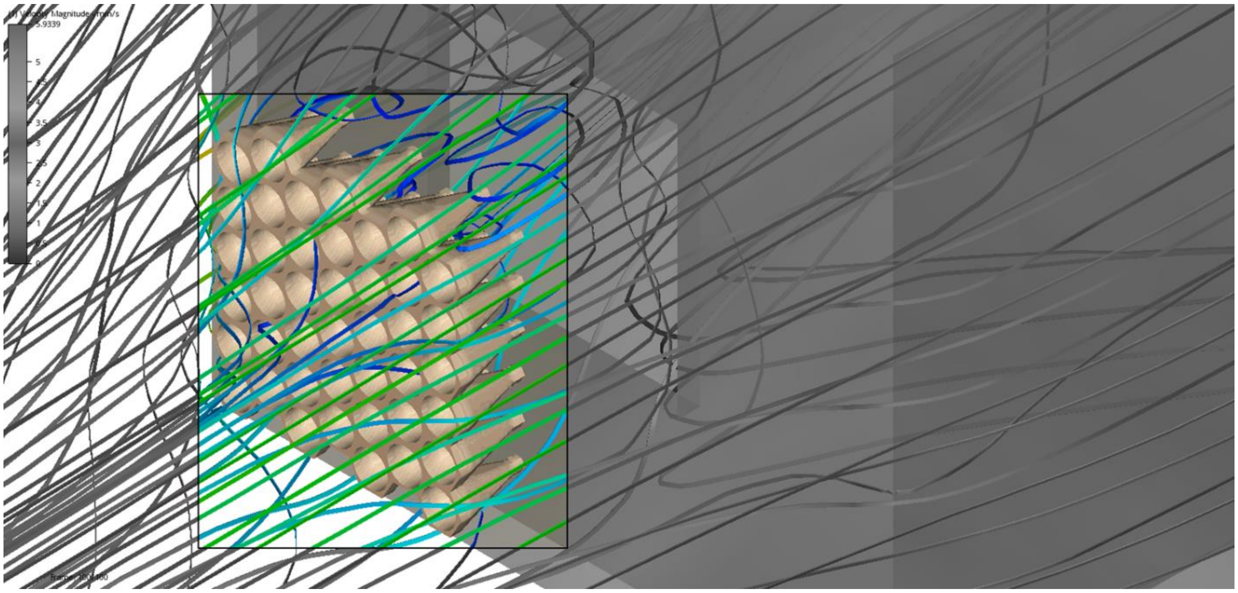

WIND BOY: AN EXPLORATORY DESIGN OF A WIND DRIVEN MODULAR FACADE

A P.h.D. THESIS BOOKLET

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Table of Contents

1. Statement of the Problem 3
2. Research Objectives 3
3. Research Hypothesis 3
4. Research Questions 4
5. Theoretical Concept 4
6. Theoretical Background 5
7. Design Description 6
8. Research Methodology 6
   8.1 The 3D Geometry 7
   8.2 Simulation in a Test Room 7
   8.3 The 3D Geometry of the Test Room 9
9. Results and Discussions 9
10. Conclusions and Thesis Statements 13

1. Statement of the Problem

Various façade types can lead to the energy performance of the building. The surfaces on the exterior of the buildings can filter air, clean water, regulate temperature, generate breeze, and contribute to public health. Additionally, limited work has been done on the potential of the building façade to harness energy. In this paper, the author hypothesizes a modular system that can improve the air ventilation inside the building. Although there have been a number of attempts to use the building envelope as wind energy generators, they are expensive and costly. Nevertheless, the use of the building façade as a wind collector can be a potential source of free energy. I therefore hypothesise that it is a promising concept that opens up to other interdisciplinary investigation of passive cooling methods.

2. Research Objectives

In this research, I explored the possibility of developing a prototype device (Wind Boy) into a wind induced building façade. Thus, the main objective of this research is:

To examine and conduct airflow simulations on the different design systems of the proposed modular façade system using Computational Fluid Dynamics (CFD) in order to determine its optimum air flow performance. Additionally, to also further examine the different variables that affects the airflow.

- To investigate air flow characteristics of the proposed Wind Boy and evaluate the available wind velocity at specific locations of the system.
- To be able to determine if the various configuration and distance of the proposed façade can influence the air flow behaviour and characteristics inside a test room using CFD.
- To explore and discuss possible applicable scenarios of the proposed façade system while providing directions for future research.

3. Research Hypothesis

The proposed Wind Boy takes advantage of the classical Bernoulli’s theory, which states that fluid must increase through the narrow portion of a pipe. The proposed design has a constricted inner core (converging section) that can amplify incoming winds. The *Wind*

Boy is therefore a wind induced ventilation system to improve the indoor thermal conditions of the building. This simple but effective concept of wind energy harvesting is both sustainable and opens up other possibilities of energy harvesting thru the building façade.

