Evaluating the Efficiency of Different Cover Forms of the Large Spans in Flowers and Plant Exhibitions Based on the Natural Ventilation System in a Moderate and Humid Climate.

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Abstract

Deciding the roof type with a large ventilation spans for uses in the flower and plant exhibitions that can operate beyond the exhibition space functions as it can provide a desirable climate for the growth of its plants, it can be designed and enhanced according to the geographical site of it. Deciding and designing the roof form can prevent dissipations in energy and assets and develops a construction with high efficiency together with low costs of maintenance, only if it is done in an intelligent way. The independent variables in this research are the climate conditions, and form of the structure is considered as the intervening variables together with factors like the internal air current and sub climates and the levels of thermal comfort for individual occupants as the dependent variables. The aim of conducting this master thesis which is considered as an interdisciplinary research, is to reach for proper patterns in covering the ventilators in greenhouses with large spans by using the climate information of the north-Iran region. The main question of this research is the most efficient roof form in regard to natural ventilation in mild and humid climate condition? Research method the study is modeling and computer simulation in a way that they are evaluated with the prevalent forms of exhibitions and greenhouses with large vents in the terms of the external wind flow impacts and natural ventilation in their interior and analyzed by employing Computational Fluid Dynamics (CFD) and moving particle semi-implicit (MPS) simulation. Results indicate that form of a building has an obvious impact on the internal airflow and the curved forms have a better impact on the internal circulation of air. As an instance, in the convex geometries, the airflow speed rate drops in the center of the construction while in the concave geometries it is quite the opposite as the speed is reduced around the sidewalls of the construction and the thermal comfort becomes a different point along with natural ventilation.

Keywords: Exhibition Roof, Geometrical Form, Natural Ventilation, Computational Fluid Dynamics (CFD), Thermal Comfort.

1. Introduction

One of the most important issues in the greenhouses with large spans is to develop and control suitable conditions for the ventilation. According to the research (Baeza, E. J. et al. 2007), the best way for cooling the greenhouse is to employ natural ventilation which should work along with a mix of efficient air exchange in order to discharge the high-temperature air that is done by a specific desirable condition under the roofing of greenhouse. The form of roofing, number and placement location of ventilator spans has a noticeable impact on the improvement of the air flow and the possibility of developing natural ventilation. There are a variety of options for deciding different geometries for the roof of the greenhouses with large ventilation spans. The geometrical potentials for each of these roof types regarding the efficient feedback compared to the natural flow of the wind according to the necessity of efficiency and points revolving the sustainability in planning and construction of such buildings. According to (Bartzanas, et al. 2004) since most of the greenhouses in the world employ natural ventilation in order to cool down the greenhouse during the hot season of the year and to absorb the humidity of the air during the cold seasons and also to provide carbon dioxides from the fresh outside air. For the greenhouses with broad and geometrical shapes with low heights, the difference between the intake shutters and exhaust pop-up vent should be increased for the ventilation to work well (Perén, J. I., et al. 2016). Type of the climate is a decisive factor in choosing the geometrical shape of the ceiling for an enhanced ventilation. As an instance, for the case of moderate and humid north-Iran climate due to the comparatively high humidity of the air which is considered

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as a perfect climate for agriculture in Koppen-Geiger classification, and the possibility of analysis and evaluations over deciding the type of ceiling geometry by computational methods and simulations. The main question of this research is the impact of wind on the roofing shell with the form of a greenhouse with large spans in a temperate and humid climate. According to the present concerns on the topics related to sustainability and also by acknowledging the scarcity of energy sources, in order to construct a sustainable building certain specification of the construction site climate and conditions should be simulated toward the issues of ventilation, etc., to avoid energy dissipation and unrecoverable damages to the environment. According to the developments in technology and computer simulations through the past decades, observation has been made on greenhouses with wide spans as the wind-tunnel together with manual experimentations were used for this purpose in the past. With the use of computational fluid dynamic (CFD) methods we can simulate the function of wind under the ceiling. We can evaluate the conditions that occur under the ceiling in different times of the year by employing these proven methods and predict some facilities to supply in regard to the placement of pop-up ventilator spans together with their number and size in order to identify the frames that brings the best feedback in the ventilation process. The applied points in the simulations include the relocation of heat and airflow and thermal comfort for human beings and plants.

1.1. Literature Review

Different studies are conducted on the subject of the windflaw in the interior spaces with wide spans, including the work of Mr. (Ameer, S. Et al, 2016) which inspected different forms of ceilings and their functions toward the distribution of interior air flow in the scale of small urban buildings. A number of five ceiling types are evaluated in this research: Flat, pitched or gabled roofs with different heights together with shelving curved roofs, the wind speed potential in developing natural ventilation under the roofs was analyzed in the different type of the roofs as the final results for the gabled roofs with different heights were compared with the ASHRAE and CIBSE standards and it is nominated as the best form.

Another issue that greenhouses with wide spans would face is the correct position of the pop-up ventilators, in his research (Khaoua. S, 2006) on the subject of locating ventilator pop-ups in front or opposite to the wind and comparing the efficiency of the mentioned methods for an external wind with a 1 mile per second (1 m/s) and the weather temperature of 30 degrees centigrade the ventilation rates were calculated accordingly between 9 to 26.5 for the pop-up ventilator spans facing the wind and 12.7 to 3.7 for the spans opposite to the wind. Although, according to (Bartza-nas et al. 2004) it indicates that the best ventilation rates do not necessarily signify the best function in the greenhouse.

According to the research of (Kim et al, 2010), the efficiency of ventilation in surrounded spaces depends on other factors including currents of the external wind, type, and height of the pop-up ventilator spans. On the subject of singularity or plurality for the number of pop-up spans in the greenhouses, in (Rico- Garcia, 2006), researchers concluded that ventilating a greenhouse with a tall ceiling and long windows is better than those greenhouses which include numerous ceiling spans, and the fact that the role of air temperature on flowing the air and provide natural ventilation raises in hot climate conditions altogether with the air transfer rates.

In greenhouses with broad intake spans, environmental factors should be provided in desirable for the plants in the terms of temperature and humidity in addition to the thermal welfare of the visitors. In a study by (Roy, J. C., et al. 2008), a research was made on the temperature and humidity level on the surface of the plants by using Computational Fluid Dynamics (CFD).

A major number of studies regarding the use of CFD in architecture is related to the buildings with medium scales and in order to simulate the mutual ventilation between them, as the research of (Ramponi. R, 2012) has a focus on various different parameters including: development of the calculation field, clarity in the development of network calculations, turbulent kinetic energy after the border of atmospheric layers, values of each simulation.

If we pay to more detail to the impacts of airflow in the interior spaces of a greenhouse and a plants exhibition place with a broad intake spans, we should consider the existence of trees with different heights and their impact on the internal flow of the air. In the research of (Endalew. A., 2009), the impact of the wind speed on the trees by computer simulation together with real simulations in smaller scales in the wind tunnel. Results indicated that growth in density of the trees crest would decrease the airflow speed in the lower parts of the tree.

An important topic of the analysis is to survey a combination of transferential energy simulation in the building and the interior airflow. In (Zhai, Z. et al. 2004), in order to reach a natural convection in the building, a grid pattern with the distance of 0.005 meter and the distance of 0.1 meter for forced convection of the interior air.

Only a few of studies are done about the applications of (CFD) in the context of architecture and the work of (Kaijima, S., Bouffanais, R., Willcox, K., & Naidu, S. (2013) is one of the rare studies which is conducted by the architects regarding the connection between CFD and its application in architecture. This research uses a toolkit that facilitates the CFD illustrations for the architects, which can help to convert the exports from Fluent software together with Rhino 3D modeling software into sets of meaningful visual compositions for the architects. Another study has an

architectural approach this is case (Schmid, F., Burrell, G. 2004) that analyzed the thermal welfare under the roof of a public building with a broad air ventilator and a conical ceiling.
The related studies regarding the relationship between Computational Fluid Dynamics and architecture are categorized with the following topics, spaces with broad ventilator spans, analysis of the wind flow on the bodies of ceiling covers, using CFD in the interior of regular buildings with square geometry, researching about the location and dimensions of the pop-ups by using wind catcher and the gabled or flat floors and defying the type of pop-ups. Related studies with the greenhouses include the analysis on providing natural ventilation in greenhouses including the articles on analyzing natural ventilations in greenhouses with a long rectangular and multi-ventilator spans (Baeza, E., et al, 2007), or to survey the impacts of temperature on the natural ventilation of the greenhouse in the hot climate conditions (Rico-garcia, E., 2008), the impact of placing ventilators in the wind direction in order to naturally ventilate the greenhouses is studied by (Bartzanas, T., 2004) using Computational Fluid Dynamics (CFD), or the analysis from the viewpoint of agricultural engineers on the natural efficiency of the greenhouses with two ventilator spans is included in (Pontikakis, C., 2006) some studies have a more comprehensive revision on the studies regarding the greenhouses through simulating the airflow current, including (De la Torre-Gea, G, 2011). The impact of wind speed on the natural ventilation in the terms of pop-up ventilators on the ceiling and sidewalls of the greenhouses with regular spans are analyzed in the work of (Molina-Aiz, F., and et al. 2004). Results indicated that the cold dense air with the minimum speed of $1ms^{-1}$ will enter from the pop-up frames in the sidewalls and will be exhausted through the ceiling frames. Simulations show that the highest speed occurs near the side ventilators and the lowest speed is perceived in the center of glasshouses, and a rate between 75% to 85% is extracted for the reduction of air speed from the intake in sides to the final exhaust from the ceiling vents. Also the air speed in the opposite of the wind direction stays on the value of ms^{-1} 0.3 in a constant degree on all of the simulation process.
It is included in the results of Bartok's research that wind plays the most important role in natural ventilation, as the 80% of ventilation is done by a 1 meter per second wind. By moving underneath the ceiling, the wind would develop a vacuum and takes out the hot air by suction into the vents. If there are pop-up frames on the sidewalls of the greenhouse cool and fresh water will be replaced. If the side pop-ups are closed, cold air would enter through the ceiling cent and the warm air will be exhausted from its above (Bartok Jr, J. W & Aldrich, R. A, 1983).
None of the surveyed studies, had a focus on the forms of ceilings with large spans and different forms including known geometrical shapes to free undiscovered forms and considering too many parameters simultaneously, e.g. dimension of the pop-up vents and their total number in addition to a better location for the vents on monolith surfaces were not considered which we will bring into the scope of this research. We also have to consider the thermal welfare of the visitors who spend time in the greenhouse beyond the thermal and cryogenic welfare of the plants in the exhibition itself through these simulations and case studies. The issue of thermal welfare is considered in simulations, according to ASHRAE 55-2004 standard, the definition of thermal welfare is mental condition which explains the satisfaction with the thermal environment and it is evaluated subjectively - by the mind.This welfare includes environmental factors including temperature, radiant heating, relative humidity, the speed of air in the environment and the levels of human activity and the type of fields in the environment are some of the impactful factors on the sense of welfare individuals. A suitable condition is provided in the cold days, due to the temperature difference between two sides of the greenhouse walls.But due to the minute difference between the interior and exterior air temperature (between 5 and 10c) during the summer, the condition for the Buoyancy force effect is not provided, as no research has been done on the synthesis of these two type of thermal welfares in relation with their forms, ventilator drawers, et. In a broad span of a glasshouse roof. There are a variety of choices in the types of fluid simulation softwares and for quick implementation and meshing of the architectural volumes, the Autodesk CFD software was selected which has a universal credit and numerous construction and research projects are done by it. To qualify the results of the renowned and powerful ANSYS Fluent 7.18 was employed.

