

PERFORMANCE ANALYSIS METHODS FOR PASSIVE DOWNDRAFT HVAC SYSTEMS

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ABSTRACT

Passive Downdraft HVAC systems are natural ventilation systems that add heating and cooling to the passive airstream to control zone temperatures and enhance the flow of air by affecting buoyancy forces.

This paper reviews different analysis approaches used to study the performance of this HVAC approach. It investigates the use of bulk airflow modelling to test comfort performance and reviews results against operational performance of buildings that used that software in their design.

The study notes that relatively robust comfort exists in existing buildings designed using similar analysis methods. It also identifies benefits and limitations to the use of more detailed analysis to measure energy consumption and further optimize and test performance.

INTRODUCTION

Passive Downdraft HVAC systems are a form of enhanced natural ventilation system. The strategic location of heating (usually through coils) and cooling (historically by convective evaporation; this paper will look at using cooling coils) in the air

pathway enhances buoyancy effects within the building to boost airflow volume and control temperature.

The purpose of this enhancement to natural ventilation is to enable buildings to obtain the benefits of natural ventilation (100% outside air and low energy) while providing improved performance in peak conditions and enabling natural ventilation for buildings that are predominantly internally loaded (a significant problem with 'typical' natural ventilation systems).

A conceptual sketch of system operation is shown in Figure 1.

The approach reduces or eliminates the need for fans and reduces free area requirements for openings. This results in a ventilation system with lower architectural impact and improved energy performance. It can also enable considerable acoustic control to natural ventilation systems.

A research group known as PHDC (www.pdhc.eu) (Passive Hybrid Downdraught Cooling) exists to investigate the feasibility of the use of these sorts of systems in buildings, funded by the European Commission and is a good source of case studies on buildings that have explored this design.

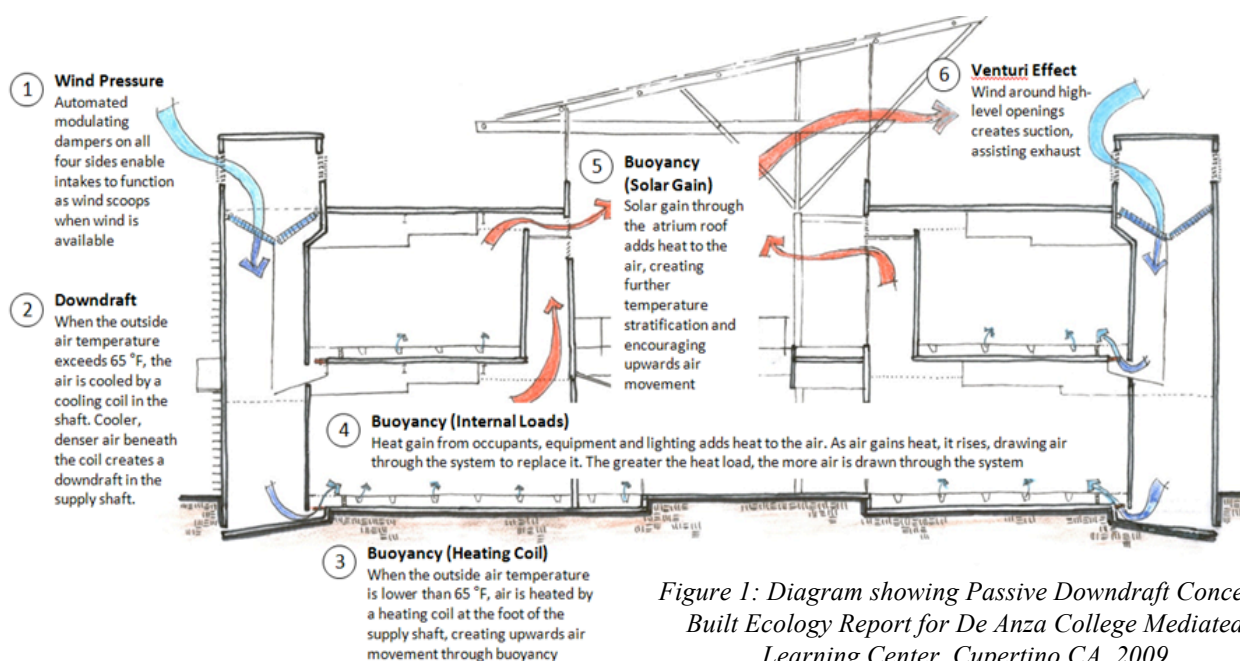


Figure 1: Diagram showing Passive Downdraft Concept.
Built Ecology Report for De Anza College Mediated
Learning Center, Cupertino CA. 2009

Although some EnergyPlus modules have been developed to look at evaporative cooling (Kang & Strand, 2009), most commercial analysis software, including software specialized for natural ventilation, is not designed to facilitate energy and performance analysis for these systems.