4. Research Questions

In this paper, the author wishes to identify the following questions:

- In what way can I use Computational Fluid Dynamics (CFD) simulation in determining the optimum air flow performance of the proposed modular façade system? What are the different variables that affect the airflow?
- How can I investigate the airflow characteristics of the proposed Wind Boy system and evaluate its wind velocity at a specified location?
- Does the various configuration and distance between the building façade of the proposed system have any influence of the airflow characteristics inside a test room?
- What are the other possible applicable scenarios and directions for future research of the proposed façade system?

5. Theoretical Concept

In this façade system, the author proposed system the author proposed four different properties (Fig. 1) for Wind Boy: modularity, multi-ability, adaptability, simplicity and prefabrication.

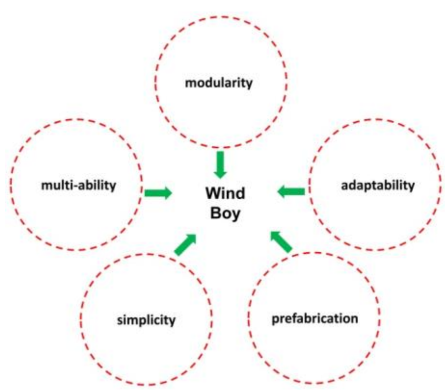


Figure 1. Theoretical concept for Wind Boy

The important feature for Wind Boy is that of modularity. The form of Wind Boy was based on the beehive hexagon structure (Fig. 2). Studies have shown that the beehive hexagonal structure has the characteristics of higher structural strength, compact layout, thinner thickness of wall and low material consumption.

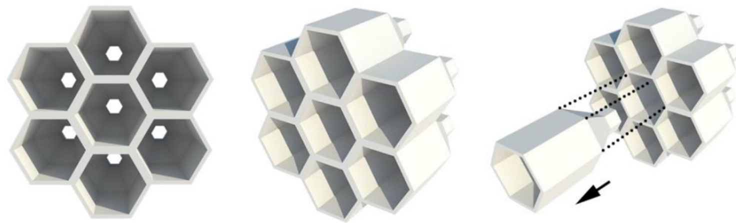


Figure 2. Modularity and Adaptability features of the proposed *Wind Boy*

The intent behind Wind Boy is to produce a relatively small modular device while minimizing structural loads. The entire component is an assemblage of many modules to fill the building skin, specifically in front of the window fenestration. This modularization enables the system to be easily applied to various types of existing buildings and make it convenient for *Wind Boy* to be installed and can easily be replaced or removed. The *Wind Boy* façade system is a movable and adaptable system that can make a transition over time to meet new requirements and cope with uncertainty. This will therefore result in an ease of modification for each of the individual components. The foremost characteristic of the proposed system is that it has no complicated movable parts. The proposed *Wind Boy* does not need electrical energy to function. Since *Wind Boy* is easily removed, it can be easily replaced without additional cost. Wind Boy can easily be prefabricated in off site. Therefore, a ready set of components and parts are easily available.

6. Theoretical Background

The *Wind Boy* system proposed in this study also applies the well-known classical concept of Bernoulli's principle (Fig. 3) which conveys us that the fluid (wind) must increase through the narrow portion of the pipe. The increase of velocity causes kinetic energy to increase at this point at the expense of pressure energy.

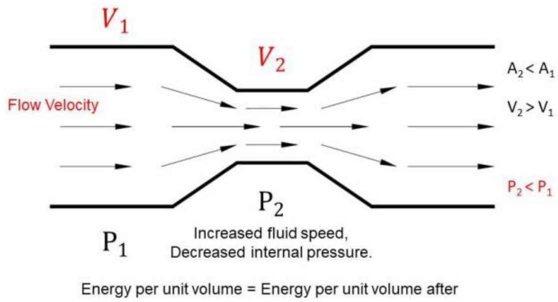


Figure 3. The Bernoulli' Equation

7. Design Description

The system consisted of three parts, the Inlet, the Converging Section and the Throat. The basic dimensions of are L=350mm, W=200mm and Thickness=10mm. The Inlet receives the incoming wind, merging at the Converging Section and exits at the Throat. It is here at the throat of the proposed system where, according to Bernoulli's theorem, wind will increase due to the narrow portion of the throat and pressure differences (Fig. 4).

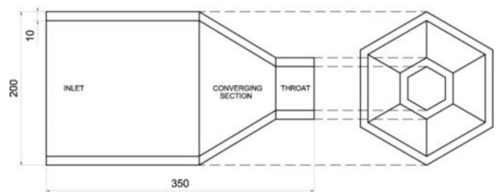


Figure 4. The basic schematic diagram of the proposed *Wind Boy*.

