AIRFLOW MODELLING SOFTWARE DEVELOPMENT FOR NATURAL VENTILATION DESIGN

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ABSTRACT

As the benefit of natural ventilation in reducing operational cost is well recognised, the concept of natural ventilation is becoming more received by residents and designers alike. For decades, Computational Fluid Dynamics (CFD) has been employed by the architectural and heating, ventilation and air-conditioning (HVAC) profession, as the modeling tool is able to provide detailed airflow analysis in aiding the incorporation of innovative natural ventilation concept into the building design phase. However, major bottlenecks for the widespread implementation of this tool has been the time-consuming effort required to prepare clean and compliant building geometry data for the CFD mesh generation process, as well as the high cost associated with the CFD specialists. With Singapore Building and Construction Authority's (BCA) initiative to launch the national usage of Building Information Modeling (BIM) solutions for the building industry, IHPC, together with Building Systems & Diagnostic & RightViz Solutions Pte. Ltd, has developed the Green Building Environment Simulation Technology (*GrBEST*) software to provide an integration of BIM and CFD simulation in one simple, time efficient and cost effective building airflow modeling tool.

KEYWORDS

Natural ventilation, Building Information Modeling, Computational Fluid Dynamics

1 INTRODUCTION

Singapore's current pursuit towards energy and environmentally efficient building designs requires great emphasis to be placed upon reducing the cooling load of a building. According to Singapore Energy Statistic Data, the total household electricity consumption has increased by 2% from 6,514 GWh in 2009 to 6,641 GWh in 2012 (Singapore Energy Statistics, 2012, 2013), mainly due to higher air-conditioning consumption. However, Singapore's monsoon conditions throughout the year with north or south prevailing wind direction provide an opportunity to optimize naturally ventilated facade designs and reduce the building cooling load (Wang et al., 2007). Building thermal heat gain can be minimized through a positive passive design that considers building location and orientation such as taking into consideration prevailing wind directions and the optimal planning of naturally ventilated spaces. The aim is to achieve maximum cross ventilation within built spaces and hence reduce the reliance on mechanical cooling methods. In the urban environment of

Singapore, good wind flow through the cities aid in reducing heat build-up and therefore helps to increase the thermal comfort of building occupant.

The Building Construction Authority (BCA) Green Mark Scheme (BCA, 2013) was launched in 2005 as an initiative to drive Singapore's construction industry towards more environmentally-friendly buildings and to promote sustainability in the built environment by raising awareness among developers, designers and builders at the project conceptualisation and design phase. The BCA Green Mark assessment identifies the specific energy efficient and environmental-friendly features and practices that are incorporated in the projects and points are awarded for incorporating environmental-friendly features that exceeds normal practice. Depending on the overall assessment and point scoring, the building will be certified to have met BCA Green Mark Platinum, Gold^{Plus}, Gold or Certified rating (BCA, 2013).

However, constraints associated with CFD studies have often prevented practitioners from bringing apparent value to building projects for the following reasons: 1) complexity, 2) turnaround time, 3) software cost and 4) hardware cost.

1) Complexity

Modeling and simulation tools are complex to use and usually require the domain knowledge and expertise of a CFD specialist. Building design features generally have to be simplified for CFD simulations and the validity and accuracy of these simplifications must be verified so that the results remain accurate for use. The requirement to obtain significant knowledge in a short time frame sometimes prevents architects who are involved in the design of a development from undertaking the study themselves. Moreover, engineers performing detailed CFD analyses are usually uncertain about the level of simplification required for modeling purposes without undermining the original design intent of the building.

2) Turnaround Time

The architectural design process evolves quickly and hence requires the airflow modeling and simulation analysis to be conducted in a timely manner for it to be relevant.

3) Software Cost

Commercially available software is generally costly to acquire and hence typically only well capitalized specialist companies, rather than smaller enterprises, can afford investment in applications and the necessary licences.