2. Research Method

The modelling analysis and simulation methods were employed in this research to evaluate the function of ceiling cover forms of the greenhouse with different geometrical shapes. Since routing the flow of air in the injective correspondence and analyzing it with modeling a set of various regular geometrical forms for covering the ceiling with broad ventilator spans based on circular and triangular plans and considering the climate conditions in temperate and humid regions with the use of computational fluid dynamic (CFD) as it is calculated by airflow current and fluids simulation softwares. The fundamental formulas that are employed in simulating the airflow are listed below:
Three dimensional simulation formulas that describe the moving phenomena for constant currents in free stimulant is as follow:

$$\frac{\partial(U\Phi)}{\partial x}+\frac{\partial(V\Phi)}{\partial y}+\frac{\partial(W\Phi)}{\partial z}=\Gamma\nabla^{2}\Phi+S_{\Phi}$$

Equation 1.

In the formula 1.ɸ represents the focus of air transfer in a dimensionless form, it includes three momentum equations (Navier-Stokes equations) and the equations for saving energy.

Continuity equation:
Continuity is an equation in the context of physics which describes the transport of a conserved quantity. Since matter, energy, momentum and other natural quantities are conserved in their specific desirable conditions, a large list of phenomena is physics can be described by continuity equations. This equation intrigued the development of specific [heat] transfer equations namely the Boltzmann equation and Navier-Stokes equation (Pedlosky, Joseph. 1987).

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_j) = 0$$

Equation 2.

Momentum equation (Newton's second law of motion)
It describes the sum of external forces which impacts the particles of liquid and it is equal to its mass and the accelerators of its ingredients.

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = \frac{\partial}{\partial x_j}\left[-p\delta_{ij} + \mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \rho g_i$$

Equation 3.

Energy equation (First law of Thermodynamics)
It describes the energy transformation rates of the fluid particle energy that is equal to its mass and the accelerators of its particles together with the amount of work that is done.

$$\frac{\partial}{\partial t}(\rho C_p T) + \frac{\partial}{\partial x_j}(\rho u_j C_p T) - \frac{\partial}{\partial x_j}\left(\lambda \frac{\partial T}{\partial x_j}\right) = s_T$$

Equation 4.

Movement of fluids (gasses or liquids) are presented with partial differential equation (PDE) which reflects the theory of conservation of mass, momentum and energy. CFD is the art of transforming differential equations with partial derivations with a series of algebraic equations which makes it possible for the computer to solve the problems; it is actually provider of quality and in some instances the quality for the anticipation in air movements with: PDE mathematical models, numerical methods (presentation techniques and solutions), software tools (solvers and postproduction services). CFD makes possible the execution of numerical experimentations in a virtual laboratory space for the fluids (Anderson, J. D., 1995).
The extra necessary equations for the Ɛ K- model is the standard chaotic current for simulation with the following form:

$$U_j \frac{\partial K}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(v + \frac{v_t}{\sigma_k}\right)\frac{\partial K}{\partial x_j}\right] + v_t\left[\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j}\right] - \varepsilon$$

$$U_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(v + \frac{v_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_1 \frac{\varepsilon}{k} v_t\left[\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j}\right] - C_2 \frac{\varepsilon^2}{k}$$

Equation 5.

In the above equations, $V_t$systematic chaos or Whirlpool Viscosity which is calculated from the following equation.

$$v_t = {}^{\mu_t}/_{\rho}$$

Equation 6.

Viscosity is the internal chaos and it is described as follow:

$$\mu_t = \frac{C\mu \ \rho k^2}{\varepsilon}$$

Equation 7.

The equations include five adjustable constants including: C_1 ،C_2 ،$C\mu$ ،σ_k ،σ_ε. These constants are taken from contained data for a wide spectrum of chaotic current, their values are as follow:
C_1= 1.44, C_2=1.92, $C\mu$= 0.09, σ_k= 1, σ_ε= 1.3

The reference for all of the simulations is the written codes in Autodesk CFD software, 2018 version. To ensure of the final exporting results, all of the simulations were done with ANSYS Fluent software, version 18 and the resulted were studied. By developing various scenarios in different weather conditions, we tried to simulate the climate conditions in order to reach for results that are more close to the reality. A number of 10 forms were 3d-modeled at first and the location of ventilator spans entries and exhausts were regarded in a two dimensional method for each section of a form by applying the climate condition of temperate and humid spaces, their internal airflow currents are were evaluated. And the important factor in the ventilation process is considered as the thermal welfare of plants and human beings since we are in the situation of an exhibition which has visitors on different days of the year, as the analysis were performed separately for the winters and summers. Two dimensional models were considered in the central layers of the exhibition floor and the glass sidewalls, and finally the current is simulated by Autodesk CFD. A re-modelling was done in Design modeler software environment in order to qualify the modeling and to develop border layers by triangular meshing and even quad meshing in order to reach a more sustainable during solving steady currents and the consolidated mesh map includes a rate between 200 and 300 rounds of modelling. In the surrounding places to the air intake or exhaust frames, and with the higher density in the central layers, Meshing was done by ANSYS environment and the simulations was performed by ANSYS Fluent with K-epsilon with two formulas in a pressure-based method.

3. Data Collection

The first topic is to discover about the climate condition of the research area (Lahijan city). More than one sources were used to take geographical data including the following factors:

- Maximum and minimum temperature (°C)
- Field of sight (km)
- Air pressure (mb)
- Percentage of cloudy weather possibility (%)
- Humidity in percentage (%)
- Maximum and minimum wind speed (m/s)
- Average storm frequency
- Number of foggy days
- Per capita for the rainy and cloudy days
- Snowfall rates (cm)
- Rainfall rates (Mm)
- Ultra Violet (UV) rates.

Description of the weather in *Lahijan*

The dry season of the year is not persistent (for near a month during June) and the rainfalls are present in most of the cases.

Rainfalls are not in the same level for all regions in the province and the freezing days were scarce and scattered as the temperature barely reaches a -1 degrees in centigrade. According to the chart of windflow in Rasht, it is dominant in the west direction which also include northwest in some of the seasons in the year. Although in the months of June and July the air humidity develops difficult sultry conditions which would generally be broken with summer rainfalls in the north and a desirable thermal condition will be replaced.

Table 1
Climate chart of *Lahijan*. (Source: *Lahijan* synoptic station located in *Falahat* garden, 2016).

2 ms^{-1}	Minimum average annual air speed	17.1°c	Annual Temperature average
3 ms^{-1}	Annual average of air speed	22,1°c	Average of annual maximum temperature
87%	Maximum annual humidity in October	12.2°c	Average of annual minimum temperature
56%	Minimum annual humidity in July	9.9°c	Difference between the minimum and maximum temperature through the year
75%	Average Annual air humidity	1.1°c	Average temperature in the coldest month of year (January)
102460 pa	Maximum annual air pressure in November	33.9°c	The average temperature in the warmest month of the year (August)
100970 pa	Minimum annual air pressure in July	20.3°c	Average annual maximum air velocity in spring
101635 Pa	Average annual air pressure in July	26.6°c	Average annual maximum air speed in summer
14.8Mj/m^2	Annual average of sun radiation	13.9°c	Average annual maximum air speed in autumn
24.6Mj/m^2	Maximum annual sun radiation in July	7.6°c	Average annual maximum air speed in winter
6.2Mj/m^2	Maximum Annual Radiation of the Sun in december	4 ms^{-1}	Average annual maximum air speed

4. Studied Models

Different greenhouses and exhibition spaces for plants and flowers are constructed in the world with different forms and in different climates throughout the history, each of them is planned and constructed by famous architects with their own specifications, this levels of experience can act as a pattern for further studies. The modelled forms are developed based on the form of these greenhouses together with different geometries for a better comparison.

6 Modelling is based on the previous constructed forms of greenhouse or spaces with flower and plant exhibition purposes and two other samples are different form than these six types which are introduced in order to test the function of internal airflow pattern.

The ventilator of these six models were fixed and a number of 6 air intake shutters were considered on the sidewalls and one exhaust air vent is designed on the top of each models. The simulation conditions which are listed in the tables 4, 5 and 6 are applied equally for all of these models.

Table 2
Studied Cases. (Source: www.dezeen.com/tag/greenhouses)

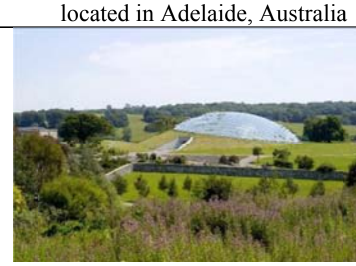
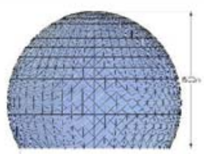
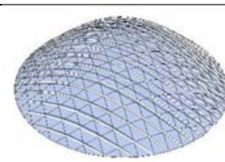
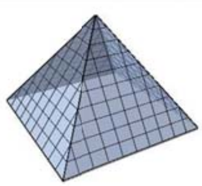
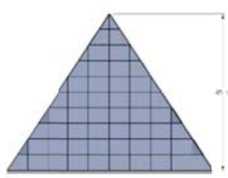
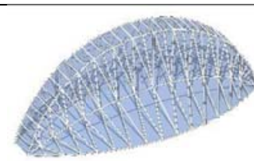
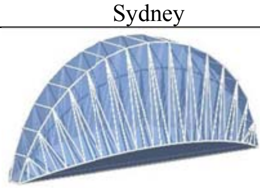
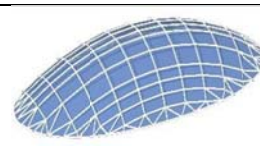
 Fig. 1: Muttart Conservatory in Edmonton	 Fig. 2: Brisbane Botanic Gardens Mount Coot-tha-Australia	 Fig. 3: Adelaide Botanical Garden, located in Adelaide, Australia
 Fig. 4: Royal Botanic Gardens, Kew: Davies Alpine House, London, UK	 Fig. 5: Bolla, Renzo Piano; Porto Antico Genoa	 Fig. 6: Great Glasshouse, Norman Foster

Table. 3
Illustrated model based on the introduced works.

