Visible Ventilation: A Return to Passive Cooling

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ABSTRACT: In 2007, the University of Oregon signed the American College and University Presidents' Climate Commitment to take steps toward becoming a carbon neutral campus by reducing greenhouse gas emissions and integrating sustainability into their curriculum. With fossil fuels supplying 76% of total building sector energy consumption (Architecture2030), campuses must adopt energy efficiency policies, which establish more stringent energy targets for new and existing construction, while utilizing renewable energy sources.

There are more then 60 double loaded corridor buildings on the University of Oregon campus that rely solely on mechanical cooling. Pacific Hall, which is one of these types of buildings, is the focus of this study. It is a long, narrow building oriented north-south, and occupants on the east and west sides often complain of thermal discomfort in the morning and the afternoon. Over the years, renovations have covered transoms above doors, openings to the corridor have been blocked, and windows, though operable, are generally left closed. Our approach to determine the passive cooling potential includes: 1) climate analysis, 2) building measurements (enclosure and interior wall systems, building proportions, operable glazing ratio), 3) onsite measurements of building base case conditions (temperature, humidity, surface temperatures, air movement, CO_2 levels), and 4) development of appropriate climate-responsive renovation strategies. The effectiveness of these strategies is evaluated through 5) prediction of comfort using the ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy, 6) manual calculations using passive cooling guidelines and computer simulations to examine energy use comparisons, and 7) a carbon emissions saved calculation.

We found that Pacific Hall can rely on passive cooling for 5 months of the year with minor interior renovations. Energy analysis revealed an EUI savings of 149.5 kWh/m^2 (25.3 kBtu/ft^2) per year. Such a protocol reveals a fairly easy approach to examine other buildings on campus and estimate the overall campus carbon reduction that is possible through a shift from mechanical to passive cooling.

KEYWORDS: ventilation, campus buildings, passive cooling, natural ventilation, energy conservation

INTRODUCTION

Not long ago, most campus buildings functioned as naturally ventilated, passively cooled buildings, but with the rising demand for air conditioning, many have moved toward active systems. As new energy conscious buildings are constructed on campus, we wondered about the potential to renovate existing campus buildings to provide occupant comfort with passive cooling.

With the building sector continuing to contribute almost half (46.7%) of the emissions to the atmosphere (U.S. Information Administration on Architecture2030.org) from the burning of fossils fuels to run HVAC and electrical systems, we must seek reversible ways to reduce or eliminate such emissions. One of the opportunities to do so lies in the extraordinary amount of square footage needing renovation in existing buildings. It is estimated 75% of the current building stock in the US will be renovated or newly constructed by 2035 (Architecture2030.org). Such renovations would primarily involve envelope retrofits (insulation, new windows, tightening); replacement of mechanical systems; re-lamping spaces (already underway in many buildings), and thermostat/building automated systems. Rather than tear down usable buildings, the research focuses on examining a common campus building type (double-loaded corridor) and determining its potential for natural ventilation. Though the study is somewhat hypothetical in nature, staff from the university campus facilities and planning are curious about these issues relative to building systems, operations, energy, and comfort.

1.0 BUILDING BACKGROUND

On the University of Oregon campus, there are more than 60 double loaded corridor buildings, constructed more then twenty years ago. These buildings rely on continuous ventilation, operated by a simple building operation system, which does not take into account CO_2 or variations in occupant load. This ventilation system operates with the heating and cooling system, however it is not tied into the heating units. The temperatures and minimum ventilation for the occupancy are the driving factors behind the ventilations system. This system utilizes a large amount of energy, since there is a tight temperature range that most occupants find too warm, which could be saved by relying on passive ventilation for a few months of the year. Pacific Hall, constructed from concrete masonry units (CMU), is a double loaded corridor building, meaning there is a central hallway with rooms on either side. The hallways receive no daylight (see Fig. 1a) as the interior walls are also constructed with floor-to-ceiling CMU and solid wood doors leading into each room. Currently the building has a variety of uses, the second floor, the section chosen for this case study, houses architectural studios and a few office laboratories. However, when Pacific Hall was completed in 1951, the intended use was a variety of science laboratories, which required individual ventilation of each room. Because of this requirement, a “breather corridor” (see Fig. 1b) was built on either side of the hallway to contain all of the mechanical and electrical systems for each room. All of the doors from the laboratories into the corridor originally had transoms above them, which provided air circulation and daylight, however these were covered in the 1980s.

