Passive Downdraft in California:
De Anza College Media and Learning Center

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ABSTRACT: Coastal California has a mild, Mediterranean style climate that is well-suited to natural ventilation for most of the year. However during the hotter times of the year, it is not culturally acceptable to have unconditioned buildings. A Passive Downdraft system with cooling and heating coils was designed on the De Anza College Media and Learning Center to provide year round conditioning with the energy savings and air quality benefits of natural ventilation. This paper reviews the design of the project, provides predicted vs measured temperature and airflow results for the building's performance from the six few months of operation and shares lessons learned from the design of the project for future application.

Keywords: passive downdraft, comfort, natural ventilation

INTRODUCTION

Cupertino in the heart of Silicon Valley has a fantastic climate. The winters are mild, with overnight temperatures rarely below 41°F (5°C) and long, dry summers with daytime temperatures typically around 80°F (27°C). Despite the mild temperatures, natural ventilation is uncommon outside of residential dwellings. There are three key reasons for this:

- commercial and institutional buildings are typically large with deep floor plates that make natural ventilation difficult;
- building codes for non-residential buildings have very strict ventilation requirements that must be demonstrated;
- it is not considered acceptable for indoor temperatures to frequently rise above a dry bulb temperature of 75°F (24°C).

Figure 1: The De Anza College Media and Learning Center[1].

The De Anza College Media and Learning Center (MLC) project started in 2008. The College wanted a building that provided comfort equivalent to full air-conditioning but that also achieved substantial energy savings in operation as well as a LEED Platinum certification. The client and design team determined that that a passive downdraft solution for the building's heating, cooling and ventilation would be a key part of achieving those goals.

PASSIVE DOWNDRAFT COOLING

Passive Downdraft Cooling has been an emerging concept for over a decade now with a number of projects previously well-documented[ii],[iii] and presented at PLEA[iv,v]. The term *passive* denotes the absence of fans (similar to SSESS in London), *downdraft* describes the use of heavy cool air flowing downwards to drive ventilation. It is not particularly well-known in the US and although some small projects have been relatively successful it had not previously been applied on a medium sized building such as this in California.

The concept of passive downdraft has been documented in other papers[vi]. The natural ventilation air-stream is designed such that both heating and cooling can be applied to the air-stream as needed to maintain airflow and acceptable temperatures in the spaces served. The cooling can either be done with direct evaporation or with a low-pressure drop cooling coil. The heating is usually done with a similar heating coil or radiator, also at or in the airstream.

As the cooling, heating and space buoyancy also assist with the airflow (even in still conditions) there should be no need for fans which is a key energy saving feature. With well-designed modulating controls, cooling and ventilation can be provided energy free across a wide temperature band and only in extreme conditions should the building need to supplement natural ventilation with mechanical heating and cooling.

THE DE ANZA COLLEGE MLC PROJECT

The De Anza College MLC is a 2 storey, 66,000sqft (6,180m²) educational building consisting of the following spaces:

- Classrooms for 50 or 100 students (1,600-3,200sqft (150-300m²) each);
- Administrative Office Space;
- Computer Rooms;
- TV Studio and associated recording booths;
- A large central atrium

The building is oriented along an east-west axis with a north and south facing façade. The south façade incorporates fixed external shading to block out direct sun during the warmer months. There is no shading of the north façade.

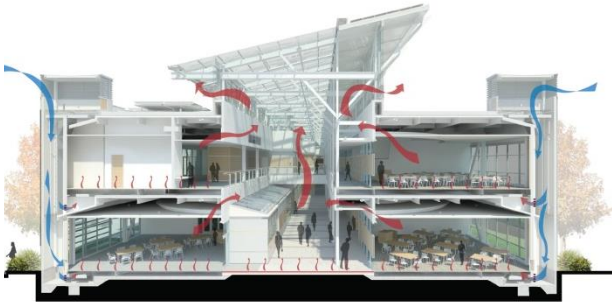

Figure 2: Architectural Sketch of the Passive Concept[vii]

Most of the spaces are conditioned and ventilated using passive downdraft (exceptions are the TV studio and recording rooms). Each 1,600 sqft (150m²) space is served by a single shaft with a minimum free area of 16sqft (1.5m²). (Most spaces are a single classroom with a capacity of 50, some are half a classroom, some are divided into multiple program spaces such as private or open plan offices. One shaft serves both a computer lab and a private office). The central atrium which serves as the passive exhaust plenum is conditioned with a radiant floor and additional hopper windows only.