This paper covers analysis methods used on the following projects:

- The NELHA Visitor Center at Kona, HI, USA
- The NIDA Foyer in Sydney, NSW, Australia
- Wendouree Performing Arts Center at Ballarat, VIC, Australia
- The NOAA Pacific Regional Center at Ford Island, HI (currently under construction)
- De Anza Mediated Learning Center in Cupertino, CA (currently under construction)
- The Conrad N Hilton Foundation Headquarters in Los Angeles, CA (under construction)

All buildings covered used an analysis method known as Bulk Airflow modelling (such as EDSL's TAS or IES) to estimate annual space temperatures. Anecdotal performance reporting from the building management has been noted for comparison with the analysis results.

Some of the newer buildings also used CFD analysis under design conditions to measure steady state airflows and temperatures. In these cases, the software used was CHAM's PHOENICS FLAIR tool. The purpose of this analysis is to optimize sizing and create a visual output of performance.

Method	Purpose	Software
Bulk Airflow Modeling	Predict Annual Comfort Performance	EDSL TAS 8.5 (A-TAS) www.edsl.net
Computational Fluid Dynamics	Predict Design Condition Comfort Performance	PHOENICS (CHAM) www.cham.co.uk
Bulk Air Flow Modeling + Spreadsheet	Predict Annual Energy Consumption	EDSL TAS 8.5 (A-TAS)

Table 1: List of analysis methods reviewed

The new buildings currently under construction have energy performance targets measured through the ASHRAE 90.1 methodology. The paper also describes the approaches used for calculating this energy for these new projects.

BULK AIRFLOW MODELLING FOR COMFORT ANALYSIS

The bulk airflow modelling process is one of the best methods available for studying natural ventilation in buildings and is a technique that has been used for all of the projects reviewed in this study.

Two examples of software tools that can be used for this type of project include EDSL's TAS and VE's IES. All of the projects studied in this paper used the A-TAS tool in EDSL's TAS 8.5 suite of tools.

Bulk Airflow modelling divides the building into a series of zones both vertically and horizontally connected. Any number of the zones can be conditioned or open to the outside with sheltered or unsheltered inlets. The free area of openings between zones and to the outside is set for each aperture, which can be controlled dynamically. Internal conditions and heat loads are established for each space.

Figure 2 provides an example of this zoning method that was used on the De Anza College MLC project.

The software then determines envelope loads, buoyancy, and wind pressure effects to establish the volume and direction of flow between zones and between each zone and the outside. This is calculated for each hour of the year with a user-defined weather file.

As part of the calculation, the model also considers building mass and surface temperatures so that resultant temperatures and thermal comfort can be assessed as well as dry bulb temperature for each hour of the year.

Results are presented in terms of the percentage of time temperature or comfort set points are exceeded.

For all natural ventilation designs and for Passive Downdraft systems in particular, it is important to consider that bulk modelling assumes air within each zone to be homogenous and, as a result, only considers interactions zone borders. The discrete zoning system created for analysing this system therefore works within this constraint to allow buoyancy and area restriction calculations at key interfaces along the air path. As shown in the example, zones are added for cooling at the top of the intake and heating at the entrance to the raised floor zones, reflecting the respective cooling and heating coils located in these areas. Additionally, the occupied zones are not conditioned themselves except in perimeter spaces to provide additional heating for occupants if a separate heating element exists.

Apertures at the roof intakes are controlled to mimic a wind-directional intake by generating a script of hours that wind comes from different directions and opening or closing inlets and outlets accordingly to mimic a control strategy of targeting positive pressure at inlets and negative pressure at outlets.

Control apertures are set to open and close to achieve a set point in the occupied zone, acting similar to a VAV box in a mechanical system.