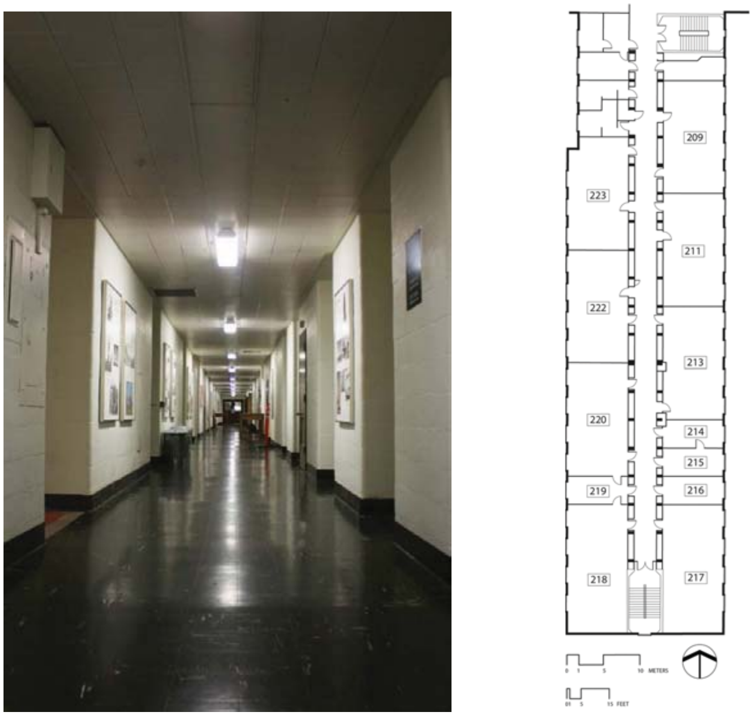

Figure 1: (a) Pacific Hall double-loaded corridor hallway; (b) Second floor plan of Pacific Hall with design studio classrooms and walls, called “breather corridor” containing the unused ventilation ducts.

The individual room ventilation systems are no longer in use since the chemical laboratories have been converted into architectural studios. The ventilation system outputs a consistent amount of fresh air, based on the occupancy of the entire floor. The heating system is separate from the ventilation system: heat for the classrooms is provided through large radiators, fed by the campus steam tunnel, which sit below the windows in each room.

The hypothesis of this paper challenges the current mechanical ventilation strategy of Pacific Hall by proposing that passive ventilation will be as successful as the primary ventilation strategy from May to

September. The hypothesis assumes the success will involve opening the non-structural interior walls to the hallway and reusing existing ductwork from most of the rooms to exhaust hot air directly to the roof.

2.0 METHODOLOGY

The methodology evaluates base conditions and seeks an appropriate low-energy, passive climate response; manually calculates the passive cooling potential; evaluates and verifies the manual calculation with building energy simulation and provides a reasonable design solution for Pacific Hall.

2.1. Base Conditions

Using the psychrometric chart and Climate Consultant 5.4 (UCLA), we determined that natural ventilation is a comfortable and viable strategy for the climate of Eugene, Oregon, from May to September. Passive cooling analysis indicates cross ventilation and stack ventilation as the most feasible strategies. Three rooms on the east side of Pacific Hall, (222, 223 and 220) and one room on the west (213) were selected as classrooms to study because of their use as architectural studios and our ability to easily access those rooms. We gathered temperature, humidity, and carbon dioxide levels in each classroom. These conditions were measured with Onset HOBO data loggers and Telaire carbon dioxide meters over a six day period to capture weekday and weekend occupancy. The existing mechanical system output was spot measured with a balometer. Students were asked not to open the windows so we could determine the conditions based on the HVAC systems. Additionally, information on the structural system and materials of the building were gathered to help guide renovation schemes to reach the performance goals.

2.2. Development of Climate Responsive Design

We examined additional user criteria to achieve successful cross and stack ventilation strategies, such as the use of the rooms, and the occupants needs. These rooms are completely closed with solid doors that operate with a key code. Occupants of the studio classrooms desire more visibility between the rooms to facilitate communication with their classmates. Faculty thought more visibility would develop better camaraderie when the students could see each other’s work. The idea of opening up the walls to the corridor takes into account occupant desires and also facilitates the cross and stack ventilation strategies.