4) Hardware Cost

The computational time required to perform airflow simulation is often dependent on computational hardware, including, processing, memory, and data transfer resources. The larger and faster a CFD simulation, the greater the hardware cost required.

The Green Building Environment Simulation Technology (*GrBEST*) project aims to address the above constraint by developing an intuitive and cost-effective airflow modeling software for usage by the green building industry. The software enables master planners, architects, sustainability consultants, BCA Green Mark officers and general green building practitioners to perform timely CFD analyses for detailed green building conceptual design and assessment.

2 MOTIVATION AND OBJECTIVE

The *GrBEST* software is catered to comply with the BCA green mark submission criteria purpose in demonstrating a development's design of good natural ventilation. It allows users to run massively parallel computations on supercomputers for large scale computational domains. The *GrBEST* modeling and simulation software enables a seamless workflow from the early design stage, utilizing BIM data from the Autodesk *Revit* Architecture software (Autodesk Inc., 2013) to the final airflow simulation analysis.

The *GrBEST* software concept is to provide cost-effective and time-efficient CFD simulation software, through the incorporation of freely available and user-friendly third-party applications. It is targeted for use by town planners and building designers during the urban planning and early building design stages.

3 METHODLOGY

The *GrBEST* software consists of Windows and UNIX-based components, where modeling and project management is performed on a Windows-based PC, and the more compute intensive tasks conducted on a multiprocessor UNIX-based workstation. Fig. 1 shows the flowchart diagram representing the modeling and simulation process between the Windows and UNIX machines and consists of the following key stages: 1) geometry preparation, requiring geometry conversion and checking, 2) meshing, consisting of surface triangulation and volume mesh generation, 3) flow solution, involving pre-processing, computation, and automatic post-processing, and 4) post-processing and report generation. The results of the meshing, solver and post-processing stages may be viewed on a Windows machine by using *ParaView*, an open-source multiple-platform data analysis and visualization application (Paraview, 2013).

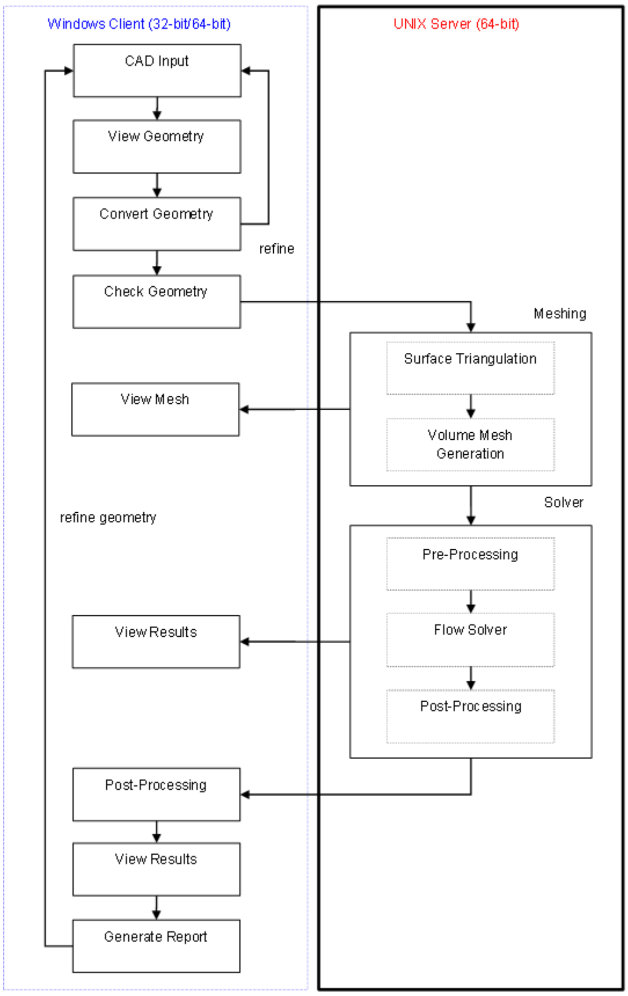


Figure 1: Windows-based client and UNIX-based server module execution workflow

3.1 Geometry Preparation

In order to conduct a CFD simulation, building geometry adhering to CFD discipline is first created using *Revit.* Buildings can only consist of walls, floors, flat roofs or wall openings. Wall thickness should be at least 0.5m. Afterwards the geometry is exported to an Industry Foundation Classes (IFC) file.

