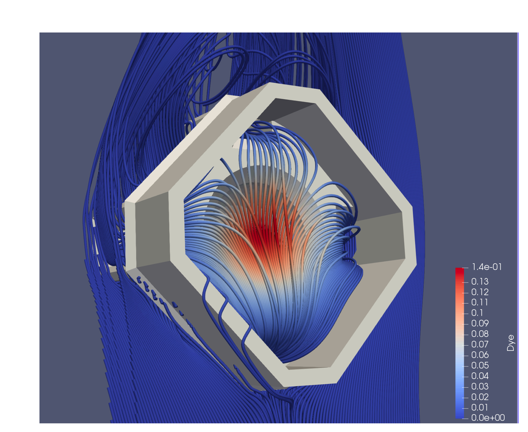
Furthermore, having a symmetrical windcatcher design with oriented towers allows for greater robustness with varying wind direction.

Finally a dome is ideal for allowing thermal convection in the windcatcher.

Next Steps:

The primary function of windcatchers is to cool and ventilate a dwelling. The scope thus far has primarily focused on the ventilation aspect of the windcatcher with some focus on thermal convection.

This is been a strategic choice since focusing on ventilation has allowed the fine-tuning of the windcatcher design which will serve as the basis for researching the cooling effects and their mechanisms. Such research will be done by adding a temperature field inside the current design as shown on the right:



The colors represent the relative temperature, where red is warmer and blue is colder.