2.3. Evaluation and Analysis Procedure

Two methods were used to determine the viability of the these passive strategies: 1) manual calculations using equations in *Mechanical and Electrical Equipment for Buildings* in which the ventilation from stack and cross ventilation were compared to the current ventilation and heat load in each room, and for the floor as a whole; 2) a building energy modelling simulation tool, DesignBuilder, to determine energy utilization intensity. Since specific construction details for Pacific Hall were not available, certain assumptions were made: U-value of 2.27 W/m^2K (0.4 $Btu/hft^{2}°F$) for the walls; internal gains for people and equipment, 12.0539 W/m^2K (3.4 $Btu/hft^{2}°F$) for office typologies (Grondzik, et al, 2010*)*. The average load over time is assumed to be the same as an office, despite the fluctuating all-night occupancy of architectural studios.

The actual energy use for the building from utility bills, are unavailable due to the segmenting of energy use to buildings on campus. Most buildings run on steam (for heating and cooling) from a central plant on campus; and electricity is not submetered at the building.

3.0. RESULTS AND DATA

3.1. Climate Data

The initial climate data for Eugene shows a fairly short cooling season (July, August), and a potential for cross and stack ventilation during this short cooling season. The psychometric chart, (see Fig. 2), shows that on the warmest day, 8 hours of the day are above the comfort zone, shown by the red line to the right of the comfort zone. However, these 8 hours all lie within the range of natural ventilation. For the warmest part of the year, passive ventilation could also become a cooling strategy for these classrooms. The average wind speed for May-September (Fig. 3), is 11km/h (7 mph). However, the design calculations can rely on no more then 9.7km/h (5 mph) since that is the lowest value, and it is better to underestimate than overestimate the wind for cross and stack ventilation.

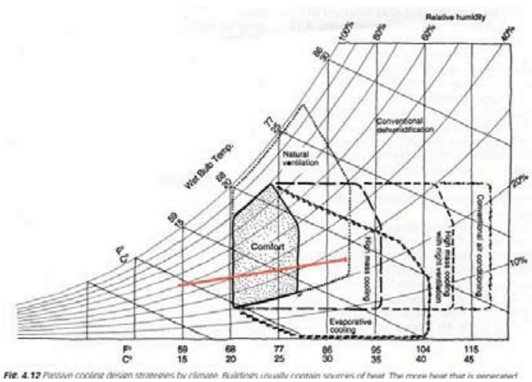

Figure 2. (left) Averaged climate data for Eugene plotted on the psychrometric chart. Source: Grondzik, et al., 2010.

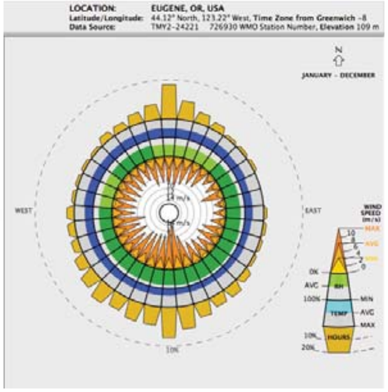

Figure 3. (right) Wind rose for Eugene from May to September. Source: Climate Consultant.

3.2. Base Classroom Conditions

The interior and exterior temperature, relative humidity and carbon dioxide levels were recorded in each case study studio from November 9, 2012 at 1pm until November 14, 2012 at 12pm. The data (Fig. 4) reflects the fluctuation in conditions provided by the mechanical systems. The interior temperatures in all four classrooms show relative thermal consistency between 18°C (65°F) and 22°C (71°F), with the exception of room 220, where the temperature drops at 8pm and increases rapidly again at 4am; this seems characteristic of HVAC timer control. The other classroom temperature dropped slightly as well, but the system seems to maintain consistent comfort temperatures. Classroom carbon dioxide levels generally fluctuated between 400 ppm and 850 ppm. Though not shown on the chart, outdoor carbon dioxide levels during the period of study was 331 ppm, and the existing mechanical system had a measured output of 0.24 m^3/s (160 cfm).