Limits to this process

This analysis methodology works well for naturally ventilated buildings and the application to passive downdraft projects provides powerful information

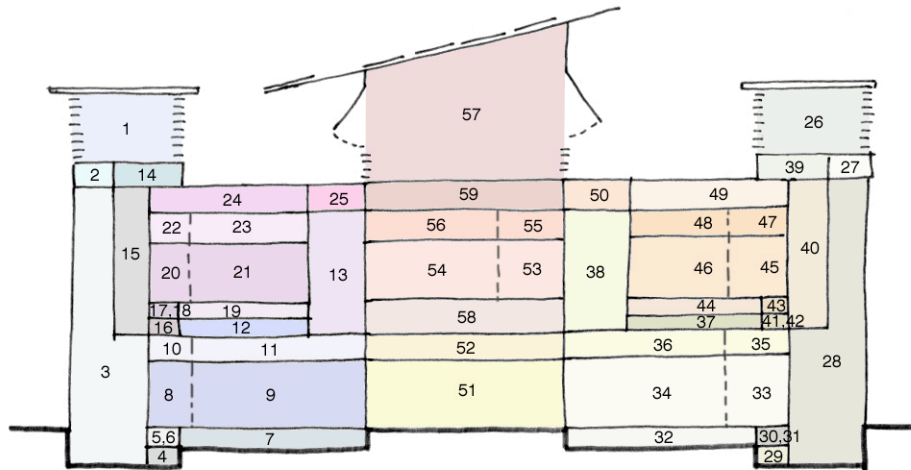


Figure 2: Example of model zoning - Built Ecology Report for De Anza College MLC project, 2009

about system operation. There are, however, a number of limits to the process:

- The bulk airflow modelling process uses free area restrictions, rather than pressure drop restrictions, for apertures. This works well in natural ventilation design where all apertures are relatively open with published free area data (such as louvers, windows and insect screens);
- At times of little or no wind, the passive downdraft system increases the level of cooling in the air stream to induce additional airflow. Many bulk air-flow tools do not allow for this level of dynamic control;
- The bulk airflow process estimates wind pressures at each aperture based on the wind direction and aperture free area but may not properly take into account wind shadows caused by other parts of the building.

Despite these limitations, the process has been effective at designing and predicting comfort performance for existing designs.

The challenge with the approach is the extent to which the analysis process can be relied upon for system design optimization. This is critical because apertures sizes required for even an optimized system to work effectively can potentially be very large, so optimization that limits the architectural impact (and cost) is very important.

Results and how they inform design

Using the process described above, bulk airflow modelling can be used in many ways to inform design for passive downdraft systems.

In analysis that was done for the Wendouree Performing Arts Centre the PMV levels in the space were determined using the bulk airflow model for each hour of the year for a range of aperture openings. The study intended firstly to quantify the performance penalty with smaller apertures before cooling is added. As the increase in the frequency of uncomfortable hours was relatively low for a significant cost saving, the net sizing was reduced in half, generating significant capital cost savings.

At a later stage in the design, changes had increased the internal loads in the building, causing a higher frequency of uncomfortable hours. The analysis allowed comparison of options such as increased thermal mass in the supply labyrinth, increased opening sizes or the addition of direct evaporative passive downdraft cooling at the air inlet (the building is located at a slight altitude in a dry, Mediterranean style climate).

The building has now been operating for almost 5 years with the direct evaporative cooling system in place. The anecdotal evidence from the building manager is as follows:

- the building conditions very well up to external dry bulb temperatures of around 22°C without the need for evaporative cooling;
- at dry bulb temperatures between 22°C and about 30°C, the direct evaporative cooling is effective at providing cooling and air movement;
- when the outdoor air temperature is above 30°C, the building starts to tend above desirable setpoints.

When the anecdotal results are aligned with the weather data (Ballarat, VIC, Australia), the analysis results are found to be accurate enough to be relied upon as a design tool. As an aside, a key lesson is the use of PMV as a measurement technique – anecdotal evidence indicates that where analysis indicates PMV levels above +1, these conditions will be considered uncomfortable, particularly in an auditorium space with no individual control.

Real vs. Modelled for Passive Downdraft with Cooling Coils

One project that uses cooling coils to cool the air passively as it enters the building is the NELHA visitor centre at Kona in Hawaii.

The building was studied using bulk airflow modelling with TAS 8.5 A-TAS.