 A third of a sphere similar to the Bola building	 Front plan of the sphere with a 20 meters wide intake spans	 Imperfect cone	 Front plan with a 20 meters wide intake spans
 The anticlastic form	 Front plan with a 20 meters wide spans and 6 meters height for the intake	 A section of donut-geometry, similar to Brisbane	 Front plan with a 20 meters wide intake spans
 pyramid with a square based similar to the greenhouse in Sydney	 Front plan with a 20 meters wide	 A geometry similar to the Adelaide's greenhouse	 Front plan with a 20 meters wide intake spans
 Geometry similar to the Alpine greenhouse	 Front plan with a 20 meters wide ınd 5 meters height for the intake	 A plane cut from a donut geometry, similar to the glasshouse	 Front plan with a 20 meters wide and 5 meters height for the intake

6 Modelling is based on the previous constructed forms of greenhouse or spaces with flower and plant exhibition purposes and two other samples are different form than these six types which are introduced in order to test the function of internal airflow pattern.
The ventilator of these six models were fixed and a number of 6 air intake shutters were considered on the sidewalls and one exhaust air vent is designed on the top of each models. The simulation conditions which are listed in the tables 4, 5 and 6 are applied equally for all of these models.

5. Simulation Scenarios

The following scenarios were used in the simulations:
1.Considering the hottest day of the summer for evaluating the best way of cooling the interior in order to reach for thermal comfort.
2.Considering the coldest time of the winter for analyzing the best approach in heating the interior air in order to reach for thermal comfort together with the discharge of gasses that were produced by the plants.
Considered suppositions for the simulations are listed in the table below:

Table 4
Assumptions of simulation in summer and winter.

Volume Flow Rate	1500 m^3/min
Interior Temperature	19 °c(Summer)- 25 °c(Winter)
Surrounding environment	35 °c(Summer)- 3 °c(Winter)
6 Inlets	1.5m*1.5m
1 Outlet	2m*2m
Pressure	100970 pa

These assumptions are done based on the given climate conditions of Lahijan in the months of summer and simulations were done based on real modeling regarding the number and size of the ventilator spans. The following configurations are applied in all of the simulations:

Table. 5
Simulation settings based on Autodesk CFD software settings

Advection	ADV5 Modified Petrov-Galerkin
Iteration	200
Result Quantities	
	Velocity
	Pressure
	Temperature
	Density
	Scalar
	Wall Film Coefficient
	Thermal Comfort
	Wall Heat Flux
	Shear Stress
	Humidity
	Heat Transfe
Turbulence Model	K-Ɛ (2 eqn)
SST K-Omega	
Far Field TKE	0.01
Far field Omega	2

Table. 5 Configurations for simulation based on Autodesk CFD software. (Source: Authors)
Simulation parameters for the analyzed models are included in the following table:

Table. 6
Configurations for simulation of models based on Autodesk CFD software.

Inlet	
Volume Flow Rate	1500 m^3/min
Outlet	
Pressure	P=0pa
Humidity	56%
Elements	U Factor & Temperature
Concrete Floor	40cm thickness
Film Coefficient	1.2 w/m^2k
Reference Temperature	35°c (Summer scenario)- 3°c (Winter Scenario)
Glass	Double Glaze
Film Coefficient	3.5 w/m^2k
Reference Temperature	35°c (Summer scenario)- 3°c (Winter Scenario)
Human	
Total Heat Generation	60w

One of the most impacting topics on analysis the internal spaces according to the airflow is to consider the movements of air in the scale of time. The following equations clears the subject based on the air pressure balance theory.

$$N = \frac{60Q}{Vol}$$

Equation 8.

Since we should refer to fixed equations and formulas as the first step in all of the simulations in order to reach a subjective image and an estimation of the events that are going to occur. In the equation 9.It is the volume current of air ft3 per minute and Vol refers to the observation space.

$$Rp = \frac{ACPH * D * h}{60}$$

Equation 9.

The other proposed equation for the thermal comfort of users of a space is regarded in the terms of ventilation in the equation 6, R is the ventilation rate based on the number of people, Air change per hour (ACPH) is the measure of the air volume added to or removed from a space in an hour, D is the density of the crowd, h is the height of the ceiling. This equation is used in order to develop subjective space and it will also help for checking the exporting data from the software. These equations does not cover all of the phenomenon that happen in reality as the air-related dynamics and the distribution of temperature for a specific space, etc., and this is the main reason that we use the simulation and computational fluid dynamics (CFD).
Evaluating the point that which one of these forms the average internal airflow has a negative impact on the visitors who spend time in the exhibition is also an important criteria for evaluating the ceiling efficiency

Table 7
Evaluating the allowable wind speed for the visitors. (Source: Shane, F. 2011)

Condition	Wind condition	Extent of welfare
Sitting	Wind Velocity ≤ 3.9 m/s	Acceptable for moderate activities
Standing	Wind Velocity ≤ 6.1 m/s	Acceptable for walking, standing and other moderate movements.
Walking	Wind Velocity ≤ 8.3 m/s	Acceptable for walking, ongoing, and other strict activities.
Inconvenient	Wind Velocity > 8.3 m/s	Inacceptable for walking
Dangerous	Wind Velocity > 25 m/s	Dangerous for walking

The most important issue that is studied in this research is the conditions that the geometry of big buildings for the exhibitions provide the thermal welfare and the movement of air in the interior space, therefore, different geometries were studied.
The comparison between the simulated models are done based on the following parameters:

- Analysis pattern of the flow
- Speed of the internal airflow
- Level of air movement
- Air temperature
- PPD (Predicted Percentage of Dissatisfied people)
- MRT (Mean Radiant Temperature)
- PMV (Predicted Mean Vote)
- Humidity

6. Simulation and Results

All of the 8 models were simulated in equal conditions to be compared on the terms of changes in the weather temperature, speed of the wind and humidity together with thermal comfort and to analyze and compare different airflow currents. All of the exported data are under the shape of the diagram based on the standing position of the exhibition visitors.

Extracted results from the Anticlastic Modeled Greenhouse

In the anticlastic geometry, simulation is done with an exhaust vent with 3 in 3 meter dimensions is developed on the roof by considering six air intake shutters. Factors like levels of humidity in the surface of human standing, temperature levels, speed of the internal windflaw, internal airflow pattern and finally the Predicted Mean Vote (PMV) was evaluated in this simulation.

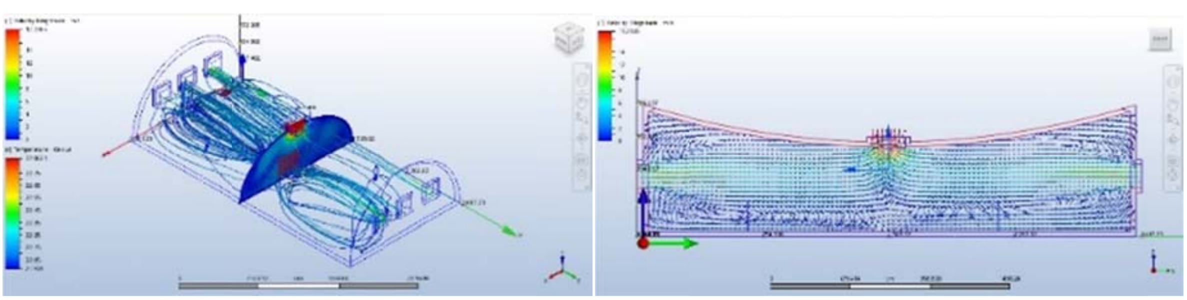
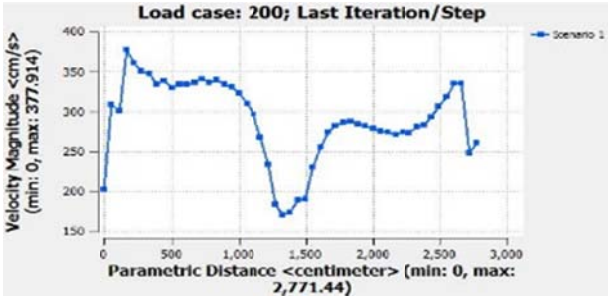


Fig. 7 and Fig. 8. Type of the current and the airflow pattern is observable on the right image while on the right image a section of the exhibition's length and the airspeed in the entrance and exhaust of the air is evident.



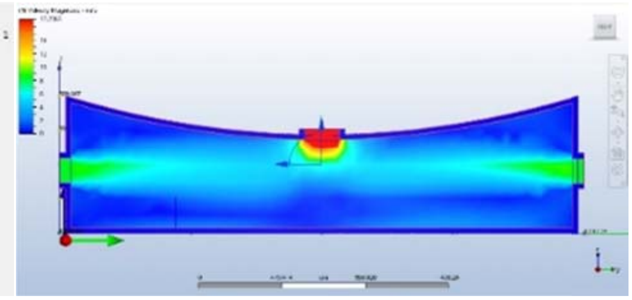
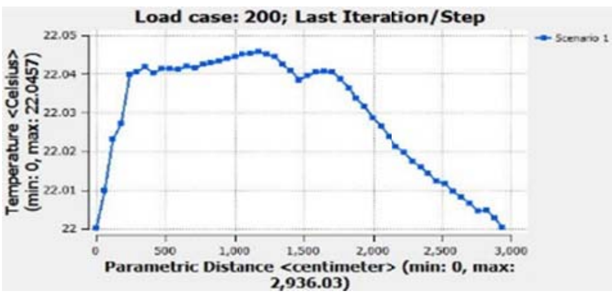


Fig. 9. and Fig. 10. diagram of the wind speed in the exhibition is shown in the left image and a section of the exhibition space length and the amount of air speed near the air intake and exhaust frames in the right.



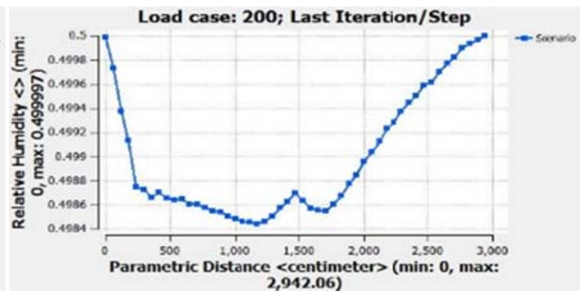
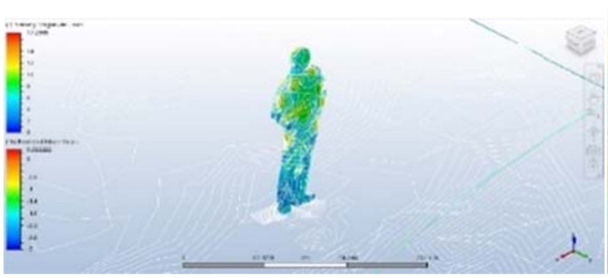


Fig. 11. and Fig. 12. Diagram of the fluctuations in the exhibition in the exhibition space is shown in the left image and the chart of changes in humidity is shown in the right image.