The temperature and CO_2 increases appearing on November 12 from 12pm to 5pm correspond to full occupancy because the students were preparing for a design review during the following day. In room 222, CO_2 levels spiked irregularly as high as 2400 ppm on November 13 between 7:45 pm and midnight. We do not know if this was due to a malfunction of the CO_2 monitor or due to something occurring in the mechanical system. In room 223, the CO_2 levels were consistently 200 ppm higher then the other rooms, likely due to larger number of occupants in that particular room. There was no difference between CO_2 levels based on east or west orientation. We determined from the data that the current mechanical system runs constantly, regardless of carbon dioxide levels, is fairly responsive to occupancy, and maintains physical conditions within the comfort zone specified by ASHRAE Standard 55-2010.

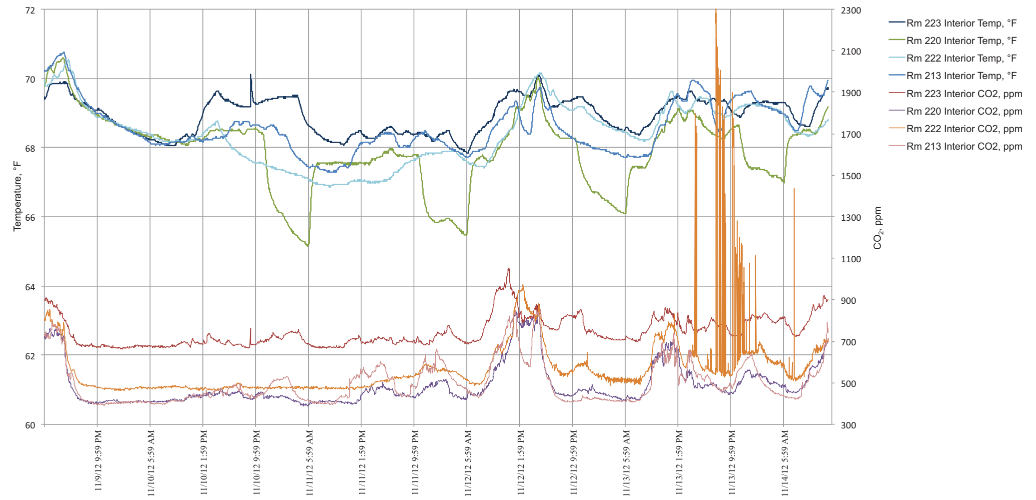

Figure 4: Temperature and carbon dioxide levels in Pacific Hall classrooms from November 9-14, 2012.

3.3. Manual Calculations and Analysis

The 88.1m^2 (948ft^2) studios in Pacific have 2.1m^2 (23ft^2) of operable window area, but only 2.0 m^2 (21ft^2) of operable door area to the interior corridor. In order to accurately calculate the passive ventilation needs of the studio rooms, we first determined the heat gains for each case study room. Per table F.3 in *Mechanical and Electrical Equipment for Buildings*, the internal heat gain from people and equipment is estimated at 11 W/m^2 (3.4 Btu/hft^2), while the internal gain from electric lights, based the room's daylight factor of 2.7%, is 6.3 W/m^2 (2.0 Btu/hft^2). Through the envelope, the gains through the walls are 8.2 W/m^2 (2.6 Btu/hft^2), while the gain through the windows, with interior blinds, is 19 W/m^2 (5.9 Btu/hft^2). Since the other walls, floor, and ceiling are shared with conditioned interior space, the gains and losses between these spaces are negligible. The total gain for each case study room in Pacific is 44 W/m^2 (13.9 Btu/hft^2), which on the hottest day of the year means that 931.2 W (13,177 Btu/h) are required for cooling. The minimum ventilation requirement for these studios, based upon 20-person occupancy, is 94.4 L/s (200 cfm).

Initially stack and cross ventilation were looked at as individual strategies to see if either one alone could provide the necessary ventilation and cooling on the warmest day of the year. For both stack and cross ventilation, the procedures are based upon the methods in section 8.14 in *Mechanical and Electrical Equipment for Buildings*. In both calculations a maximum interior temperature of 24°C (75°F) is used.

Stack ventilation calculations are based upon the following equation.