3.2 Geometry Conversion

This file is converted into the appropriate input files required of the UNIX *muSICS* system by a Geometry Converter application developed by RightViz Solutions Pte. Ltd (RightViz Solutions Private (Pte.) Limited (Ltd.), 2013). The workflow of the viewing and subsequent conversion of an IFC file to the geometrical definition, background mesh and boundary condition files required by the UNIX *muSICS* modules is shown in Fig. 2.

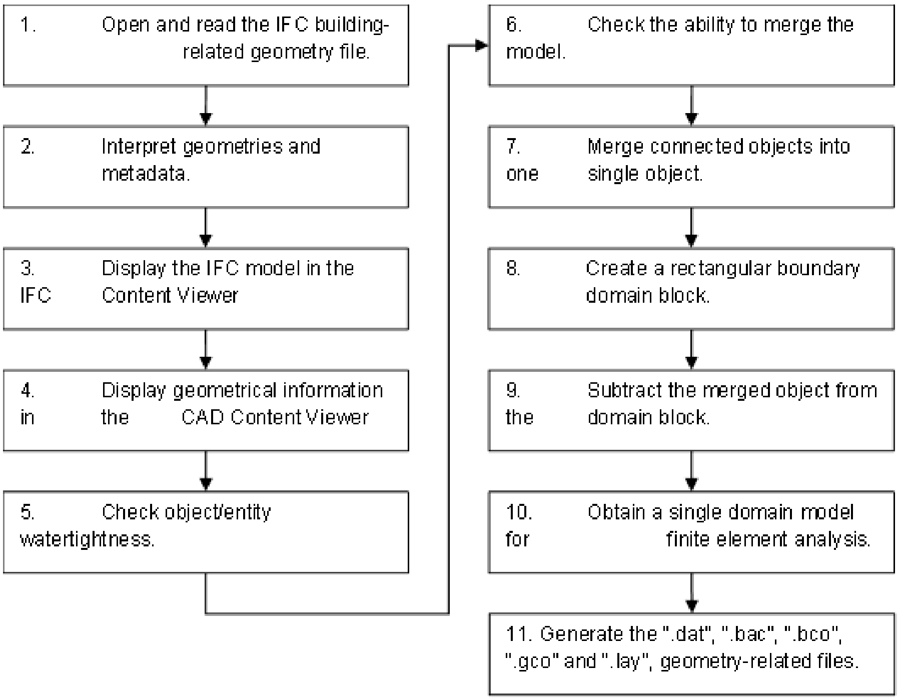


Figure 2: Overview of the IFC file viewing and conversion process

3.3 *GrBEST* Software

The computational stage involves consecutive execution of the ST, VT, Preproc, Solver, and Postproc modules, where the Solver module can perform computer number crunching using multiple processors. The Solver dialog, shown in Fig. 3, allows the user to enter the characteristic length, $L\,(\mathrm{m})$, magnitude of the free-stream velocity, $v\,(\mathrm{m\,s^{-1}})$, wind direction, number of processors and the simulation result type.