At the top of the shaft are wind-directional dampers, insect screens and then a cooling coil with a rated pressure drop of 0.01 inches of water at 200 feet per minute (3Pa at 1m/s). The cooling coils ensure a maximum supply temperature of 75F/24C, with the temperature reset down as low as 57F/ 14C to maintain the zone cooling set-point when it cannot be achieved with the dampers fully open.

The base of the shaft turns back upwards where a heating coil (also rated at 0.01 in H20 at 200fpm) maintains comfortable supply temperatures (>60F / 15C) at the entry to an 18 inch (450mm) raised floor plenum. Two sets of dampers separate the shaft from the rest of the raised floor. One damper opens to the perimeter, the second to the center zone. Air flow monitoring is installed at each damper. The dampers modulate first to provide cooling. When the dampers are fully open and the space is too warm the cooling is activated.

The raised floor has a large amount of diffusers, mostly located around the perimeter that provide a total of 16sqft (1.5m²) free area. In the ceilings of each space there is a void with a 16sqft (1.5m²) transfer plenum to that leads the air to the top of a central atrium.

In the atrium, wind-directional dampers open on the leeward side only to relieve the air out the building. The free area of the dampers is equivalent to 1% of the entire floor area of the building.

A 1,500 sqft (140m²) solar thermal array combined with a 4,000 gallon (15,200L) tank was designed to provide 40% of the heating hot water demand. The remainder of the hot water and chilled water is provided by a district heating and cooling loop. Excess heat from the solar thermal array is added to the district heating loop when the tank is fully charged.

The college conditioning is on from 6am to 10pm, Monday to Saturday.

ANALYSIS METHODOLOGY - DESIGN

Most of the analysis used to the design the building used bulk-air-flow analysis (using EDSL TAS 8.5)[viii]. Thus the method similar to that used for naturally ventilated buildings. The heating and cooling coils were mimicked through the use of small bulk zones were added at the points where there was heating and cooling to condition those zones. These zones were controlled to condition a small zone in the airstream to the off-coil condition, which then allowed the natural ventilation calculations in the software to estimate the impact on airflow.

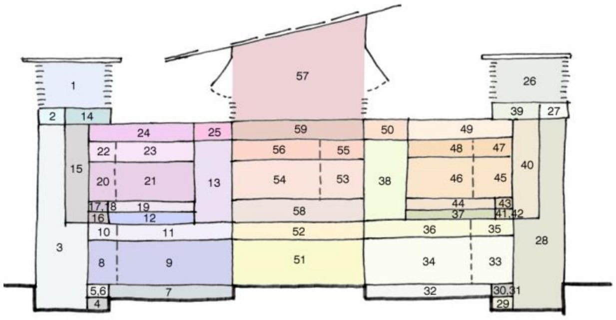

Figure 3: Zoning diagram used for bulk air flow analysis. [ix]

Intake dampers that respond to wind direction at the roof were controlled using a schedule programmed based on the wind directions and speeds annual weather file. The intakes were set to always open in the windward direction and close in the leeward direction. At wind speeds less than 5mph (2.2 m/s), all intakes opened.

The sectional zoning diagram below shows how the building was divided into bulk thermal zones. Spaces with identical design loads, orientations and areas were modelled with duplicate zones.

This model was used to test the performance on an annualized basis in the same way that a natural ventilation model would study the frequency of hours with temperature thresholds exceeded. The goal was to achieve internal temperatures for all zones in the range of 70-75°F (21-24°C) for 98% of hours.

This test model found that for the second floor, an off-coil temperature for cooling of 57°F (14°C) was necessary to drive the flow of air, with reheating of the air up to 65°F (18°C) as it entered the plenum. The thermal model uses only free area for air restrictions, so hand calculations considering pressure drop were also used to check pressure drops at the design condition.

ANALYSIS METHODOLOGY - ENERGY

The design model was also used to determine the load on the cooling and heating coils for the system. This turned out to be complicated because the TAS software used was not able to control the off-coil temperature in a cooling zone to achieve a space temperature, especially with the primary control being an aperture at a different zone boundary.

The result was that each off-coil condition for cooling in 1.8°C (1°C) increments from 73.2°F down to 57°F (23°C to 14°C) needed to be tested with temperatures and coil loads output to a spreadsheet. The maximum off-coil temperature that could meet the zone setpoint was noted and the corresponding coil loads used to determine energy. Since this design, we have found that IES Virtual Environment now has controls that are able to mimic the system with minimal post-processing.

Once the hourly coil loads were calculated, supplemental spreadsheets were used to compare incident loads with the hourly output of the solar thermal array and the storage tank instantaneous capacity. This allowed these two components to be sized optimally.

For cooling energy, a simple COP was used for the district plant because there was not enough information available on the dynamic COP range of the district system.