$V = 1000KA\sqrt{(2gh(T_i\text{-}T_o)/T_o)}$
V = Ventilation airflow, L/s
K = discharge coefficient, 0.65
A = Inlet or outlet area, whichever is smaller, m^2
g = gravitational coefficient, 9.8 m/s^2
h = stack height from inlet to outlet, m
T_i = the indoor temperature, °R
T_o = outdoor temperature, °R
°R = °C + 273.15

The initial calculations looked at stack ventilation solely utilizing the existing chemical hood ventilation, with the existing 1 square foot of opening, and height to the roof of 12m (38 feet), neither increasing the diameter, nor the height above the roof. The results show a capacity of 165 L/s (349.7cfm), which equates to 1916.6 W (6539.0Btu/h) on the warmest day of the year. Therefore, although the stack by itself would provide sufficient ventilation, it would not provide enough cooling to fully replace air conditioning on the warmest days of the year.

The cross ventilation calculations began by assuming the openings into the corridor would equal the operable window area of 2.1m^2 (23 ft^2) in the adjacent studios, as well as a maximum reliable wind speed of 8km/h (5mph). Since the windows are perpendicular to the prevailing wind, there is an effectiveness reduction factor of 0.6. Pacific Hall is also located in an area of dense buildings, so there is an additional urban reduction factor of 0.35. In addition to these wind reductions, another reduction of 0.45 is made for hopper windows, which allow 45% of the total opening to pass air into the space. The following equation is used for cross ventilation calculations.

$V = 1000C*A*v_w$
V = Ventilation airflow, L/s
C = effectiveness factors
A = operable window area multiplied by window type reduction factor, m^2
v_w = Wind velocity multiplied by urban reduction factor, m/s
1000 = conversion from m^3/s to L/s

This equation yielded a ventilation rate of 458 L/s (970.1cfm), higher than the required ventilation rate of 94.4 L/s (200 cfm). This converts to 1251 W (4268 Btu/h) on the warmest day of the year, an insufficient amount to replace mechanical cooling. On their own, both stack ventilation and cross ventilation strategies would provide the required ventilation but not the required cooling on the warmest day of the year. However if the two strategies are combined, they could together cool Pacific during the warmest time of the year, while providing adequate ventilation during the remaining portions of the five months for which we determined passive ventilation is a viable strategy.

Opening the hallways to a portion of operable window area, 1.3m^2 (14ft^2), in each studio would yield 785 L/s (1,663.2cfm) and 2,144 W (7,318 Btu/h). Allowing the stack vents to remain as is, and combined with the partial opening of the hallway would yield a total of 819 L/s (1735.5cfm) and 4,065.5 W (13,857.3 Btu/h), which is both adequate for ventilation and cooling in the peak of summer.

3.5. Building Energy Model

For the building energy model, DesignBuilder was chosen to analyze energy use, cross ventilation and air movement via computational fluid dynamic (CFD) analysis. In the simulation, the first floor and northern segment of Pacific Hall were excluded from the simulation. All surfaces adjacent to excluded spaces were defined as adiabatic and do not contribute to heat loss or heat gain. Custom construction templates (based on modified IECC-1998 Semi-exposed, medium weight construction) were defined for the exterior wall, interior partitions, floors and windows to match the transmissive properties used in the manual calculations. Given the nature of the equipment activities and schedules associated with Pacific Hall, the “Office-OpenOff-Occ” template was used in this simulation. Steam to hot water DHW supply, radiator heating fixtures, shading from adjacent trees and contributions of adjacent buildings were additional elements that were excluded.

Given our interest in examining the potential for passive ventilation to substitute the mechanical cooling and ventilation systems, the simulation time period was constrained from May to September.

Table 1: Summer site energy EUI for case study building area

	Energy Per Total Building Area kW/m^2 $[kBtu/ft^2]$
Pre-Renovation	126 (39.8)
Post-Renovation	45.7 (14.5)

Simulated results for the summer season (May 1 - September 30) indicate a pre-retrofit EUI of 126 kW/m^2/summer (39.8 $kBtu/ft^2$/summer) and a post-retrofit EUI of 45.7 kW/m^2/summer 14.5 ($kBtu/ft^2$/summer), representing a 79.8 kW/m^2/summer (25.3 $kBtu/ft^2$/summer) or a 65% decrease in energy consumption for the simulated time period. Since the retrofitted area of 537 m^2 (5,780 ft^2) represents 23% of the total simulated area 2408.7 m^2 (25,927 ft^2), there would be a larger savings in energy over the entire building.