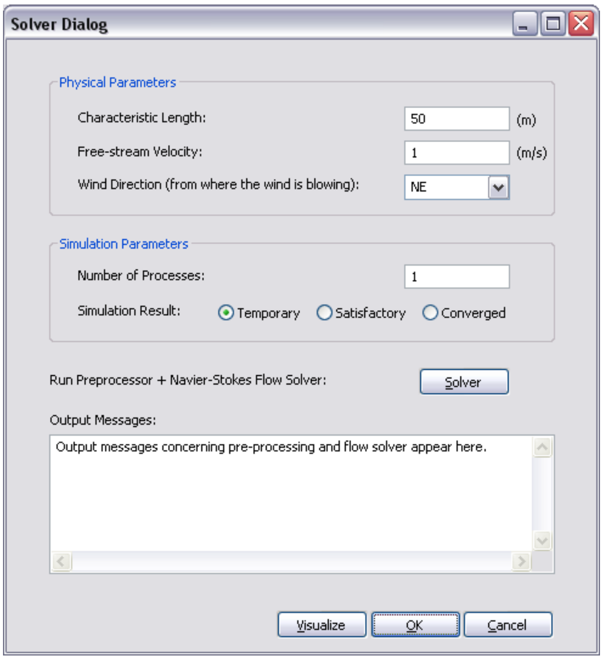


Figure 3: Solver dialog window showing default values

4 VALIDATION

The case study described in E. Simiu and R. Scalan (Simiu et al., 2011) is used as benchmark test case. The geometry is a typical building complex as shown in Figure 4. Wind tunnel studies of surface wind around this building complex have been conducted. There are three main types of surface winds: vortex flows, corner streams and through flows.

Surface winds expressed in terms of speed ratio R_H=V/V_H where V is the wind speed at pedestrian height (region A), V_H is wind speed at building height H. Dimensional analysis gives: R_H = f(L/H,W/H,D/H,H/h,Re) where Re is Reynold number. If D/H is small as in many tall buildings, then the effect of Reynolds number is insignificant.

CFD simulation using *muSICS* is depicted in Figure 4. Plots of V_A/V_H against W/H (aspect ratio) for a given L/H = 0.5, H/h = 5 on both experiment data and CFD simulations is shown in Figure 5. As can be seen from Figures 4-5, the simulation results from muSICS can capture all three types of building aerodynamic winds and are in good agreement with wind tunnel experiment data. The speed ratio R_H increases to a max with increasing W/H but changes less once W/H aspect ratio reached unity.

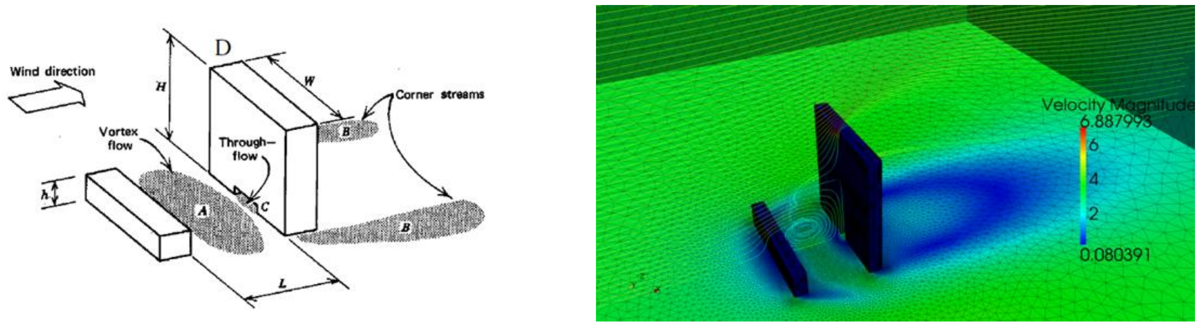
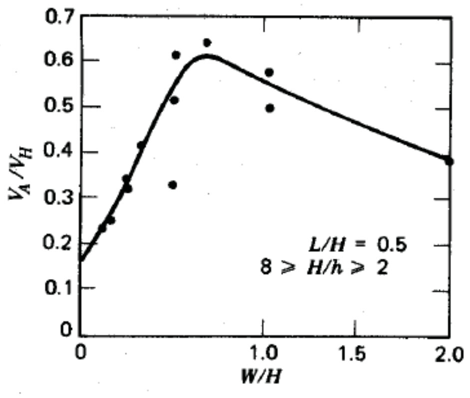


Figure 4: Geometry of building complex used for solver validation (left), CFD simulation using muSICS showing surface winds for a typical test case (right)