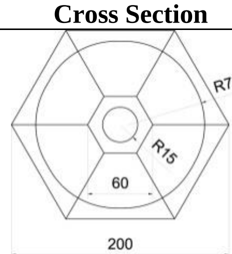
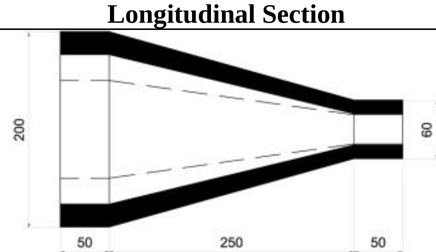
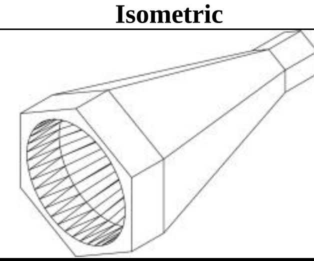
8. Research Methodology

In this study, the author follows a four step Methodology Workflow Process in order to determine which design options variables affect airflow inside the test room using the *Wind Boy façade* system. In Step 1, the 3D model geometry of the façade system and test room will be generated using Autodesk® AutoCAD. The model will then be imported into Autodesk® CFD, in which the Flow Domain, Boundary Conditions will be established. Grid/Mesh generation will be generated by the software. In Step 2, the simulation scene was performed and monitored for completion. In Step 3, the simulation results were examined and analysed. Finally, in Step 4, the performance of the proposed system was evaluated and discussed. The studies are intended at examining the efficiency of the *Wind Boy* in different configurations of the test room, wind and velocity magnitude distribution under constant approaching wind speed.

8.1 The 3D Geometry

The geometry and configuration (Table 1) of *Wind Boy* is intended to create a negative pressure in the narrowest section which can be used to partly or completely drive the incoming wind. In this first study, all of the proposed *Wind Boy* designs have the basic Inlet Diameter (D=200 mm) and Outlet Length (L3=50 mm). The various design configurations consist of different specific geometrical change to the Outlet Diameter (d), Taper Angle (a), Inlet Length (L1) and Throat Length (L2).

Table 1. The proposed *Wind Boy* designs considered in this study.

Design no.	Cross Section	Longitudinal Section	Isometric
1			

8.2 Simulation in a Test Room

In this chapter, five (5) different *Wind Boy* façade configurations (Fig. 5) are examined in a theoretical test room using CFD analysis (Table 2). These configurations are listed as Study 1 to 5:

- Study 1 is the control variable in which it is held constant and in this case, the CFD simulation does not include the *Wind Boy* façade on the window of the room;
- Study 2 has the *Wind Boy* Inlet (D) *flushed* into the window of the room at the windward side of the wind at 3 m/s;
- Study 3 has the *Wind Boy* Outlet (d) flushed into the window of the room. This means that there is no distance between the window and the Outlet of the proposed façade. This is the 0 mm distance from the windward window;
- Study 4 has the façade distance at 100 mm of the window of the room in respect to the Outlet (d) of *Wind Boy*;

➢ Study 5 has the façade distance of 600 mm of the window of the room in respect to the Outlet (d) of *Wind Boy*.

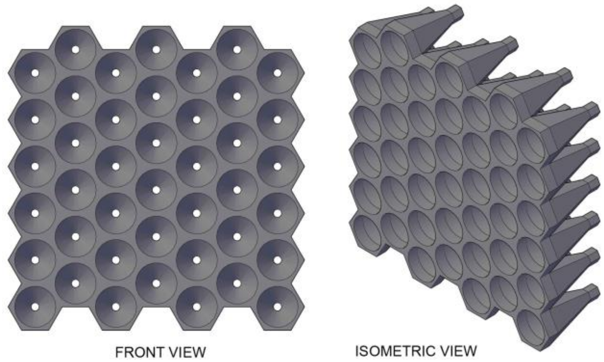
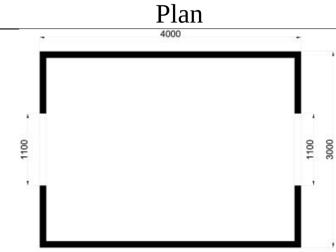
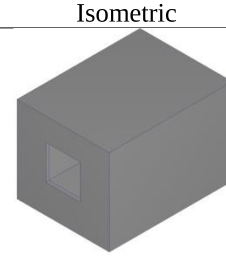
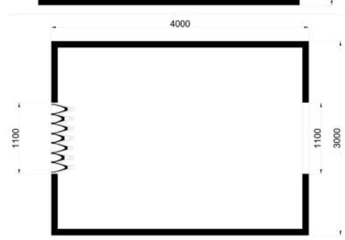
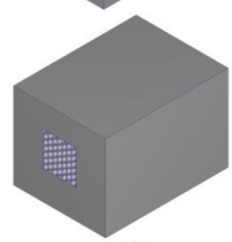
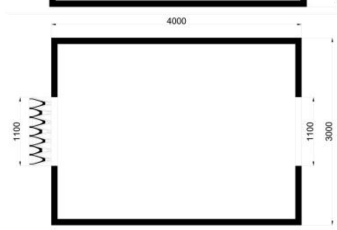
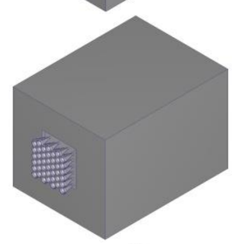
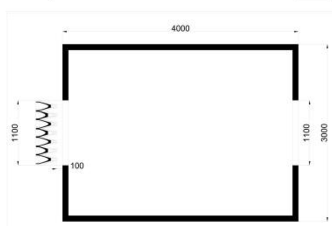
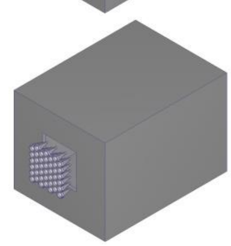
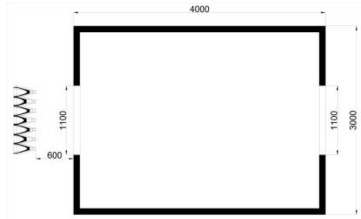
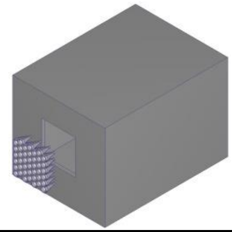