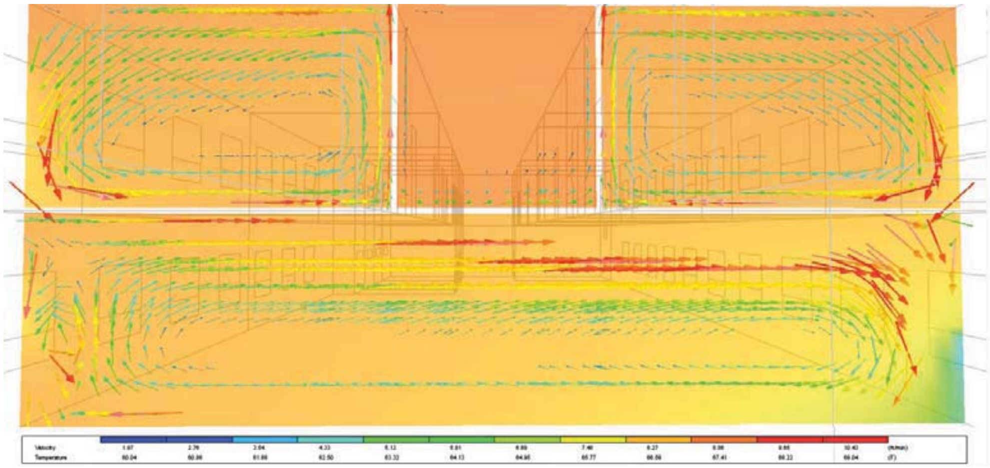

Figure 5: Computational fluid dynamics analysis illustrating the range of cool (blue) to warm (red) temperatures. The colored arrows indicate air velocity from 0.003 m^3/s (1.9 cfm) to 0.02 m^3/s (10.4 cfm).

A single CFD slice for the cross ventilation strategy through the renovated simulation model (see Fig. 5) shows a clear comparison of typical existing conditions (top floor) and typical renovated conditions (bottom floor). In the above illustration it is apparent that 1) there is a cooler and more even distribution of temperature across the building section, and 2) there is a higher velocity of air movement within the renovated building area. Both these factors will contribute to decreased energy use and increased occupancy comfort during the summer months. Due to an underestimation in difficulty of time and scope that it would take to do an accurate CFD model for the stack ventilation strategy, that component was excluded from the simulation.

Similar to the manual calculations performed, this simulation suggests that there is a net energy savings and increase in occupant comfort as a result of passive cooling. However, both the CFD and energy analyses present a scenario that is less effective than the manual calculations indicate. This discrepancy raises the question of whether the manual calculations are not accurately accounting for complex variables, or whether the simulated models are underperforming due to a lack of detail and specificity within the modelling parameters. Our inclination is toward the latter, which presents a further dilemma. Without question, digital simulations of this nature produce results and graphics that are the product of a more robust calculation, and yet this does not necessarily equate to a more informed results, but rather a result with more information. All of this underlines the importance of consulting proven strategies and guidelines during these types of investigations.

3.6. Renovation Strategy and Architectural Impact

The renovation strategy for Pacific Hall relies on both cross and stack ventilation. Since there are existing ceramic vents from each room up to the roof, minimal construction would be required to convert these to stack ventilation cavities. Each room also has enough windows to provide cross ventilation, presuming the hallway can have the same size openings installed to allow proper airflow. The illustration (see Fig. 6) shows the corridor with lowered walls to allow for cross ventilation, better light distribution through the hallway, and increased visual connections to create a sense of community between studios.

The implementation of proposed ventilation strategies would greatly benefit the internal spatial configuration of the Pacific Hall studio spaces. The partial or full removal of interior corridor walls could simultaneously improve daylighting and social characteristics of space while achieving a highly efficient ventilation strategy. In Pacific Hall, there are concerns about noise levels with the opening of the corridor walls, since every surface is concrete, however, these can be dampened with acoustic paneling.

The design was first approached by looking at the locations of the existing ducts within the breather walls and their proximity to structural columns. Many of the ducts are not longer in use, or can be moved to alternate locations. Ducts that are next to columns will remain a single mass, while the remaining breather wall cavities are seen as opportunities for low walls or pinup spaces for each studio. As the renovation iterations continued, it became clear that a series of conditions had to be met to justify the implementation of a low wall, set at 48 inches from the floor. The security of each studio was a concern when developing renovation strategies, as these studios are currently closed. However, many of the architectural studios at the university are open, with the only locks being on individual student desks. The low walls would allow for a stronger visual connection into the studios by people passing, and most importantly, they begin to open the dark hallway and create connections between the many studios.