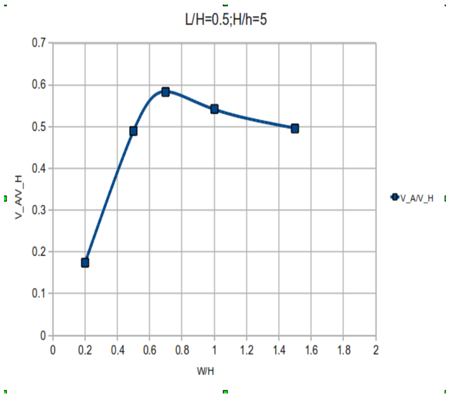
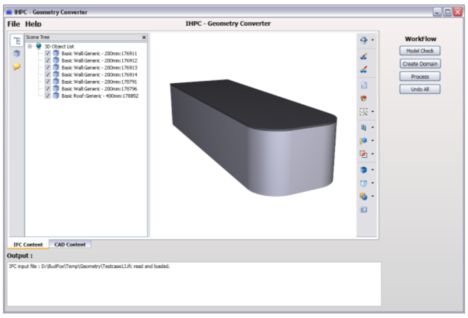


Figure 5: Speed ratio of surface wind: wind tunnel data (left), CFD simulations (right)

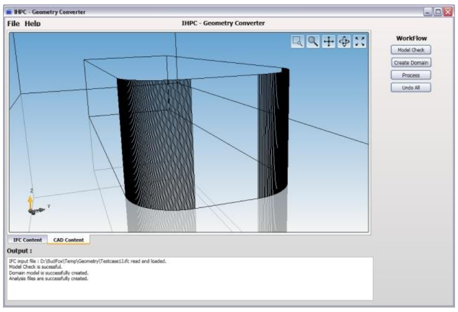
5 RESULTS

5.1 Natural Ventilation for External and Internal Airflow

Example 1 is presented here concerning the external airflow around a building with walls, a curved surface and a flat roof, as shown in Fig. 6. The model geometry was prepared using *Revit* to create an IFC file. The IFC file is then converted into the necessary input files for CFD simulation (Fig. 6(a),(b)) thereafter, *GrBEST* is used to perform surface triangulation followed by CFD flow solution (Fig. 6(c),(d)) using the embedded CFD solver, *muSICS*. The input parameters for the flow solver are shown in the Solver dialog (Fig. 3) and the airflow is from the northeast (NE) to the southwest, as shown by the streamlines of Fig. 6(d).



(a)



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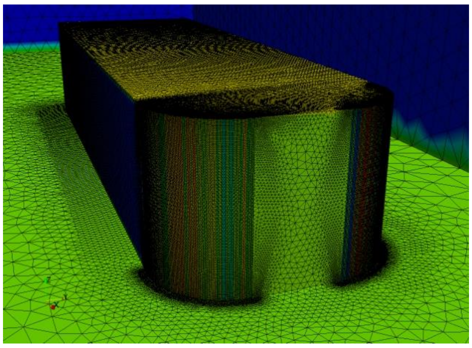

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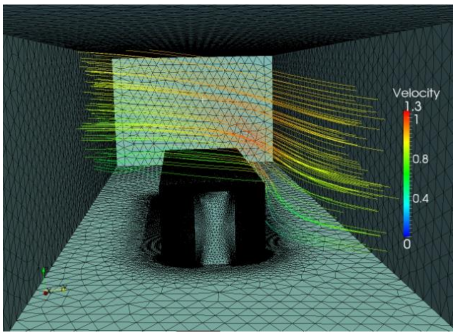

(d)

Figure 6: Simple building geometry used for external airflow simulation: (a) IFC content, (b) curve structure, (c) surface triangulation, and (d) converged flow solution

Example 2, demonstrating internal airflow is presented in Fig. 7, where the building geometry consists of two floors, external walls, one lower-level internal wall, and four openings on the front and rear walls. The workflow procedure for this example is similar to that employed in Example 1, with the only difference being that the airflow direction is from the west to the east.