Figure 5. Front and Isometric view of the proposed *Wind Boy* arrangement.

Table 2. The Proposed configurations of *Wind Boy* for airflow analysis in a test room using CFD.

Study No.	Distance to the window	Plan	Isometric
1	No facade		
2	Flushed		
3	0 mm		
4	100 mm		

5	600 mm		

8.3 The 3D Geometry of the Test Room

A 3D geometry of the test room (Fig. 6) was generated using the program Autodesk® CAD program and imported into Autodesk® CFD software for analysis. The length of the test room is 4000 millimetres with a width of 3000 millimetres. Both of the windows at windward and leeward side are 1126 x 1100 (L x W). The height of the test room is 2800 millimetres.

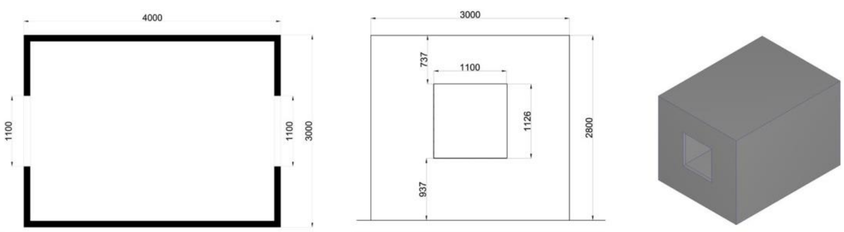


Figure 6. Plan, front elevation and isometric of the test room.

9. Results and Discussions

The airflow characteristics inside the test room, with different configurations of the façade, as a way to introduce natural ventilation was analysed by means of CFD analysis. In the visual analysis, air flow in the room is shown with the help of vectors and corresponds to actual indoor air flow exchange. From the results, I have found the following:

- In Study 1 (control room), the wind velocity is constant until it exits at the leeward side of the room, in which due to pressure differences, the velocity decreases (Fig.7). From the visualization (Fig. 8), the airflow distribution is evenly distributed.

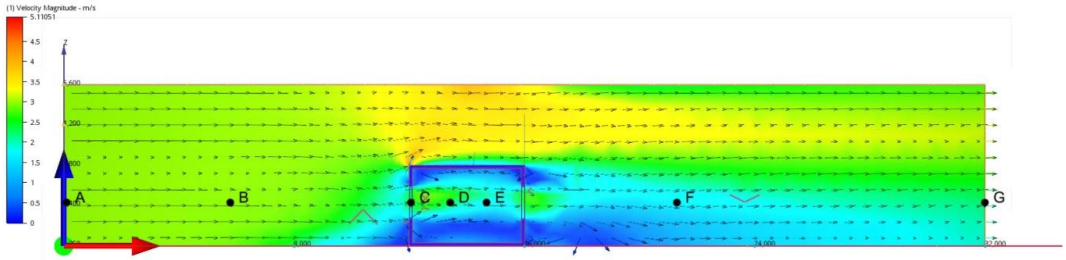


Figure 7. Velocity Vectors along the x/y plane with no *Wind Boy* applied to the window