Similar to the previous example, simulations were used to study design optimizations that would reduce the cost of construction. Examples include the

frequency (in hours) of different air change rates is plotted for 3 different opening free areas (3% in red, 2.5% in blue, 2% in green) and the same results for frequency of different PMV ranges.

The results allowed a value judgement on opening size to be made relative to the performance of the system.

Other examples of design aspects that were analyzed using this technique included:

- The height of the exhaust chimney;
- The impact of shading the exhaust chimney with PV collectors;
- The material properties of the chimney and roof;
- The need for an elevated inlet (this project ended up with an inlet at the ground with airflow more driven by an exhaust chimney than a passive downdraft shaft);
- Impact of increasing the plenum size and separation of plenums.

The building has now been operating for over 6 years and frequent conversations with the building manager have indicated that the space is consistently maintained at 24C/75F.

A similar system was used for the NIDA foyer in Sydney, Australia. This space has been operating for over 8 years has achieved similar results, supporting the analysis carried out on the project. A recent visit to the building and conversation with the facilities manager indicated that the system at NIDA is providing effective cooling all year round.

The operational performance results indicate that the methods used to design the project were effective in proving the concept and making it work, and that many of the analysis limitations described above for this project at least were not found to be critical.

BULK AIRFLOW MODELLING FOR ENERGY ANALYSIS

Estimating operating energy for natural ventilation systems is typically determined by calculating when a building is operating in natural ventilation mode and when it is running in conditioned mode (usually heating). Energy use is then calculated for conditioned mode hours assuming conventional conditioning systems. Once a successful natural ventilation model has been created (usually in a bulk airflow analysis tool that can also provide space loads) it is simply a matter of the software opening and closing apertures to achieve setpoints and determining heating and cooling loads outside of the set point range for which natural ventilation is considered acceptable.

These types of Passive Downdraft systems operate more like VAV air conditioning systems than mixed mode natural ventilation systems.

First, there is initially one supply air set point and airflow is modulated from a minimum (needed for

ventilation) to a maximum (based on peak cooling load). Heating is done separately on a zone-by-zone basis.

Second, natural ventilation in this case is always in operation and is enhanced to meet setpoints rather than switched off. This enhancement can be a combination of any of the following:

- Buoyancy pressures are driving airflow through the building;
- Wind pressures are driving airflow through the building;
- Heating of supply air is driving airflow through the building;
- Cooling of supply air is driving airflow through the building.

If there is not enough wind, additional heating and cooling are necessary to boost buoyancy forces that increase the flow of air through the building. While bulk airflow modelling is capable of simultaneously measuring zone temperature, accounting for buoyancy forces, and calculating the impact of wind pressures, the control logic in most natural ventilation tools are not detailed enough to enable these factors to be accounted for in a logical sequence.

In addition, when the bulk airflow tools were used for the comfort analysis, it was simply enough to determine whether a comfort condition or range could be met. In real life, the objective is to run an HVAC system at the point in the set-point range that is most efficient (e.g. 24C/75F for most cooling situations) rather than any point in a range of 21-24C/70-75F that it happens to be able to hit.

Simple Passive Downdraft Systems

Many passive downdraft systems in operation are designed to be very simple, with only heating or cooling and often with evaporative cooling provided so that most energy use is limited to pumping energy.

At the NELHA Visitor Center in Hawaii, the passive system uses no heating energy and the chilled water is pumped up directly from a deep sea well. In this example, the predictive energy model used for the LEED energy submission could be analysed fairly simply, with pumping energy based on a constant flow rate of chilled water.

Operationally that project is using less energy than expected and achieving a net zero energy outcome (originally, in the LEED submission, the PVs were expected to provide 80% of energy demand). The pumping energy is still a large energy user, primarily because the water is pumped a long way but also because there are no variable flow controls on the pumps. Neither the modelled nor the actual results from the project provide an effective prediction of energy consumption for more sophisticated passive downdraft systems.

At the NIDA building in Sydney and the Wendouree Performing Arts Center in Ballarat, the boiler and

chiller energy was not estimated as part of the design process and has not been metered separately from non-passive downdraft spaces. The only information available on energy consumption for those projects is that chiller and boiler energy use has not been found to be excessive in those cases.