Pumping energy was accounted for hourly by looking at the load on different components, a design temperature difference across the heating and cooling networks and the pump efficiency curves.

POST OCCUPANCY MEASUREMENT

The project design team is engaged in an on-going basis to measure and verify the performance of the building systems and make sure that no further adjustments need to be made to achieve the project's performance objectives.

A wide range of sensors are included in the project to test performance. These include:

- Center and perimeter zone thermostats in each 1,600sqft (150m²) space;
- Thermostats in each shaft to determine dry-bulb temperature after the cooling coil;
- Thermostats in each raised floor plenum to determine supply temperature;
- Air-flow monitoring across each damper;
- CO2 monitoring in each center zone;
- Btu (load) meters across 4 typical cooling coils
- Btu (load) meters across 4 typical heating coils
- Btu (load) meters measuring chilled water and heating hot water use from the district
- Btu meters for solar thermal input
- Status and position readings for a wide range of components including dampers and valves

The results will show that these measurement points have been invaluable in showing how the system is working and also in troubleshooting features that were overlooked during design, construction or commissioning.

The building has been operating since September 2012. Measured data has currently been collected for the period up to the end of January, 2013.

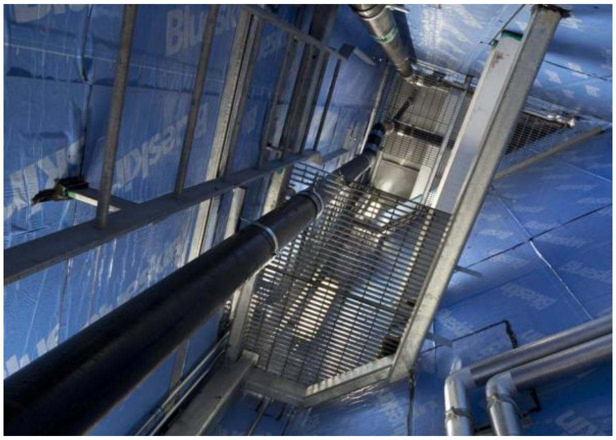

Figure 4 – Photo of the interior of the shaft[x]

MODELED VS ACTUAL – SUMMER DAY

The building has not been operating for a full year yet, but we were fortunate that in the 3rd week of operation (which corresponded with the first week of October, 2012) there were extremely hot temperatures for which data on comfort performance was obtained.

These temperatures exceeded the highest temperatures in the weather file used to assess the annual comfort performance. As a result, the temperatures from the hottest day in the weather file analysed have been compared with the recorded data from the hottest day in October.

The following charts show results for the following spaces that were known to be occupied during the day:

- Level 1 south facing classroom
- Level 2 north facing classroom

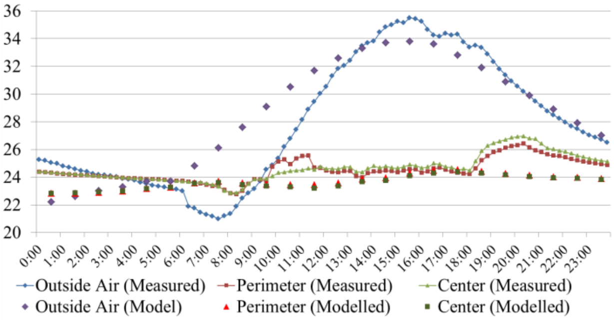

Figure 4: L1 South class – summer temperatures (°C)

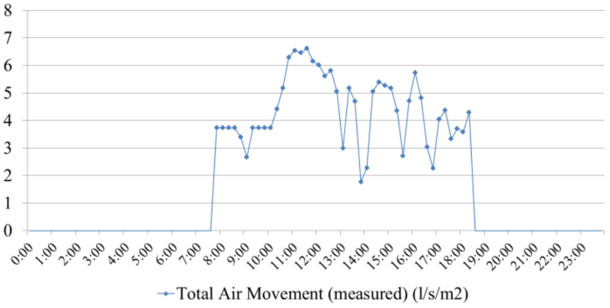

Figure 5: L1 South classroom – air flows

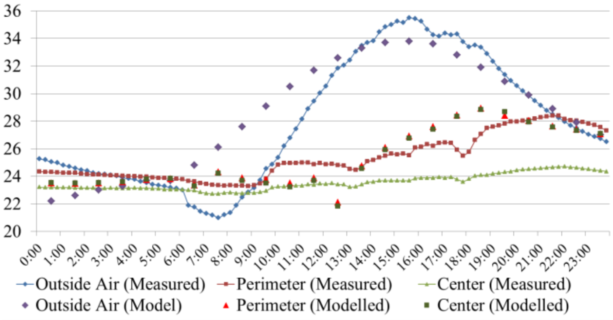

Figure 6: L2 north class – summer temperatures (°C)