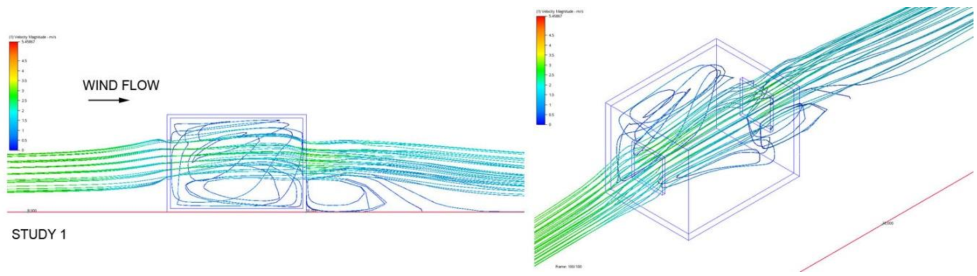


Figure 8. Velocity traces for the test room with no façade

- In Study 2, the wind velocity drastically decreases at point C due to the presence of the flushed *Wind Boy* façade. The velocity gradually increases at point D and continues to drop at the leeward side to pressure differences (Fig.9). From the visualization Fig. 10, this configuration has the highest velocity output of 4.5 m/s at point *x=1234.1, y=4500, z=1456*.

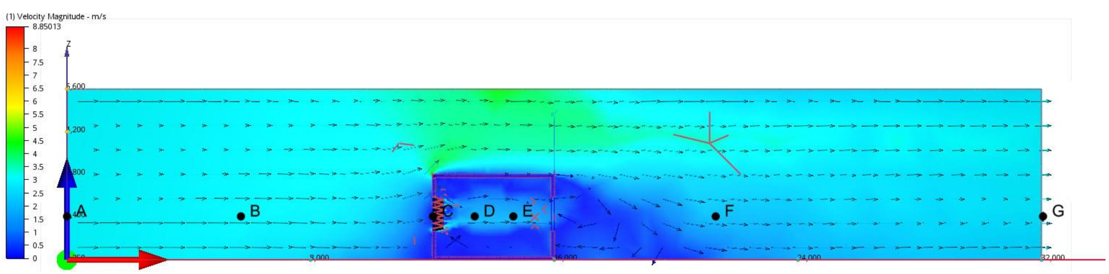


Figure 9. Velocity Vectors along the x/y plane with *Wind Boy* flushed the window.

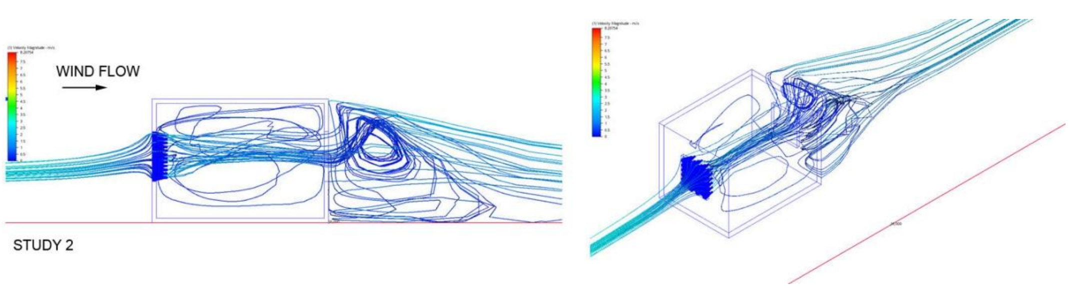


Figure 10. Velocity Traces for the test room with *Wind Boy* flushed into the window.

➢ In Study 3, where the façade is at 0 mm from the window, there is a high increase of incoming wind velocity upon entering the test room. There is a sudden drop in velocity in points D and E and a gradual increase of the air velocity upon exit at the leeward side of the test room (Fig. 11). From the visualization shown in Fig. 12, there is a huge amount of air distribution inside the test room. This configuration distance resulted in the second highest velocity output of the experiment at 3.5 m/s at point *x=1200, y=4500, z=1456*.

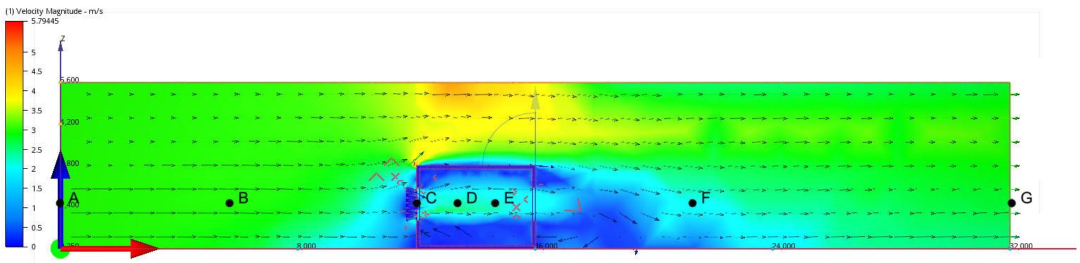


Figure 11. Velocity Vectors along the x/y plane with *Wind Boy* at 0 mm from the window.