A Stream Tracer filter is created in *Paraview* to visualize the airflow as a set of streamlines coloured by the magnitude of the velocity. The airflow is from the external to the internal region and the fluid flow is from the west to the east as specified (Fig. 7 (d)).

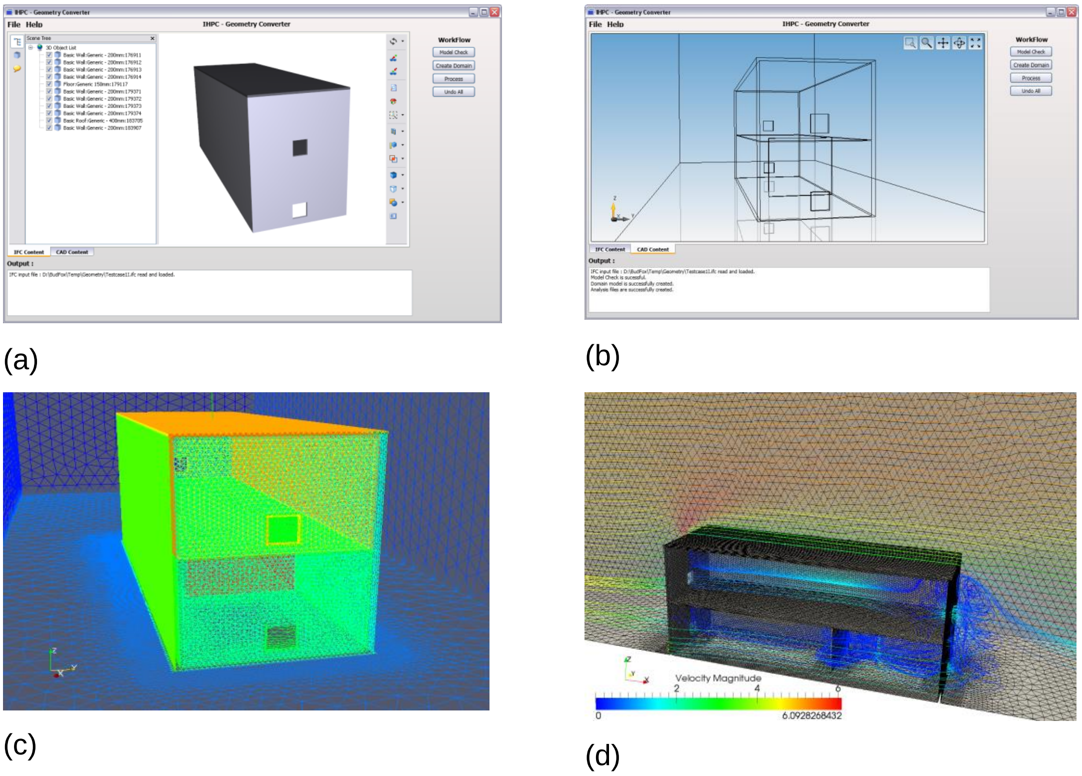

Figure 7: Two-storey building geometry with openings and an internal wall used for internal airflow simulation: (a) IFC content, (b) curve structure, (c) surface triangulation, and (d) converged flow solution

5.2 Case Study – Community Facility

An industrial project collaboration involving IHPC, BSD & RightViz with RSP Architects and Planners Pte Ltd (RSP) to generate a case study on estate airflow simulation work and evaluate the natural ventilation scenario is carried out from 1 Mar to 31 May 2014. The results are used in determining the optimal building mass, geometry, orientation and layout to achieve good natural ventilation conditions. Upon receiving the .rvt format of the model from RSP, simplification of the model to suit CFD discipline commenced with the aim of studying the natural ventilation on levels 1 and 2 in mind.

5.2.1 Geometry Simplification Steps

1. Vegetation, topology, doors, windows and basement levels are deleted.
2. Room separation lines, elevated floor, ramp, structural columns near to walls are removed. Enclosed spaces are replaced by solid blocks. Thin walls are replaced with 0.5m walls.