Full Control Passive Downdraft Systems

In full control systems, where the downdraft system represents a significant proportion of the building, and where there is cooling and heating, it is very important to be able to predict the energy consumption so that design decisions regarding energy impacts can be assessed.

One method that was pursued to achieve at an operating energy outcome for the De Anza College MLC project was to generate a spreadsheet of results for a wide range of operational conditions and then use look-up tables to identify at each hour the condition that achieved comfort with the least possible cooling

This approach assesses of the energy performance for the natural ventilation system by accounting for wind pressure effects on apertures and for hours where temperature and wind conditions call for sub-cooling of the supply air to drive flow.

The primary limitation of this approach is that it is not an effective design tool because the time taken to produce results from a change in the model is too long. Seven complex simulations and time/data intensive spreadsheet post-processing are necessary for each change. Even during the LEED documentation process, variations causing modifications to the building and review comments each trigger significantly more additional work than typical to arrive at new results.

Bulk Air Flow Analysis was used to determine how frequently the supply air needed to be cooled beyond 64.4°F [18°C] to achieve an adequate airflow for cooling. These results account for the buoyancy and wind but do not fully account for the pressure drop across the cooling coil. When compared against the number of hours with an elevated temperature and low wind, they were generally consistent with the performance expected by the CFD model.

To overcome the amount of analysis needed to generate results and the need to test design options, sub-cooling was either assumed to be fully operational or not operational when considering design options being compared for their effect on energy consumption.

COMFORT ANALYSIS USING CFD

CFD modelling Method

The computational fluid dynamics (CFD) modelling method employed in this study intended to show steady state performance under particular design conditions. In the case discussed within this report, ASHRAE design conditions for the NOAA PRC

building in Honolulu, HI were used as these design conditions were also used by project mechanical engineers for component sizing. It was assumed that hourly energy simulations would provide insight into annual energy performance and a broad check of the system's ability to perform under an array of conditions.

In contrast, CFD analysis was used to ensure that the system would perform under what was identified as the worst-case scenario: a peak hour on a hot, sunny, windless day. The primary strength of CFD analysis over hourly whole building energy simulation is its ability to account for the impact of individual components within the airflow path specifically including intake units, exhaust ventilators, heat exchangers, dampers, diffusers, and grilles. CFD can also demonstrate in zone performance with a greater degree of accuracy with regard to stratification and airflow around obstructions. This section covers the methodology that was used to incorporate key design parameters into the model, the criteria used to evaluate performance, and the way in which model size and scope were selected and detailed.

Overview size and scope

The NOAA PRC project for which the analysis examples in this section were carried out is significantly larger, with three stories over 220,000 sqft (20,000 m²) serviced by the passive downdraft system.

Modelling this system in a CFD environment required that each model worked within the size and scope constraints presented by computational limits of available hardware. In particular, the approach used in this design effort defined each model to provide the highest level of meshing refinement at critical flow points as well as in the occupied zones where the temperature was a critical part of the analysis outcome. To achieve this outcome within hardware constraints, analysis was confined to a set of models that examined specific sections of interest within the building rather than attempting to model the entire building in one model. This review includes the following examples:

- The central atrium and adjacent floors including two intake shafts and one recirculating shaft for additional cooling capacity.
- A south facing representative section of the rest of the building including two intake shafts.

The primary goal through this phase of analysis was to create representative models of key sections of the building to test their ability to provide thermal comfort to occupants during design day conditions.

Intake airflows and exhaust airflows were modelled proportionately to model size so that the relevant intake- area-to-floor-area ratios were proportional to the actual ratios included in the whole building.

Meshing was refined in the following key areas:

- Rooftop intake unit especially near flow restrictions and components within the airflow path
- Rooftop ventilator exhaust units
- All cooling and heating coils
- Within the entire underfloor plenum
- Supply air diffusers
- Transfer air grilles and other flow restriction points along the transfer and exhaust air path
- Occupied zone
- Surrounding in zone loads such as façade loads and equipment/lighting loads

Performance Criteria

The key measures of success were:

- Air temperature in the occupied zone: During design development, design changes were suggested in cases when the maximum temperature in the occupied zone exceeded the design criteria of 24°C (75F). Note that it is expected that higher levels of air movement will occur in the occupied zone than is accounted for as a part of the steady state assumption. Air movement due to occupants will create a higher level of mixing and result in an average temperature between 21-24°C (70-75F).
- Airflow distribution matching across varying heat load profiles: Models were checked to ensure they showed airflow would successfully reach various portions of the floor plate to meet demand in areas with varying cooling or heating demand profiles.
- Airflow path and direction confirmation: In addition to ensuring that occupied zones were achieving temperature targets, the analysis was checked to ensure that air was flowing in the correct direction along its anticipated path. Where this was not the case, design changes were made to correct these problems.