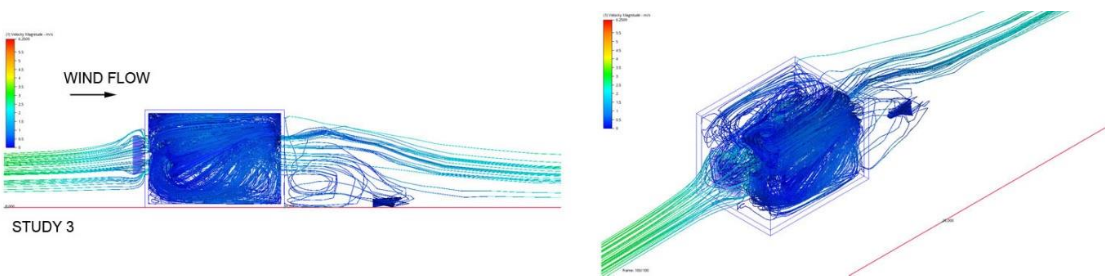


Figure 12. Velocity Traces for the test room with *Wind Boy* at 0 mm from the window.

➢ In Study 4, air flow velocity was reduced upon entering the façade at point C. At this point the airflow decreased gradually due to the different pressure variables and continues to increase upon exit at the leeward side of the window (Fig. 13). From the visualization (Fig. 14) this configuration resulted in the lowest airflow velocity at 2.3 m/s at point *x=11900, y=4500, z=1456*.

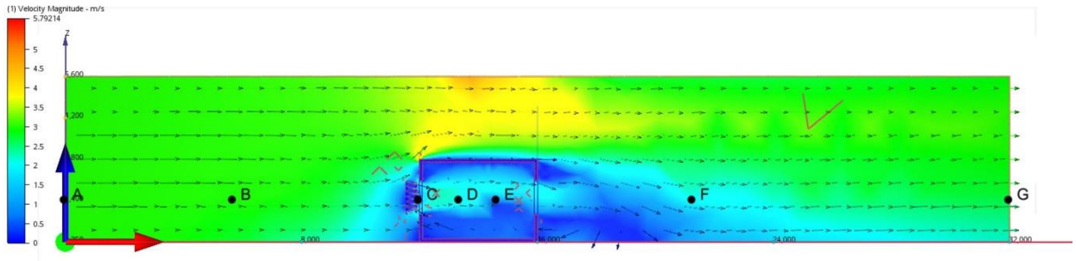


Figure 13. Velocity Vectors along the x/y plane with *Wind Boy* at 100 mm from the window.

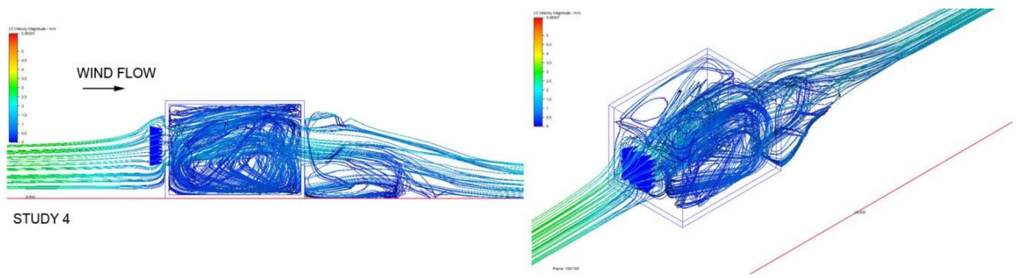


Figure 14. Velocity Traces for the test room with *Wind Boy* at 100 mm from the window.

- In Study 5, airflow velocity reduced dramatically upon entering point C. The descending velocity airflow continues until it began to exit at the leeward side of the room (Fig. 15). From the visual analysis (Fig. 16), this configuration distance resulted in the third highest velocity output at 3.2 m/s at point *x=11370, y=4500, z=1456*.

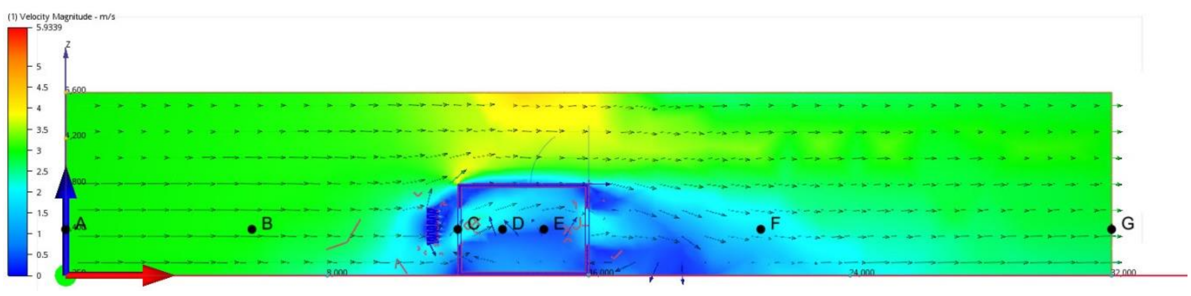


Figure 15. Velocity Vectors along the x/y plane with *Wind Boy* at 600 mm from the window.