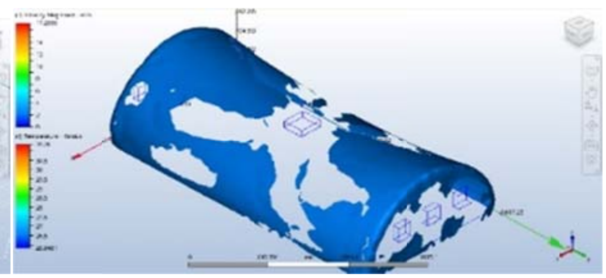
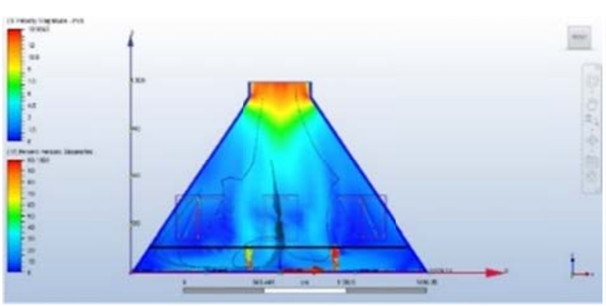


Fig. 13 and Fig. 14. PMV index of thermal welfare on the situated people in the exhibition in observable and on the right the pattern and temperature levels of the space is shown.

Extracted results from the cone greenhouse:

The internal airflow speed:

Evaluation of the internal airflow speed, temperature and humidity are applied on a 1.80 meter distance between the air intake frames in a diametric line.



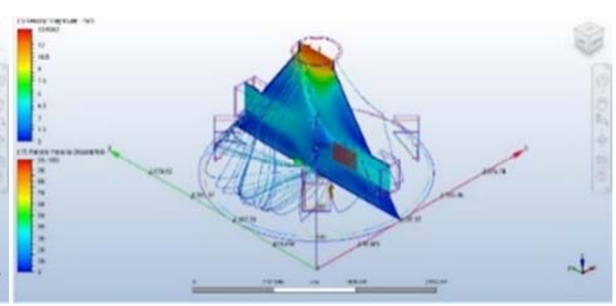


Fig 15 and Fig 16: Type and pattern of airflow is shown on the right while the airspeed flow rates are shown in the left image.

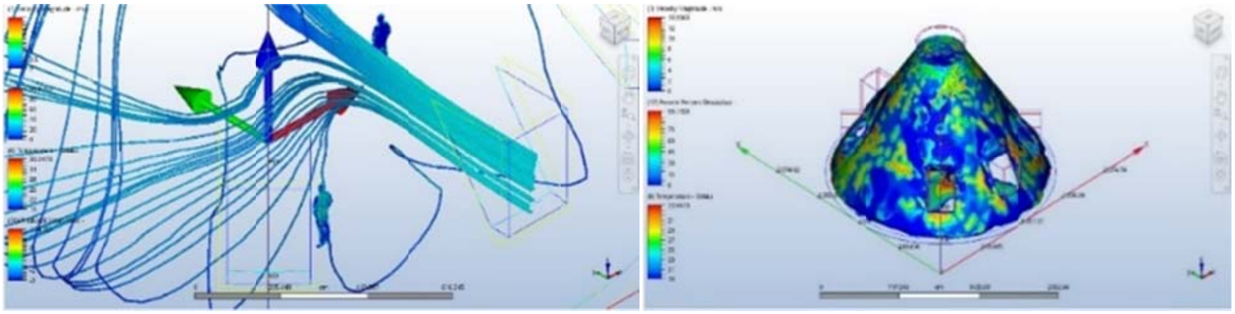


Fig. 17 and Fig 18. Airflow pattern and the extent of thermal comfort based on the PMV index is shown on the right image and the temperature dispersion in the environment is shown in the left image.

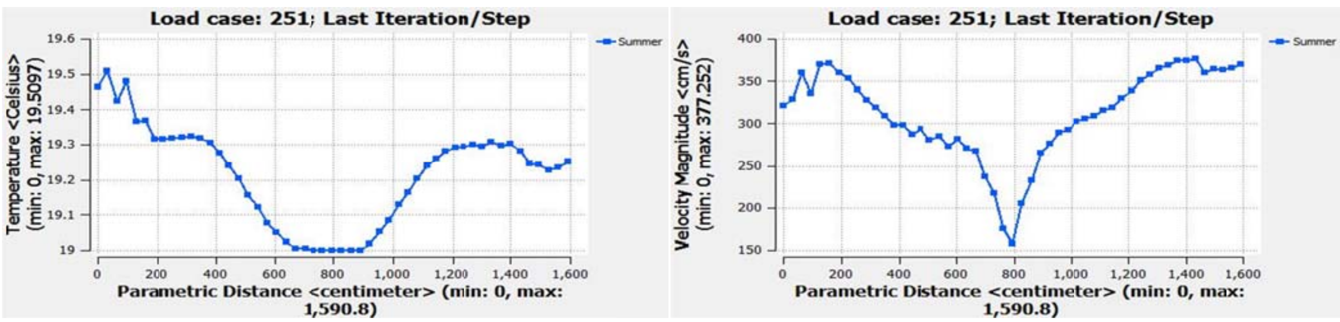


Fig 19 and Fig 20. Temperature pattern is evident on the 16 meters on the right image while the internal air speed is shown in the 16 meters.

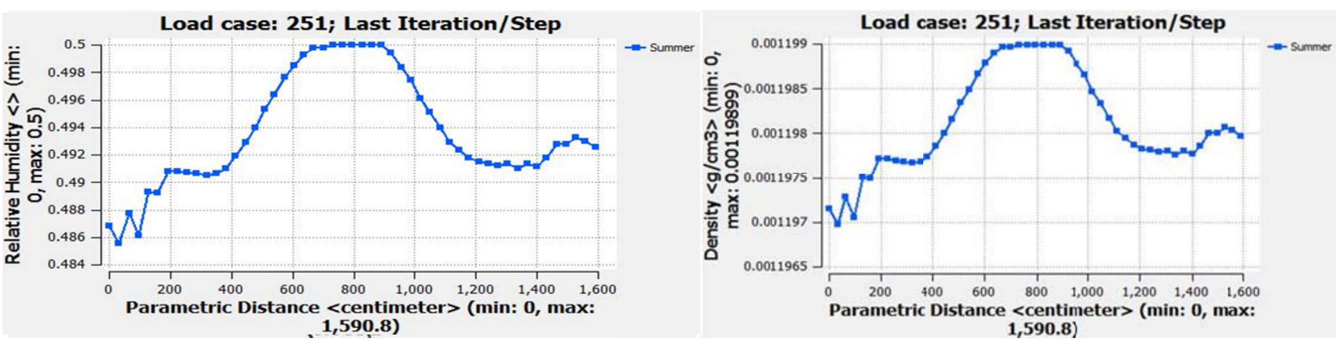


Fig. 21. and Fig. 22. The air density in the 16 meters is shown on the right image while the humidity rates of the internal air is shown on the section of the construction on the 16 meters of it.

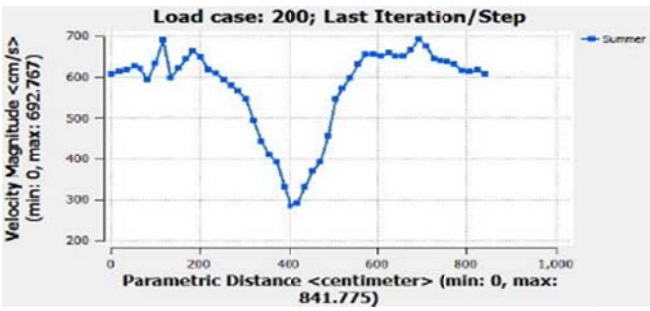
The air temperature stays fixed in the middle of the intake opening and only increases when it gets closer to the sidewalls due to the difference between the inside and outside temperature and by considering the heat temperature coefficient of the glass sidewalls. The internal airspeed pattern is decreasing from the air intake openings to the center of the construction and this change reaches a value of 2.5 meters. Patterns of the air density and humidity charts are reduced in a similar form when approaching the center of construction as the temperature and humidity is increased around the wide walls.

Extracted results from Adelaide greenhouse

This greenhouse was designed and constructed by Australian architect Guy Marone in Adelaide city in 1988. The weather and climate of Adelaide city is very similar to Lahijan city in a way that the maximum air temperature reaches for 30 centigrade over nights and the highest amounts of rainfalls reaches for 177 millimeters in September. In the greenhouses in a big-type like Adelaide greenhouse, with a long dimensions, the airflow pattern and density in the space is simulated with two perpendicular x and y planes according to the placement of ventilators in front of each other.

Table 8
Weather information of Adelaide city in 2006. (Source: en.climate-data.org)

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	22.1	22.1	20.1	16.9	14	11.7	10.8	11.6	13.1	15.6	18.2	20.3
Min. Temperature (°C)	15.7	15.7	14.3	11.7	9.6	7.6	6.9	7.4	8.4	10.2	12.3	14.3
Max. Temperature (°C)	28.5	28.6	26	22.2	18.5	15.8	14.8	15.8	17.9	21.1	24.2	26.4
Avg. Temperature (°F)	71.8	71.8	68.2	62.4	57.2	53.1	51.4	52.9	55.6	60.1	64.8	68.5
Min. Temperature (°F)	60.3	60.3	57.7	53.1	49.3	45.7	44.4	45.3	47.1	50.4	54.1	57.7
Max. Temperature (°F)	83.3	83.5	78.8	72.0	65.3	60.4	58.6	60.4	64.2	70.0	75.6	79.5
Precipitation / Rainfall (mm)	19	15	24	44	67	69	76	65	55	44	31	27



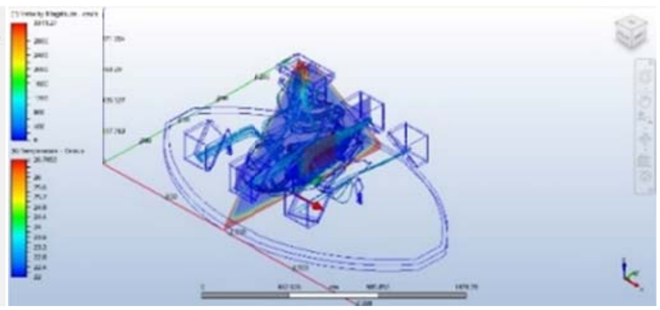
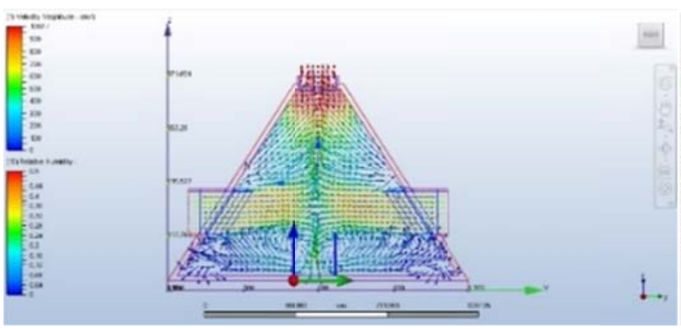


Fig. 23 and Fig. 24. Fluctuations in the air current speed in the 10 meter radius of the greenhouse is observable on the left while the type and pattern of the airflow current is shown in the right.