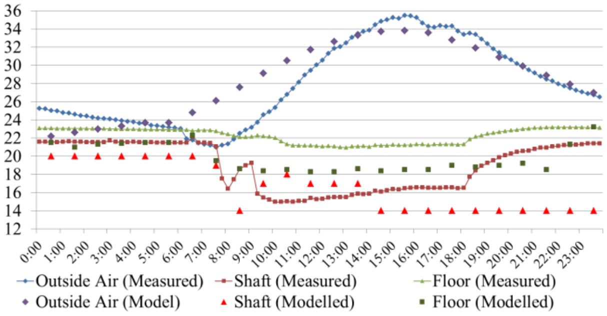

Figure 7: L2 north classroom – summer shaft and raised floor temperatures over 24 hours (°C)

We made 3 observations from the actual data to improve performance:

- The data indicated that cooling setpoints in the controls had been set at 78°F (25.5C) instead of 75°F (24°C). These values were subsequently changed.
- The temperature increased significantly after 6pm when the building was found to have shut down. The operating schedule was subsequently changed.
- The raised floor temperature was found to be higher than expected for the amount of cooling provided. It was concluded that the thermostat should be moved closer to the damper.

More importantly, the results show:

- The design approach for designing cooling was effective in sizing a system that would meet the college's cooling expectations;
- The level of control over the zone temperature was better than expected, with temperatures fluctuating within a 3°F (1.5°C) band.

Airflows were also measured for the zones described above. The modelled vs actual airflows achieved during the peak day are shown in the graph below.

The actual airflows are slightly lower than anticipated. This is probably because the thermostat that controls the reheat coil was found to be located too far from the supply point in the raised floor plenum. As a result, the air supplied to the zone for cooling was at times significantly lower than the modelled 65°F (18°C) setpoint, meaning that less air was needed to maintain the zone cooling setpoint.

Interesting anecdotal and observed feedback of the system is that with a design airspeed of less than 200 feet per minute (1m/s) the air movement is practically imperceptible at the diffusers. This means that future buildings could probably get away with lower supply temperatures than 65°F (18°C) (which is what is happening here anyway) without compromising occupant satisfaction.

In a general observation of preliminary feedback from building occupants, women have found the building to be more comfortable and men less so. This is probably because there is much less of a sense of draft than with conventional air-conditioning systems.

MODELED VS ACTUAL – ATRIUM IN WINTER

One of the key early observations from the building when the weather got cold was that the atrium was significantly colder than in the thermal model and was consistently cold throughout the winter. The chart below shows the atrium temperatures for a series of winter days compared to modelled conditions.

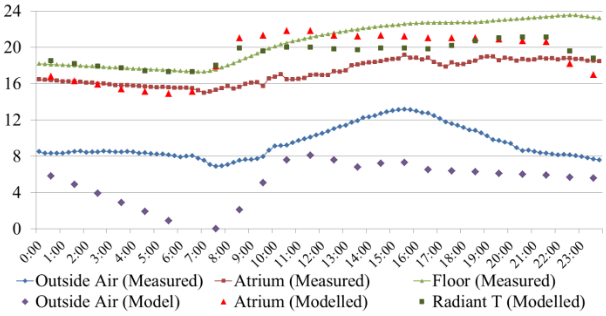

Figure 8: Atrium winter air & radiant temperatures (°C)

This finding was consistent throughout the winter and the atrium was frequently reported as cold.

Some operational issues were identified that could have been the cause included:

- Inconsistent operation of the radiant floor and faulty valves in the manifold, which were subsequently replaced;
- Lower occupancy rates and therefore less spill air emerging from the classroom spaces into the atrium;
- Early opening of dampers during morning warm-up, frequently causing the building to have trouble reaching design temperature in the atrium;

In spite of these factors, however, a similar trend had been identified on a similar project with a similar design approach. On that project, the controls for the relief dampers had full modulation (although the initial controls had not set them up to use modulation) and once the dampers were modulated down to maintain a setpoint in the atrium space, the problem of the cold atrium was significantly reduced.

We therefore have a theory that the bulk airflow analysis may not be as accurate when considering cold outside air cascading into the atrium from openings that are too large at the top. Perhaps the zone configuration in the model created too many boundaries between the occupied zone and the atrium, or perhaps assumptions about the convective heat transfer of the radiant floor were too optimistic.