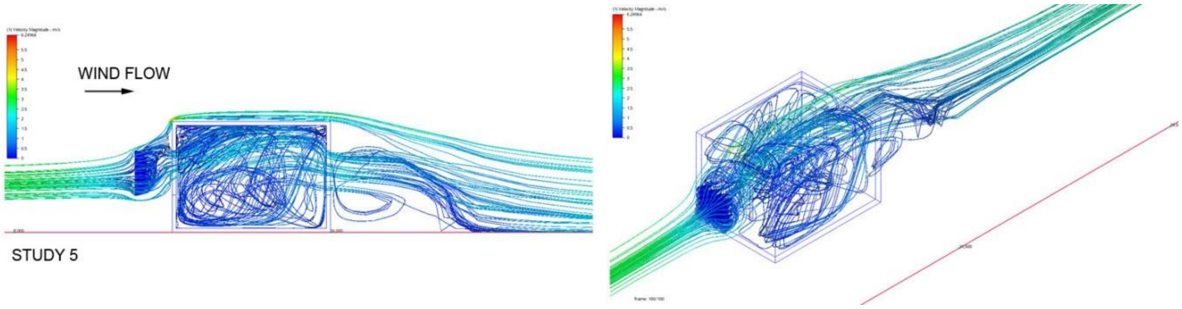


Figure 16. Velocity Traces for the test room with *Wind Boy* at 600 mm from the window.

From the given results stated above it is apparent that the indoor air flow and distribution was influenced by the location of the wind boy façade system. The analysis also showed the efficiency of cross ventilation as opposed to single sided ventilation in a room. Furthermore, the results revealed that the location of Wind Boy resulted to different characteristic air flow patterns. Different airflow rates into the test room could be anticipated whenever the location or distance of Wind Boy is mounted.

10. Conclusions and Thesis Statements

In this study, Computational Fluid Dynamic (CFD) software was used to predict the airflow inside a test room with a wind induced façade system. The investigation measured the distribution of air velocity and airflow distribution for four different façade configurations. As a consequence of my investigation, I have come to the following conclusions:

- The simulation results indicate that natural ventilation, with the required driving force, can have optimal mode and maximum wind circulation in the interior space. However, the application and distance of the façade can have an over-all effect on the internal airflow and distribution inside the room. This is evident from the graph shown in Fig. 17 and Fig. 18. In Fig. 17, when the façade is located at 100 mm distance between the building façade windows, there is a very minimal change in the maximum velocity that the system can deliver in terms of wind velocity.

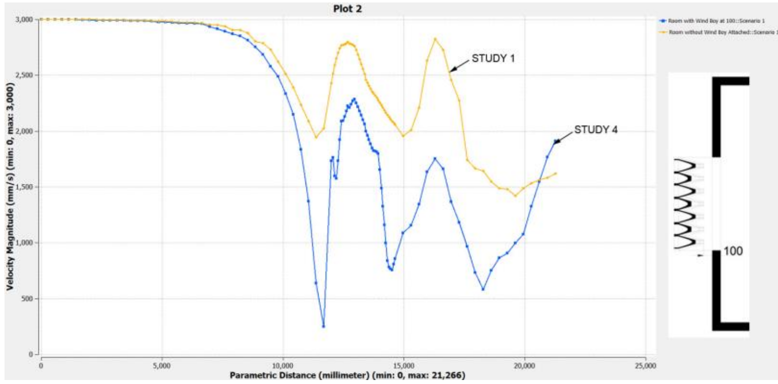


Figure 17. The Velocity trend between the control room and *Wind Boy* façade at 100 mm distance.

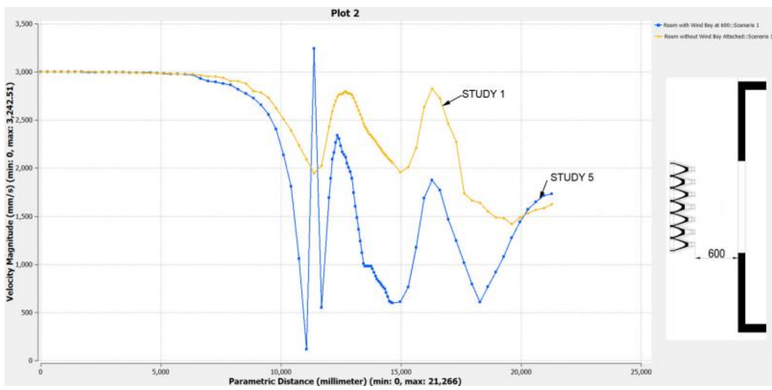


Figure 18. The Velocity trend between the control room and *Wind Boy* façade at 600 mm distance.