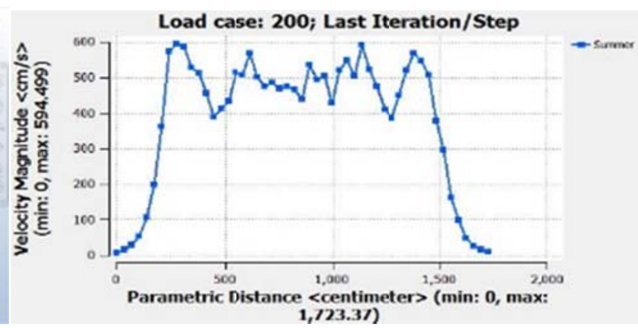
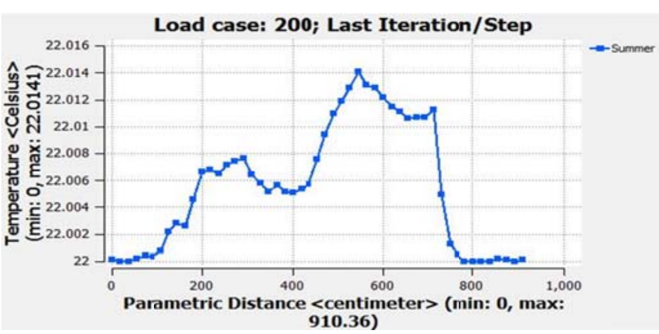


Fig. 25. and Fig. 26. The quality of air movement in the greenhouse is evident on the left while the air speed in the 20 meters space of the greenhouse is evident on the right.



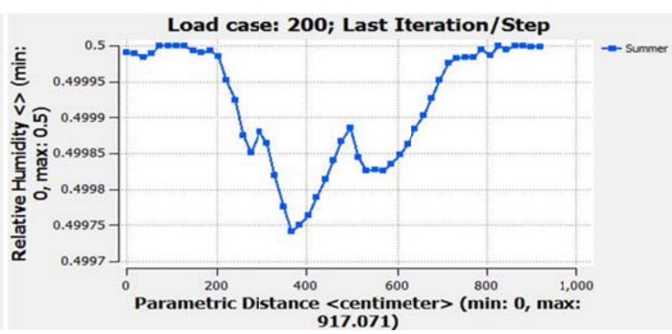


Fig. 27. and Fig. 28. Fluctuations in the temperature is shown on the right image while the rates of changes in the air humidity is shown on the right.

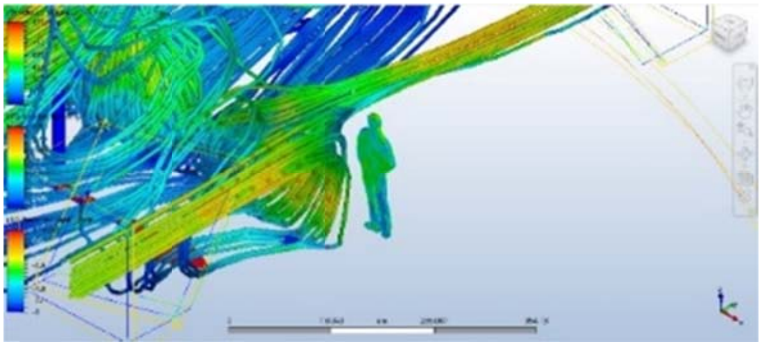


Fig. 29. T ıermal comfort of the people situated in the exhibition which is calculated based on the PMV index.

Extracted results from Alpine greenhouse:

Construction of Alpine plant exhibition space was done ir Kew, in the suburbs of London by the Wilkinson Air architecture groups in 2006. Kew has a weather similar to Lahijan but has a higher humidity rate of 80% in December and January.

Table 9
Weather information of London city in 2006. (Source: en.climate-data.org)

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	4.9	5	7.2	9.7	13.1	16.6	18.7	18.2	15.5	11.6	7.7	5.6
Min. Temperature (°C)	1.8	2	3.4	5.7	8.6	11.8	13.8	13.3	10.9	7.7	4.5	2.7
Max. Temperature (°C)	8	8.1	11	13.8	17.7	21.4	23.6	23.1	20.1	15.6	11	8.6
Avg. Temperature (°F)	40.8	41.0	45.0	49.5	55.6	61.9	65.7	64.8	59.9	52.9	45.9	42.1
Min. Temperature (°F)	35.2	35.6	38.1	42.3	47.5	53.2	56.8	55.9	51.6	45.9	40.1	36.9
Max. Temperature (°F)	46.4	46.6	51.8	56.8	63.9	70.5	74.5	73.6	68.2	60.1	51.8	47.5
Precipitation / Rainfall (mm)	56	39	46	45	49	50	48	53	56	60	61	58

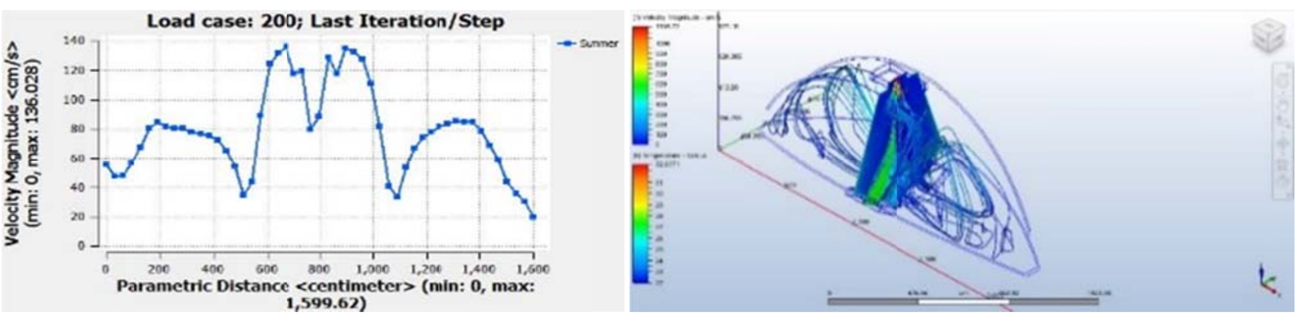
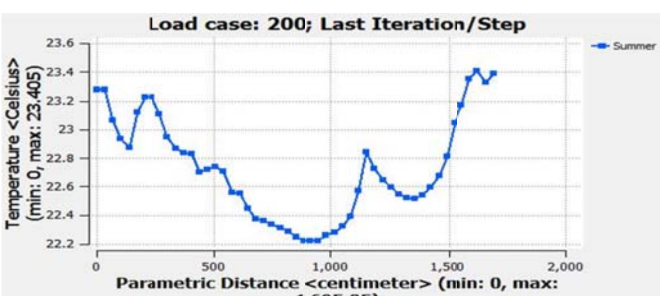


Fig. 30. The airflow speed in the length of greenhouse is indicated in the left image and the air flow type and pattern is shown in the right image.



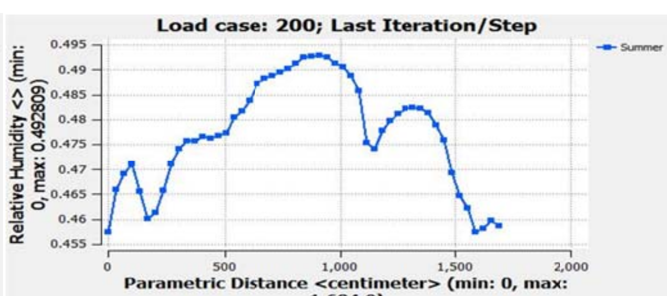


Fig. 31. and Fig.32. Fluctuations in the air temperature levels in the length of greenhouse is shown in the left image while the changes in the rates of air humidity is shown in the right image.

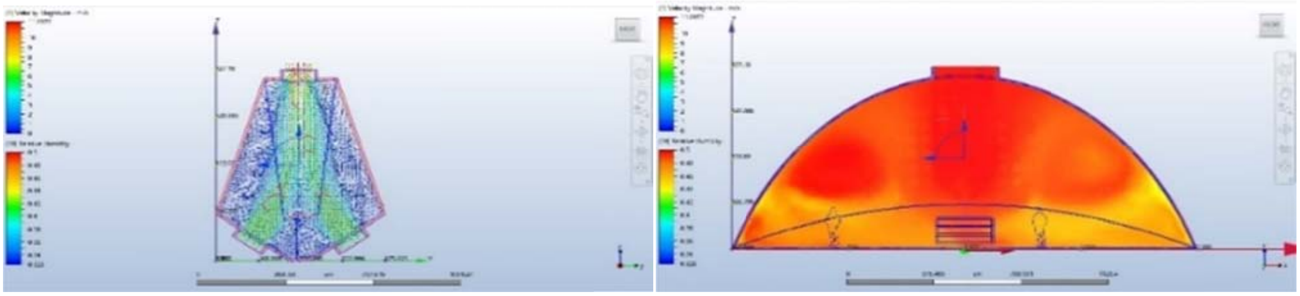


Fig. 33. and Fig. 34. Fluctuations in the air temperature levels in the length of greenhouse is shown in the left image while the changes in the rates of air humidity is shown in the right image.

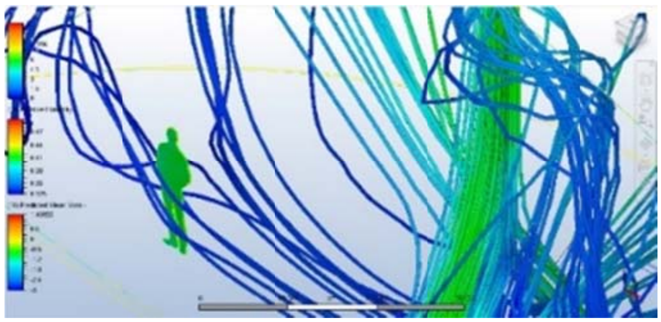


Fig. 35. The PMV index level is observable on a value of -0.6.

Extracted results from Bola biosphere:

This greenhouse was designed and constructed as a biosphere in the Geneva, italy by Renzo Piano in 1996. The air temperature and pressure of it and the airspeed in Geneva is similar to Lahijan but the high level of humidity that reaches for a rate of 85% is 30% more humid than the condition in Lahijan.