3. Second, third, fourth storey and roof are replaced by a solid block. Geometry of third level and roof are altered to enable successful meshing.

5.2.2 Results and Recommendations

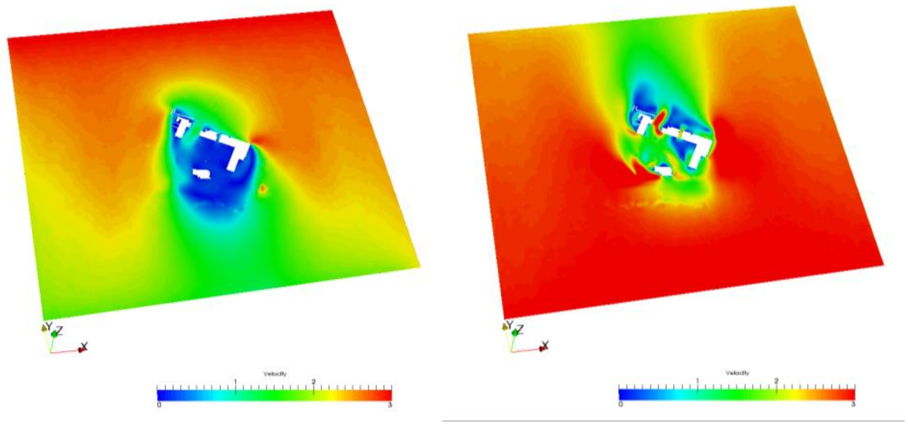

Figure 8: Simulation Result with North Wind, 3 m/s (left), South Wind, 3m/s (right)

Approximately 4.5 million cells are generated on meshing. The time taken for geometry simplification, meshing and solution generation is approximately two days. Under the present architectural design, it is observed that under North wind condition, the airflow movement on level 1 is slow or stagnant (illustrated by large regions of dark blue colour). To further improve the natural ventilation performance on level 1, it is suggested that the gap move from the present location 1, further east, to location 2 (Fig. 9). This would allow the North wind to penetrate to the central region of level 1.

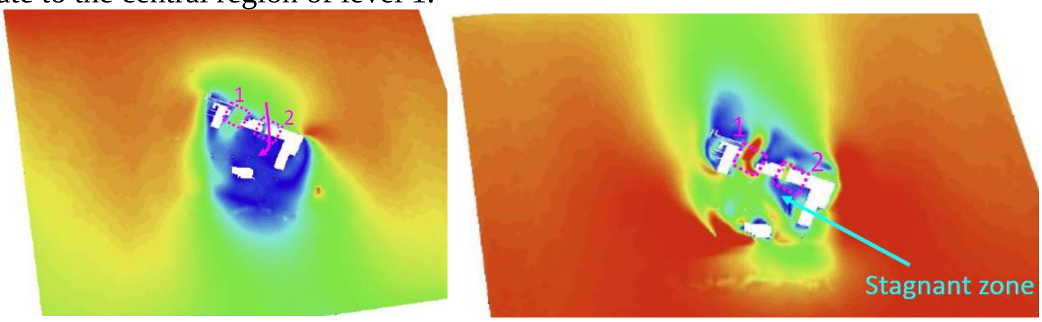

Figure 9: Recommended changes during North Wind scenario (left) South Wind scenario (right)

The overall natural ventilation performance on level 1 under South wind is better than that of North wind. If the gap is moved from the present location 1, further to the east, to location 2 (Fig. 9), then under South wind condition, it is anticipated that the highlighted stagnant zone would be eliminated.

5.2.3 Modifications

Three simulation stages are proposed by RSP. The first stage consists of the following three scenarios. In Scenario 1, the corridor is widened to 3.5m. Pantry and food preparation area remain enclosed. In Scenario 2 – Option 1, the corridor is widened to 3.5m and the walls at two ends of food preparation area are changed to 900mm high wall with opening above. In Scenario 2 – Option 2, the corridor remains at 2m and the walls at two ends of food preparation area are changed to 900mm high wall with opening above.