Load modelling

The CFD model included key internal loads in addition to external conduction and solar heat gains due to the environment. Internal lighting, equipment (computer), and occupancy loads were modelled as individual loads in the space rather than as block loads to account for relevant heat plume effects.

Solar heat gain and conduction loads were added as heat flux loads on individual surfaces including the floor, walls, ceiling, and façade. The loads were derived from outputs based on hot day loads calculated by the hourly building loads model created for the purposes of energy modelling.

These models were used as a test bench for proving the concept for the specific application in addition to validating the basic assumptions made regarding component sizing and performance specifications.

Key component modelling

Pressure drops for the following key mechanical components and flow restrictions were explicitly included:

- Cooling coils
- Heating coils
- Diffusers
- Transfer air grilles
- Dampers
- Fly screens
- Exhaust ventilators

Cooling and heating coil heat transfer was modelled at a component level using a fixed temperature assumption in combination with a pressure drop restriction, which required an iteration between the CFD modelling and mechanical designers to ensure that assumed component performance and designed cooling or heating capacity were compatible under physical space constraints.

The pressure drops associated with exhaust air grilles, dampers, and other mechanical components within the air stream were included according to the pressure drop characteristics provided by manufacturers.

Tests and parameter variation

After initial results showed that airflow path and direction were confirmed to be behaving as planned and airflow distributions were adequately serving zones of varying heat loads, the goal was to ensure that sufficient airflows were being provided to reach target temperatures in the occupied zone.

The primary variables that were altered to achieve this were:

- Varying off-coil temperatures for intake shaft cooling coils (effectively increasing the buoyancy forces created by temperature difference)
- Varying area at various flow restriction points (effectively increasing face area with constant porosity)
- Varying pressure drop characteristics through flow restrictions (effectively increasing porosity through a constant face area)

Each of these variations were driven and limited by the engineering limitations, architectural limitations, or the desire to minimize increased energy usage.

For example, coil temperatures were often dictated by either dehumidification requirements or the desire to minimize overcooling and energy loss; intake shaft area, exhaust area, and other limitations were based on roof area availability and the trade-off between shaft area and usable floor area; diffuser pressure characteristics were set primarily by availability of components, architectural space limitations, or the need for weather protection.

Overall system validation: Representative building section

At a more detailed level, CFD was used to test the impact of various component sizing variables such as temperature or pressure drop. In others, confirmation was needed to show that the components were working as a system to provide the desired temperature outcomes.

In this case, the analysis was used to determine whether the system was equipped to deal with peak load conditions.

Troubleshooting potential design conflicts: Underfloor obstruction analysis

One design problem common to all underfloor systems is the circulation, flow and thermal decay of air within an under-floor plenum. CFD was used to review the impact of flow obstructions in the underfloor plenum.

The analysis method was used to study a case where shear walls blockages were shown to be preventing air from freely reaching diffusers (indicated with the black dashed box). The blockage resulted in air recirculation zones where air collected too much heat in the underfloor plenum. This issue was identified as part of the performance testing for the model.

A range of options was considered as a means of overcoming this issue. Eventually the penetration of the shear wall was found to be the most effective.

The analysis showed the impact that penetrations in shear walls were able to have in reducing the recirculation caused by the shear wall.

This is a key example of how CFD was able to address design conflicts prior to construction. In this particular case, shear walls were identified early as a potential flow blockage. CFD was able to quantify whether concern was merited. In addition, CFD allowed the team to test and quantify possible solutions.

Underfloor separation of Perimeter zones

This portion of the analysis focused on ensuring that zones with varying load profiles could achieve temperature and flow rate targets. The example shown here studies the supply of air to both perimeter offices and centre zones via a shared raised floor plenum.

This analysis tested whether walls and dampers in an underfloor plenum would be necessary to dedicate air supply to perimeter zones with higher loads and load variations.