Table 10
Weather information of Geneva city, Italy.In 2006. (Source: en.climate-data.org)

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	6.7	7.9	10.1	13.1	16.8	20	23.1	22.9	20.1	16.1	11.3	7.9
Min. Temperature (°C)	3.5	4.7	6.4	9.1	12.8	16.2	19	18.9	16.2	12.3	8	4.6
Max. Temperature (°C)	9.9	11.2	13.8	17.1	20.8	23.9	27.3	27	24	19.9	14.6	11.3
Avg. Temperature (°F)	44.1	46.2	50.2	55.6	62.2	68.0	73.6	73.2	68.2	61.0	52.3	46.2
Min. Temperature (°F)	38.3	40.5	43.5	48.4	55.0	61.2	66.2	66.0	61.2	54.1	46.4	40.3
Max. Temperature (°F)	49.8	52.2	56.8	62.8	69.4	75.0	81.1	80.6	75.2	67.8	58.3	52.3
Precipitation / Rainfall (mm)	101	95	100	88	75	52	31	66	94	156	131	97

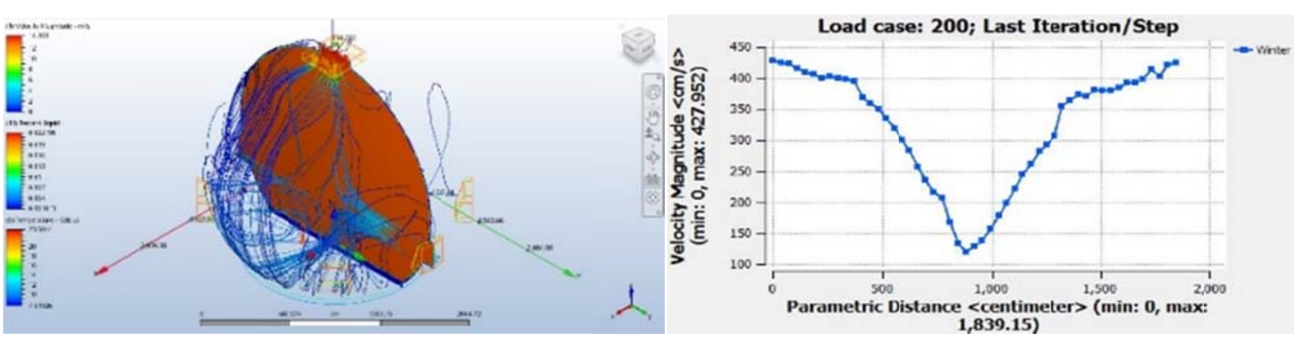
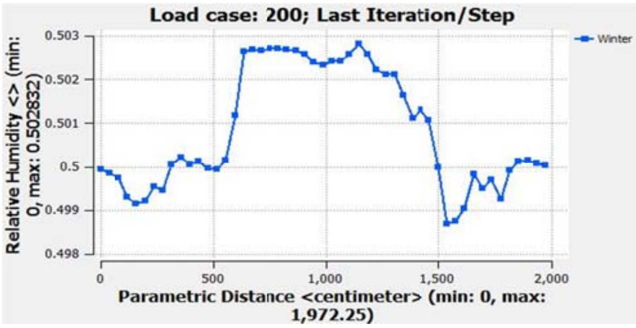


Fig. 36 and Fig. 37. Type and pattern of the airflow is shown in the left image while on the right image the changes in the airflow speed in the exhibition is indicated.



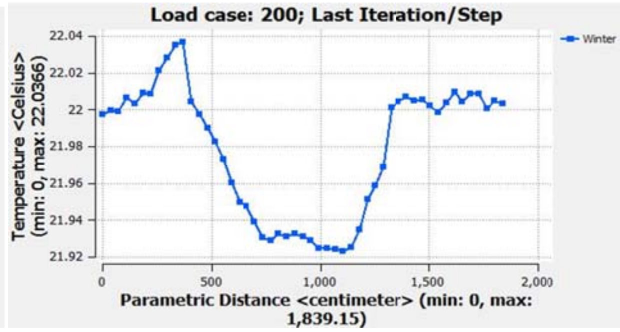
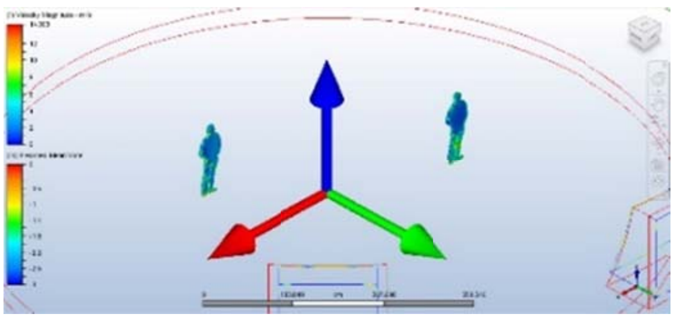


Fig. 38 and Fig. 39. The rates of fluctuations in the humidity of exhibition space is shown in the left image while the amount of fluctuations in the air temperature is indicated.



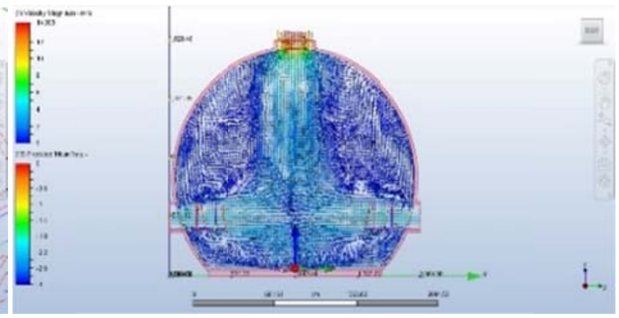
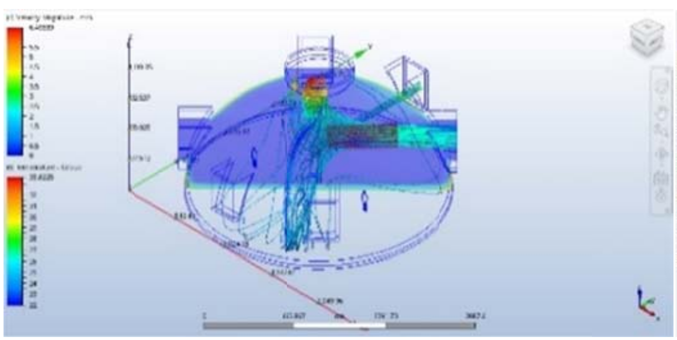


Fig. 40 and Fig. 41. The PMV index is shown in the left image and on the right image the airflow pattern is shown.

Extracted results from Brisbane greenhouse:

It is located in Queensland, Australia. With a higher degree of humidity, it has a humidity similar to Lahijan.



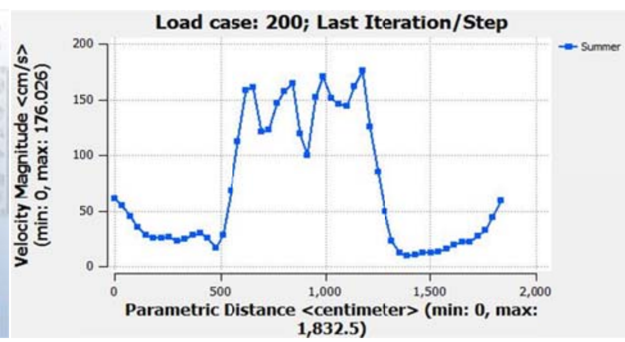
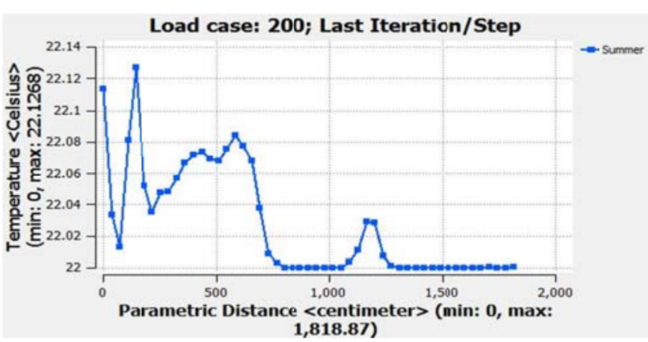


Fig. 42 and Fig. 43. Type and pattern of the airflow is shown in the left image while on the right image the changes in the airflow speed is indicated with a 1.4 m/s tolerance.



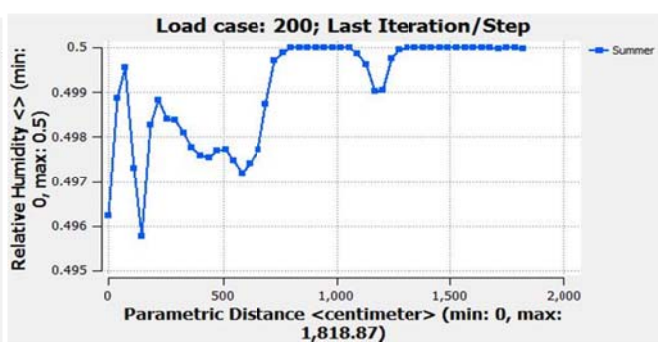


Fig. 44 and Fig.45. The levels of fluctuations in the exhibition space temperature is indicated with a 0.13 centigrade tolerance while in the left image while the amount of fluctuations in the humidity is indicated.

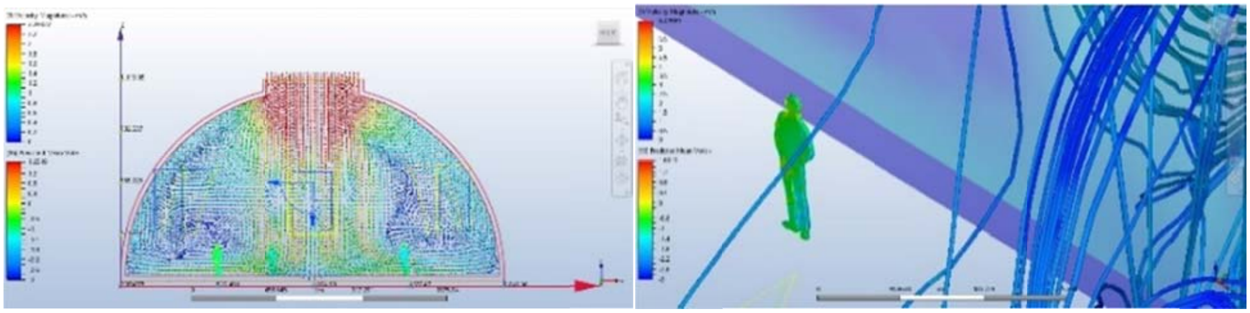


Fig. 46 and Fig.47. The airflow pattern and the air temperature is shown on the right image and the PMV index with a desirable high degree is shown in the right image.

Extracted results from the Muttart greenhouse in Sydney.

Seasons with high levels of humidity and rainfalls in Sydney are different with Lahijan, but Lahijan has the more amount of humidity throughout the year.