- ➢ The distance between the *Wind Boy* and façade of the room had an effect on the internal airflow velocity, direction as well as the air distribution inside the room. The velocity output of *Wind Boy* was drastically reduced if it is farthest from the façade. This analysis can be seen in the summary of the velocity trend magnitude plot (Fig. 19).

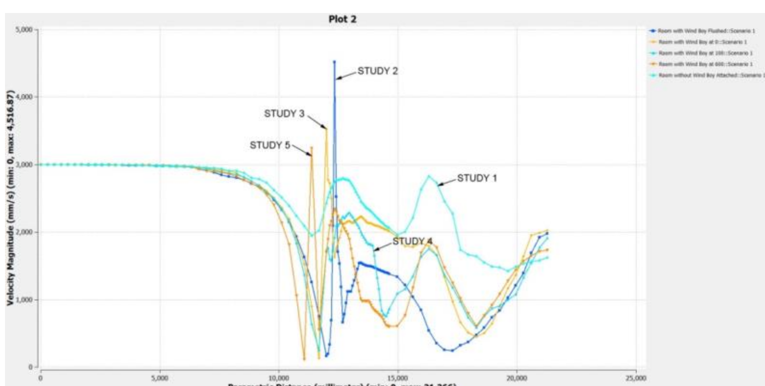


Figure 19. Summary of the Velocity Trend Magnitude Plot with the test room simulation.

- From this investigation, the façade with the *Wind Boy* at 0 mm (Study 3) from the windward window had the highest airflow distribution. Therefore, by integrating an evaporative cooling system, this façade configuration has the ability to improve thermal conditions through airflow dispersion as shown in Figure 20.

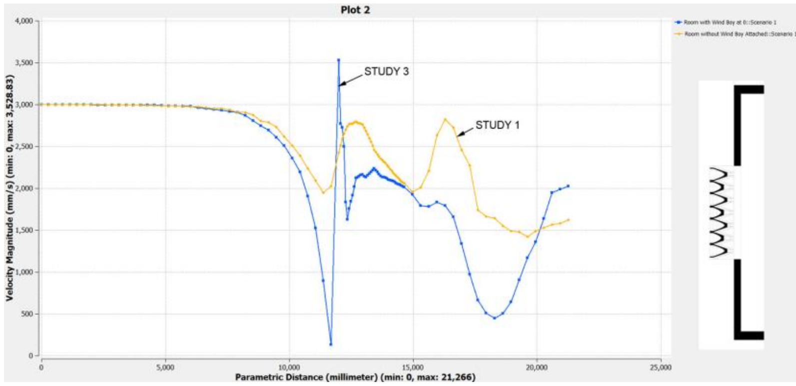


Figure 20. The Velocity trend between the control room and *Wind Boy* façade at 0 mm distance.

- The façade configuration with the facade flushed from the windward window resulted in the highest velocity output of Wind Boy. Due to this high velocity output, this alignment output can be used to integrate a system that can harness wind energy (Fig. 21).

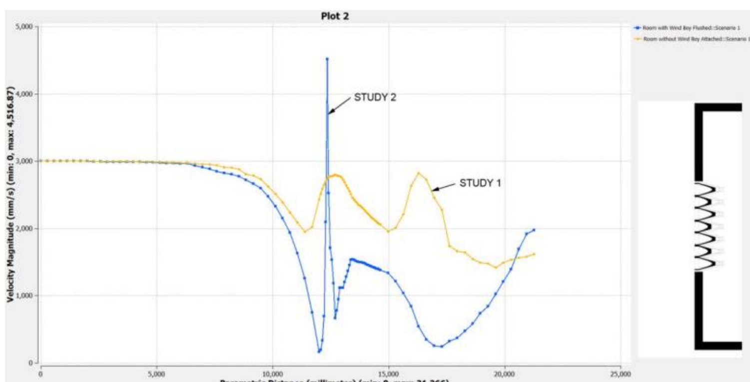


Figure 21. The Velocity trend between the control room and flushed *Wind Boy* façade.

Finally, this study was carried out to explore the fundamental connection between building façade and natural ventilation, so as to make the best use of natural wind resources. As designers and architects, we must further explore natural ventilation as the key element in sustaining the built environment. With suitable combinations of distance and location, the ventilation rate can therefore be achieved.