Discussion of limitations of CFD analysis

CFD analysis was a very useful tool in answering detailed design questions regarding component sizing, overall system validation, and troubleshooting of design conflicts.

There are a number of limitations in the use of CFD to study passive downdraft HVAC systems. Some of the limitations are as follows:

- Much of the hardware currently available to engineering consultancies for doing CFD analysis is limited in capacity to study large multi-zoned models with passive downdraft systems. Although representative sections are capable of analysing key aspects of the design and airflow path, larger whole building models would allow engineers to more effectively study the detailed interaction effects of multiple intake and exhaust air flows into central spaces (such as atria);
- The impact of wind on the performance of the system is particularly difficult to test with CFD due to similar hardware limitations. External wind studies typically require extremely large domains and do not model building interiors explicitly. The authors contend that in this case, the interaction of internal and external forces are coupled sufficiently to warrant a full-scale model that accounts for both the macro scale impact of external wind forces and building level forces due to buoyancy, internal building loads, and internal and external control dampers. Unfortunately, the domain size and cell count required to include both the coarse external mesh for wind analysis and the fine internal mesh for component analysis results in a model too large use under practical time constraints.
- Another limitation of steady state analysis tools is that in operation, dampers apply a variable pressure drop to the inlets based on a goal of achieving temperature conditions in a given zone. The author is not aware of CFD analysis tools capable of this level of iteration in the steady state analysis. This means that a trial and error approach would need to be taken for each wind condition to set the pressure drop across operable dampers to the correct level. Given the time taken for each analysis run, this is not practical with current hardware and tools.

CONCLUSIONS

Based on the studies summarised in this paper, we offer the following conclusions and recommendations for the use of analysis tools in studying passive downdraft HVAC systems:

- Bulk Airflow modelling with EDSL TAS 8.5 has been found to be robust as an analysis method for determining how comfortable spaces will be for natural ventilation systems. This is supported by anecdotal evidence from operating projects that correlates quite well to predicted performance in terms of frequency of temperature ranges.
- The primary limitation to using bulk airflow modelling for passive downdraft systems is how

to account for free area openings across cooling and heating coils, which are more frequently expressed as pressure drops by manufacturers and which affect the flow of air differently to conventional natural ventilation apertures.

- CFD is a much more appropriate tool to analyse a design condition for pressure drops across any heating or cooling coils that may exist in the design. (CFD could potentially be used to back-calculate an openness or free area for a cooling coil by using a perforated plate in a design condition model and then applying that free area back into the bulk air-flow model)
- A secondary potential limitation of bulk airflow analysis is the ability of the software to account for wind shadowing caused by parts of the building on inlets and outlets although this was not borne out in the review of operational buildings.
- CFD is limited in the ability to consider the impacts of wind on inlets and outlets because of the size of domain required to combine within one coupled model, the large-scale effects of wind and the details of building level components, including, for example, the pressure impacts of dampers and coils.
- Due to scaling and computational time limitations of CFD, the best method for determining comfort for a building on an annual basis is still a bulk-airflow model with a free area correctly specified for heating and cooling coils.
- Energy analysis methods are still limited either by the ease of considering options or by the level of assumptions that are needed to make the analysis relevant. One approach that has not been described in this paper but has been used is to apply the findings of the bulk airflow analysis and CFD findings to a conventional fan-driven ventilation model. Although some post-processing is still required to account for the impact of wind, this process allows design variations to be compared against an ASHRAE 90.1 baseline more efficiently.
- The best solution would be the addition of better controls to bulk airflow analysis programs in their natural ventilation programming that can allow for the controlled heating and cooling of the air stream and air volume as part of the natural ventilation calculations. Further study of this is encouraged.
- It is recommended for all designers seeking to apply this design approach to use both CFD and bulk airflow analysis to verify the design.

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The following sources were used in for this paper:

- Built Ecology studies and reports (not publicly available) used to assess performance for the following projects:
 - NELHA Visitor Center, HI
 - Wendouree Performing Arts Center, Ballarat VIC, Australia
 - De Anza College Mediated Learning Center, Cupertino, CA
 - NOAA Pacific Regional Center, Ford Island, HI.
- Various conversations with facilities management staff at the following facilities:
 - NELHA Visitor Center, HI (2010)
 - Wendouree Performing Arts Center, Ballarat VIC, Australia (2010)
 - NIDA Foyer, Sydney, NSW (2011)

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