Table 11
Weather data of Sydney city in 2006. Source: en.climate-data.org

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	22.2	22.3	21.1	18.4	15.2	12.9	12	13.1	15.2	17.8	19.5	21.5
Min. Temperature (°C)	18.3	18.4	16.9	13.7	10.5	8.3	7.1	8	10	13	15	17.2
Max. Temperature (°C)	26.2	26.3	25.4	23.2	20	17.5	15.9	18.2	20.4	22.6	24.1	25.8
Avg. Temperature (°F)	72.0	72.1	70.0	65.1	59.4	55.2	53.6	55.6	59.4	64.0	67.1	70.7
Min. Temperature (°F)	64.9	65.1	62.4	56.7	50.9	46.9	44.8	46.4	50.0	55.4	59.0	63.0
Max. Temperature (°F)	79.2	79.3	77.7	73.8	68.0	63.5	62.4	64.8	68.7	72.7	75.4	78.4
Precipitation / Rainfall (mm)	126	147	155	112	110	152	74	93	60	92	103	85

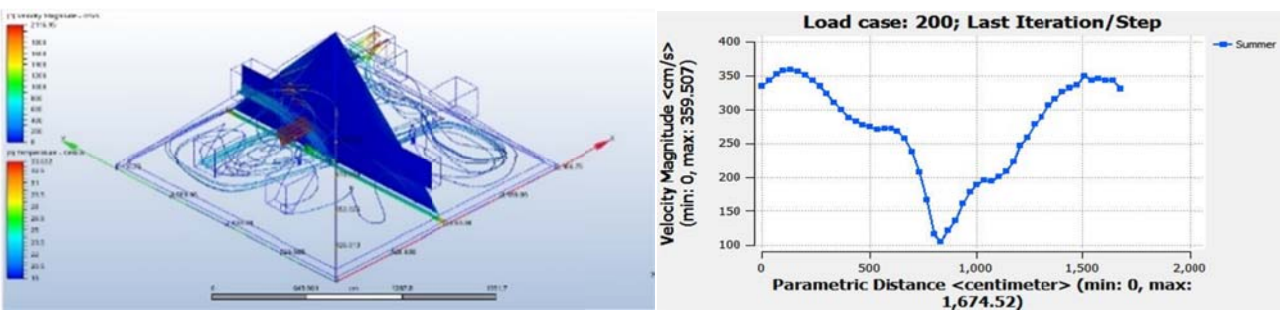


Fig. 48 and Fig. 49. Type and pattern of the airflow is evident in the left image while on the right image the changes in the airflow speed is indicated with a 2.5 m/s tolerance.

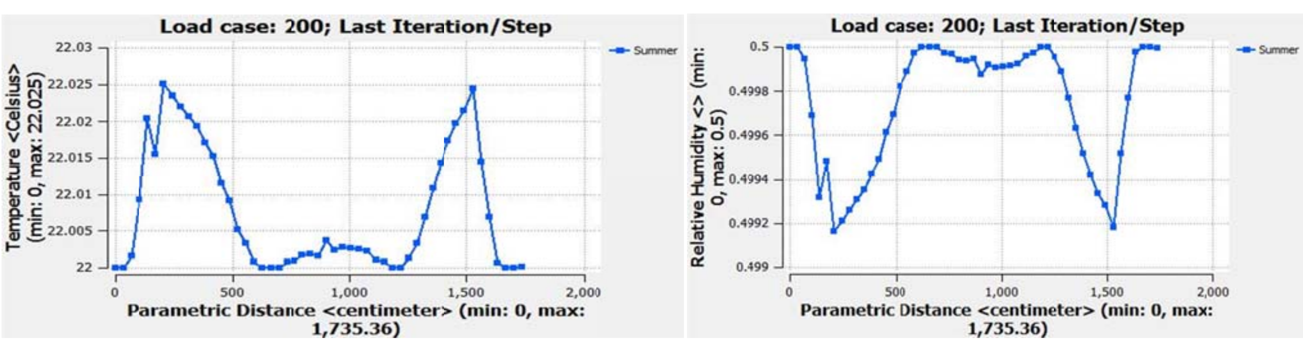
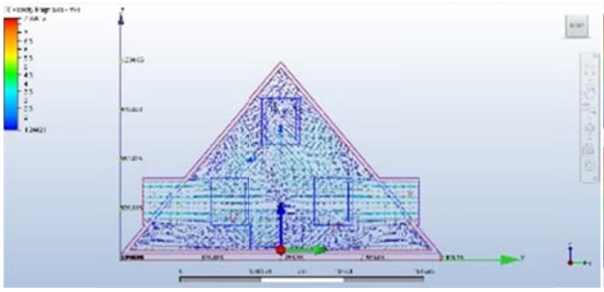


Fig. 50 and Fig. 51. The levels of fluctuations in the exhibition space temperature is indicated by a tolerance of 0.025 degrees in centigrade in the left image while the amount of fluctuations in the humidity is indicated.



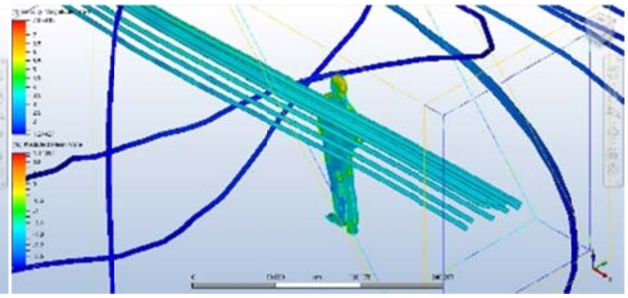
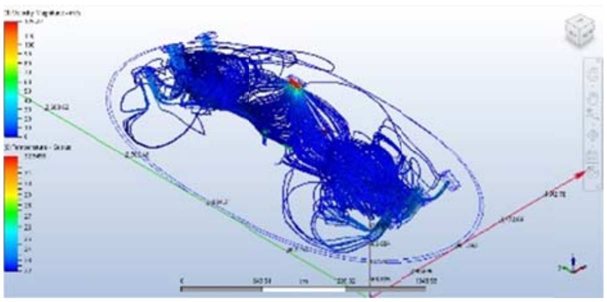


Fig. 52 and Fig. 53. The quality of air movement is evident on the left image and the level of thermal comfort index is shown on the model.

Extracted results from the Kew Royal Great Glasshouse in London

In the simulation of this garden which is conducted by Norman Foster in 2000, a similar geometry which is modelled as a section of a donut shaped geometry as it is done according to the real air intake and exhaust frames.



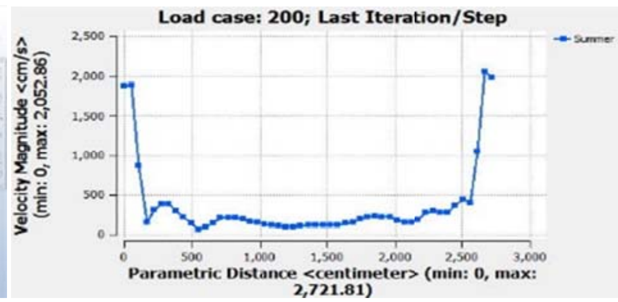
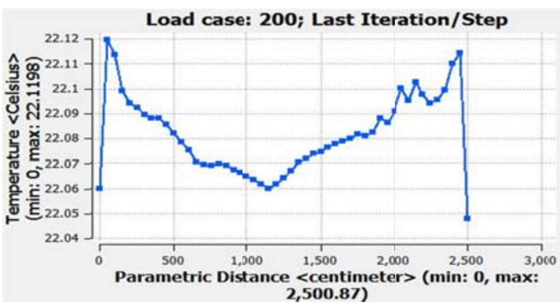


Fig. 54 and Fig. 55. The quality of air movement with the maximum speed of 2 meters per second is observable on the left hand while on the right side changes in speed is indicated which is in its maximum amount in the in take frames which increases to 0.5 meter per second.



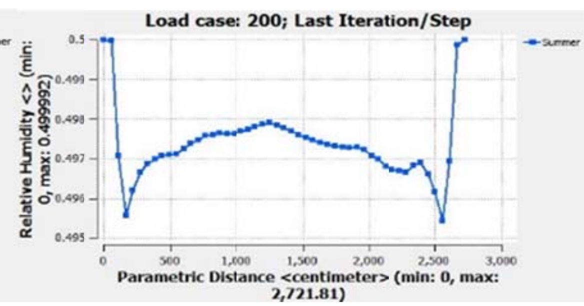
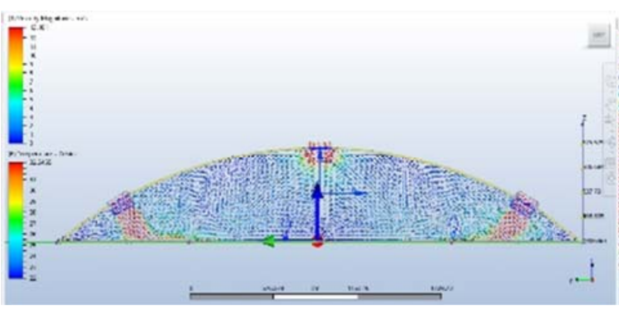


Fig. 56 and Fig.57. Levels of fluctuations in the temperature with the tolerance of 0.08 degrees centigrade on the left while on the right hand we can observe the fluctuations in humidity with the tolerance of 0.003%.



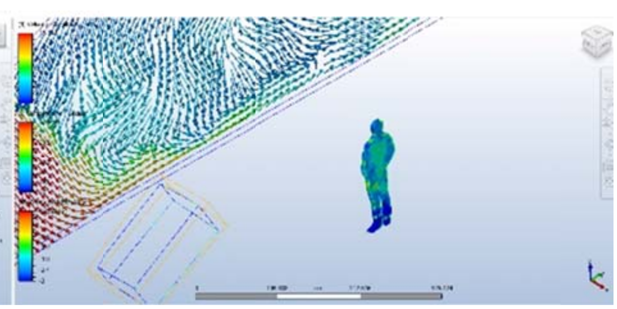


Fig. 58 and Fig.59. The quality of air movement is evident on the left image while the PMV thermal welfare index on the model shows that the cold air is located at the bottom of the model.

The results have indicated that in this table about the flow speed, humidity and temperature of air is taken from the standing position of the visitors which indicates the changes what the external form have made on the internal conditions and the air intake.

Table 9
Data export from the simulations.