In any case, as additional results are available and once we can confirm properly the correct operation of the radiant floor, we will be able to provide a more detailed assessment of this issue.

In the meantime it would be prudent for anyone pursuing this design approach to employ multi-stage or modulating dampers at the atrium relief. Computational Fluid Dynamics is also recommended for the design verification of the radiant floor in this situation as well.

MODELED VS ACTUAL – ENERGY AND CO$_2$

Although there are a number of Btu meters in the heating system including 4 for individual heating coils (not perimeter radiators) and one for the district hot water system, it has not yet been easy to get accurate data for the energy consumption during the first winter.

One interesting observation is that there is significantly less ventilation that anticipated from the modelling, partly because the thermal model maintained high occupant and equipment loads that required cooling air to maintain setpoint.

The following chart shows first week of December in one of the double classrooms. The CO$_2$ levels in the classroom are tracked and never exceed the control threshold, despite there clearly being occupancy. Heat is presumably lost through infiltration, conduction through glazing and probably air exchange with the cold adjacent atrium space.

This data has led the college to reduce the CO$_2$ thresholds after studying the winter data in order to encourage more ventilation and operation of openings. Note there are no issues with the system being able to provide ventilation, as typical airflow rates when the dampers are opened to provide cooling are over 0.65cfm/sqft (3.3 liters/s/m2)

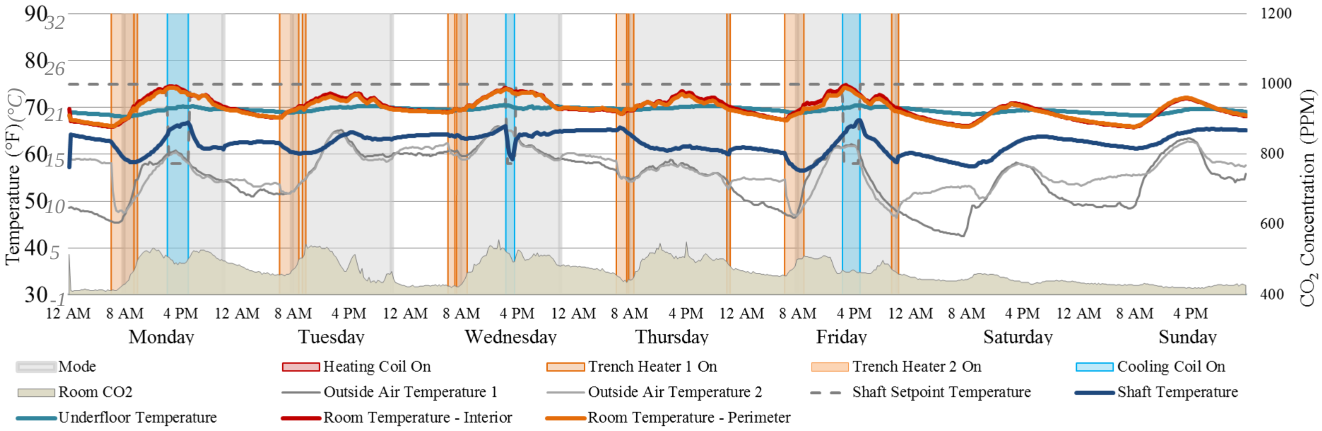

Figure 9: December week of measured data including CO2 emissions

CONCLUSIONS

There are many more observations that can be made from the measured data of the passive downdraft system at De Anza College. This short paper covers some of the key observations that were most poignant from this process and that hopefully provide the broadest interest and applicability to other projects.

These observations are:

- The passive downdraft system at De Anza College has been observed to achieve temperatures and airflows that provide a high degree of comfort in external design conditions that are well above the space cooling setpoint;
- The use of bulk air flow calculations and hand-calculated pressure drops was effective at designing the passive downdraft system in cooling;
- Modulation of dampers should be provided for both relief and supply dampers in passive downdraft systems;
- There may be some limitations in the effectiveness of bulk air flow modelling to study downdraft effects in an atrium although this is still to be confirmed;
- Inter-zone air movement, infiltration and heat loss through glazing are observed to be in full effect in the building as means of providing cooling and ventilation in winter for heavily occupied classrooms.

Future studies and analysis of the building will focus on heating effectiveness and in the energy efficiency in heating and cooling of the system. The building is also a good test case for pure displacement ventilation and it is anticipated that stratification and thermal decay studies will also be worthwhile.

ACKNOWLEDGEMENTS

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[vii] Sketch courtesy of Ratcliff Architects, California

[viii] Performance Analysis Methods for Passive Downdraft HVAC Systems, A Corney, IBPSA 2011

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[x] Photograph credit: David Wakely