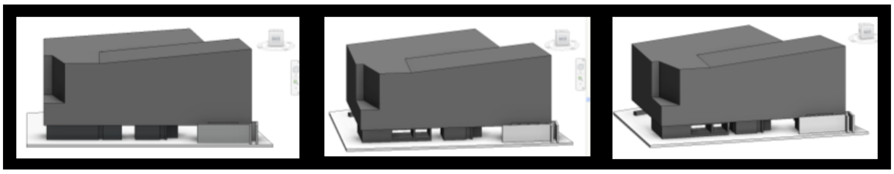

Figure 10: 3D view of Scenario 1 (left), Scenario 2 – Option 1 (centre), Scenario 2 – Option 2 (right)

In the second stage, using the geometry of the scenario which gives the best natural ventilation, that is scenario 2 – Option 1, level 2 foyer is added. In the third stage, surrounding buildings are added.

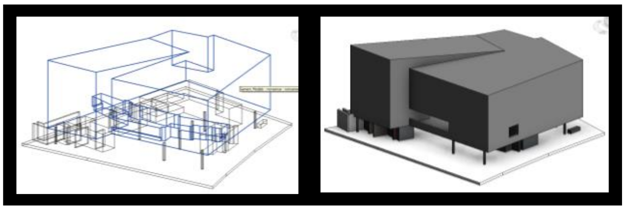

Figure 11: 3D view showing level 2 foyer

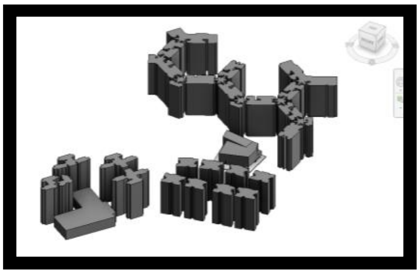

Figure 12: 3D view with surrounding buildings

5.2.4 Results

Table 1: Number of cells and mesh, solve time

	Cells	**Mesh Time**	**Solve Time**
Stage 1	4,409,997	9 min	3 hr 36 min
Stage 2	5,019,539	6 min	2 hr 14 min
Stage 3	32,475,715	1 hr 59 min	19 hr 19 min

Scenario 2 Option 1 gives the best natural ventilation scenario, as the corridor widening to 3.5m together with end walls removal are proven to be effective measure to promote cross ventilation. In this study, *GrBEST* capability to perform simulation with surrounding buildings around the site has also been demonstrated.

As compared to the current CFD software (e.g. ANSYS FLUENT, CFX, STAR-CCM+ and etc), it can be concluded the *GrBEST* can produce the estate level natural ventilation result that is of equivalent standard to the commercial and validated version. This is because our *GrBEST* estate airflow simulation is able to capture all essential features of wind aerodynamic phenomena across the buildings such as through flow, corner wind, stagnation region and vortex flow; as well as give comparable wind velocities within the natural ventilation premises. In addition, the CFD turnaround time for *GrBEST* is about 1 – 2 days, and can be rated as “fast wind modeling tool”.

6 CONCLUSION

At present, the *GrBEST* software application allows the user to perform a CFD modeling and simulation to determine internal and external airflow in and around a building development. As shown in the examples and case study, *GrBEST* is able to provide airflow simulation results of simple estate building geometries with a short turnaround time, all in a single graphical user interface, simple enough to be carried out with a few clicks of a button. The case study also demonstrated the feasibility of using *GrBEST* tool to determine the optimal building mass, geometry, orientation and layout to achieve good natural ventilation conditions for a typical building project.

Moving ahead, further development work will involve improving the software to further automate the reporting and result visualization processes, and to provide an Internet-based mechanism for CFD project submission and execution on supercomputer resources. This, together with more developmental work on geometry manipulation, software development and *muSICS* computational engine extension is required to bring this software towards commercialization stage.

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