	PMV	PPD	MRT	Temperature	Humidity	Velocity	Local Mean Age
Anticlastic	Warm	Dissatisfied	0.03 °c	0.03°c	0.0015%	2.1 m/s	Max: 1.3 min
Cone	The feet Slightly warm	Most dissatisfaction occurs in the upper parts of the body	0.22 °c	0.13°c	0.008%	4.1 m/s	Max: 1.9 min
Adelaide	Slightly warm	70% Satisfaction	0.6° c	0.5°c	0.00026%	6 m/s	Max: 1.4 min
Alpine	Neutral Rate	High satisfaction	1.3° c	1.3°c	0.036 %	1.2 m/s	Max: 1 min
Bola	Slightly warm	High dissatisfaction	0.14 °c	0. 06°c	0.006 %	3.1 m/s	Max: 1 min
Brisbane	Slightly warm	Most dissatisfaction occurs in the upper parts of the body	0.065°c	0. 13°c	0.005 %	1.4 m/s	Max: 1 min
Sydney	The feet Slightly warm	Satisfaction in all parts of body	0.012°c	0.025° c	0.001 %	2.51 m/s	Max: 3 min
Great Glasshouse	The feet warm	Most dissatisfaction occurs in the upper parts of the body.	0.37 °c	0.08°c	0.003 %	2 m/s	Max: 7 min

Comparison between the simulations

1. Based on the levels of humidity

According to the fact that the humidity level is supposed tc stop at a certain degree, therefore it indicates the most disability in the interior of the exhibition area.

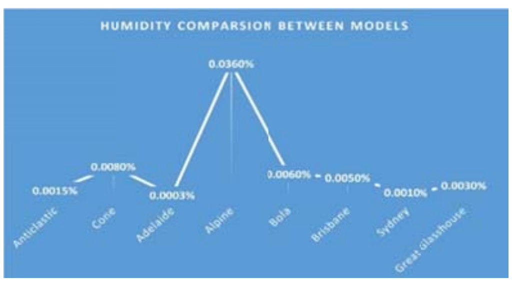


Fig. 60. Comparison between the humidity difference for the outside and inside of the research models.

It is evident that the Adelaide, Sydney greenhouses anc even the anticlastic form have gained bests of results accordingly in comparison to the other models.

2. Based on temperature changes

According to the fact that the simulation is performec during the summer, the best point would be to achieve the most difference between the inside and outside aii temperature.

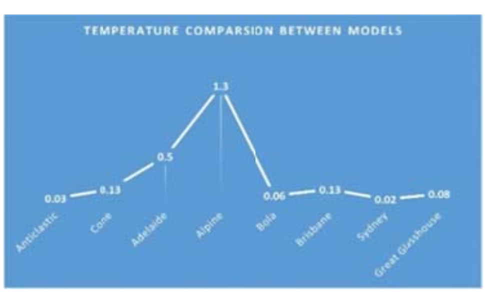


Fig. 61. Comparison between the temperature difference between the internal and external area of the greenhouse.

The best efficiency is won by Alpine exhibition space which keeps the greenhouse cooler in several internal spaces to a desirable degree comparing to the outside temperature.

3. Based on the fluctuations in the wind speed

Severe fluctuations and changes in the speed of internal wind will result in unwanted results on the user of the space. In this instance, the lowest possible of changes in the rates is most desirable.

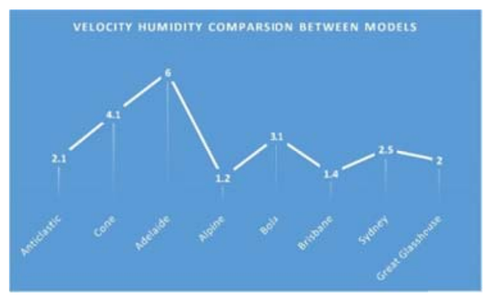


Fig. 62. Comparison between models in regard to changes in the air speed inside the exhibition space.

4. Based on the Mean Radiant Temperature (MRT)

The uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure.

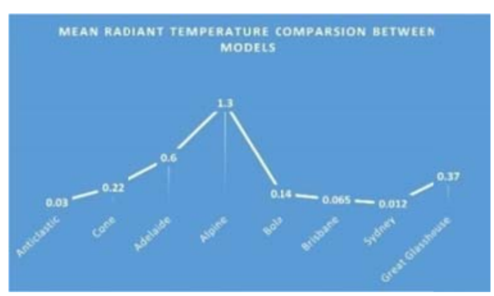


Fig. 63. Comparison between models in regard to the resulted rates of MRT index.

5. Based on Local Mean Age (LMA) the average time of streams that pass through from the local region to the exhaust

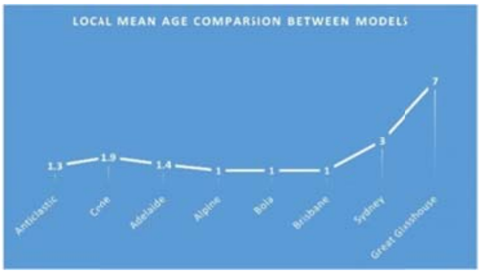


Fig. 64. Average of presence time for the fresh air in the interior space of the exhibition.

6. Based on Predicted Percentage of Dissatisfied (PPD) People regarding thermal welfare PPD is an index that defies a quantitative estimation of the dissatisfied people with thermal comfort.

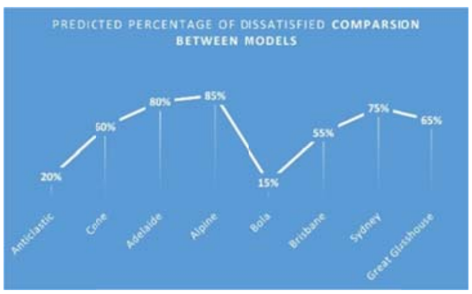


Fig. 65. Percentage of the visitors satisfaction in different locations of the exhibition, based on PPD index.

7. Based on the Predicted Mean Vote Index (PMV)

PMV is an index that predicts the mean comfort response of a large group of people based on the thermal sensitivity in seven scores.

Table.8
PMV index

Value	Sensitivity
3-	Very cold
2-	Cold
1-	Slightly cold
0	Neutral
1+	Slightly warm
2+	Warm
3+	Very hot

Source: Yao, R., Li, B., & Liu, J. (2009)

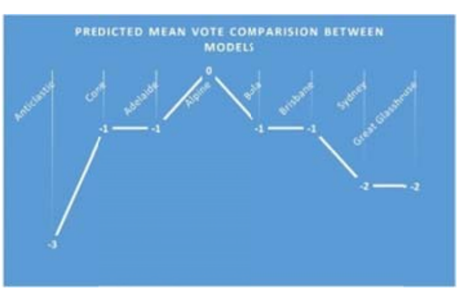


Fig. 66. Satisfaction rates of visitors, situated in different places of the exhibition based on PMV index.

7. Conclusion

Different geometries of a building can impact the airflow current and interior temperature like a container. The efficiency of function of different forms of buildings based on the natural ventilation and the airflow rate in the interior space and the levels of thermal welfare of people based on the weather of Lahijan city. Air flow takes place in a variety of patterns, as we witness attenuation of speed in the center of constructions with convex geometries and the growth in speed over the edges which is quite opposite in the anticlastic form. Also other analyzed factors including the changes in humidity, changes in the air circulation speed, changes in the temperature in the exhibition space have differences among the studied models. These differences reflect the functionality of the forms in the studied climate. And the mentioned factors have a direct impact on the indexes of thermal comfort. Results indicated that the forms which the lengths are greater in respect with their widths, and those with convex and tall geometry would lead to a growth in the rates of thermal welfare for the visitors in the exhibition space. But in the forms with low heights and concave shape, the satisfaction level of the visitors reaches for its minimum level. Role of the geometry in providing thermal welfare in different climates is considered impactful and the importance of evaluating form of the ceilings for the exhibition spaces and large arenas based on the climate in order to reach for a more efficient design in the terms of energy is pertinent as it prevent the loss of budget, time and energy and reduces the expenses related to the operation and maintenance of the building, too.

- Results indicates that the geometrical shape of the covering layers in the large spans in ventilators have a bold role in enhancing the thermal comfort for the users of the space.
- There is a fundamental relationship between the type of climate and form of the ceiling in ventilators with large spans.
- In the mild and humid climates, as the length of the glasshouse increases in respect to its width, or in the case of increase in the height, the function of the space to naturally ventilate and supplement the thermal comfort indexes increases.
- Concave forms with high arcs have a more efficiency compared to the convex shaped forms in the moderate and humid climate.

In the following studies we can also: 1. reevaluate the issues considering the plants and trees in simulating the interior of plants and flower exhibitions and the alteration that are caused in the internal ventilation of the exhibition by trees. 2. Also the location of fans and their impact on the ventilation can studied on further studies. 3. The importance of considering to discharge the gases that are produced by the plants in greenhouse during the winter with natural ventilation can be also subject of further studies on this context.

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Appendix: A

Nomenclatures

Interior temperature of greenhouse (c)	T_c	Area of the greenhouse roofing (m^2)	A_c
Exterior temperature	T_i	Area of the greenhouse roof covers (m^2)	A_f
Temperature of greenhouse floor ($^{\circ}$c)	T_f	Specific heat capacity.(m)	d
Equivalent radiant temperature ($^{\circ}$c)	T_{sky}	Specific heat capacity (Jkg$^{-1\circ}$c^{-1})	C_{pa}
Heat loss factor of the greenhouse cover.(W·m^{-2}·c^{-1})	u	Gravity (m^{3}kg^{-1}s^{-2})	g
Wind Speed outside of the greenhouse (ms^{-1})	v	Height of the greenhouse crest (m)	h
Greenhouse air volume (m^3)	v_g	Heat transfer coefficient Between the shell and the air outside (wm$^{-2\circ}$c^{-1})	h_{c-o}
Width of the Greenhouse	w	Heat transfer coefficient from fluid (wm$^{-2\circ}$c^{-1})	h_f
Viscosity of molecules (m ^{2}/s)	µ	Enthalpy of interior humidity(Jkg^{-1})	I_i
Stefan–Boltzmann constant	σ	Enthalpy of exterior greenhouse humidity (Jkg^{-1})	$I_.$
Level of air movement (m ^{3}/s)	Q	Thermal conduction (W·K^{-1}·m^{-1})	k
Surrounded air volume (m ^{3})	V	Length of the greenhouse (m)	l
Density (Kg/m ^{3})	ρ	Greenhouse ventilation level (kgs^{-1})	m_a
Time (s)	t	Air exchange rates for an hour (h^{-1})	N_a
Air exhaust time (s)	$T_{exhaust}$	Pressure (pa)	P
Average Air exhaust (s)	T_{age}	Temperature transfer rate between the covers and the outside	Q_{c-o}
Turbulent Prandtl number from Turbulence kinetic energy	$_k\alpha$	Turbulent kinetic energy Due to floating property (m^2/s^{-2})	G_b
Turbulent Prandtl number for energy dissipation rates	$_k\alpha$	Turbulent kinetic energy according to the average gradient per hour (m^2/s^{-2})	G_k
Supply	S_ϕ	Components of the air speed	UV W
		Amount of air movement	ϕ

Appendix: B

Abbreviations

CFD	Computational Fluid Dynamic
FVM	Finite Volume Method
LMA	Local Mean Age
CFM	Cubic Feet per Minute
ACH	Air Change per Hour
PDE	Partial differential equation
PPD	Predicted Percentage of Dissatisfied People
MRT	Mean Radiant Temperature
PMV	Predicted Mean Vote