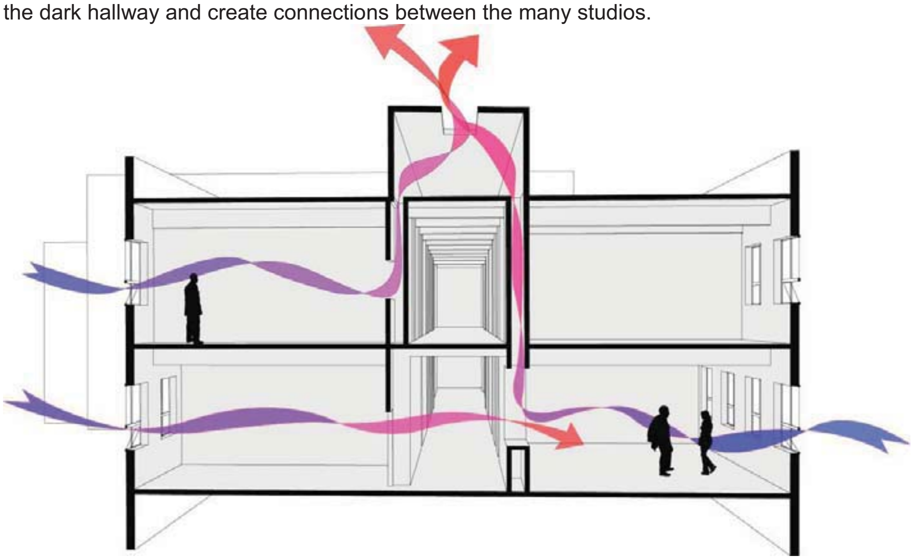

Figure 6: Renovated half walls to facilitate cross ventilation. Stack ventilation occurs through existing ductwork.

CONCLUSION

Although the building energy model and manual calculations have some discrepancies, they both reach the same conclusion that the proposed renovation in Pacific Hall would be an improvement over the current conditions. The manual calculations conclude that a hybrid strategy of cross and stack ventilation would be the best solution, while the building simulation model showed success with cross ventilation, despite the stack ventilation not being modeled.

Pacific Hall is fortunate to have existing ventilation stacks from each floor to the roof. This study found that Pacific Hall can be passively ventilated from May to September and cooled on the warmest day of the year by renovating the hallway and utilizing both cross and stack ventilation strategies. The passive ventilation reduces the EUI by 79.7 kWh/m^3 (25.3 kBtu/ft^2), which equates to a 7029.1 kWh (23,984.4 kBtu) savings per classroom, during the summer.

Despite the mostly correlating conclusions, we were surprised by the discrepancies between the two calculation methods. Each of these methods make assumptions about the surrounding conditions and the reliable amount of wind, yet the manual calculations are more sure of the feasibility of cross and stack ventilation as a combined strategy for natural ventilation. With all the new CFD and building simulation software available, as designers, we have many options for analysis. Yet, how do we rely on the accuracy of each method? Do we trust the manual calculations that have been tested over time and proven to work, or do we trust the new building simulation models that can take into account a multitude of factors? These questions are important for the profession, educators, and most importantly for the generation of future designers (students).

Many other buildings on campus can be examined in a similar evaluation of passive ventilation potential. Through this study, we have shown passive cooling to be a viable option in this typology of campus buildings with the climate of Eugene. However, implementation is not without barriers. In each building, a close look at the use of the spaces and feasibility of stack ventilation would be necessary in order to implement the same methods as Pacific Hall. In many buildings on the University of Oregon campus, which were not originally science buildings, an alternate method to stack ventilation, such as night ventilation of thermal mass might be a more viable option. Also, there are opportunities to look into advances in HVAC control and systems for hybrid ventilation strategies over the course of the year. This study serves to show the potential within many campus buildings to conserve energy during the summer months while keeping occupants comfortable. Converting even a few buildings to passive ventilation during the summer months would save the university money, reduce our carbon footprint, and help the university reach the goals agreed upon in the American College and University Presidents' Climate Commitment.

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