IT'S HOT UP HERE! A STUDY OF THERMAL COMFORT IN THE LILLIS BUSINESS COMPLEX 4TH FLOOR OFFICES

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ABSTRACT

We studied the passive systems of the Lillis building in order to determine why occupants of the fourth floor offices reported uncomfortably hot temperatures in summer during the one-year post-occupancy evaluation. We hypothesized that the passive cooling strategy employed in the building does not provide thermal comfort to the fourth floor offices. Our results, while inconclusive on the whole, indicate that there are aspects of the building in need of further study to resolve this issue. We speculate that the ductwork exhausting air from the passive offices is too small, and that the atrium stack does not effectively exhaust hot air from the building before it is sucked back down the corridors by the corridor's mechanical exhaust system.

1. INTRODUCTION

The post occupancy evaluation of the Lillis building showed that while the innovative mixed-mode mechanical systems in the classrooms were working well, a complaint was that the third and fourth floor offices were too hot. We chose to explore the cause of this observation, and in doing so we had to understand the design intentions of the mechanical systems in the building as they pertain to the third and fourth floor offices. To maintain an approachable scope of work, we chose to specifically investigate the fourth floor offices, with the assumption that the problems experienced there would be similar to or more extreme than those on the third floor. Although the study took place in the winter, we still heard complaints of the offices being too hot. We attempted to set up an investigation that would serve as a model to compare seasonal comfort or discomfort.

The fourth floor is a double-loaded east-west corridor with offices lining the north and south faces. The incorporates both a mechanically driven systems—serving the corridor and the south offices—and a passive ventilation system serving the north offices. Both sides draw air from the outside through a damper beneath the window, but in the mechanically conditioned spaces this air is cooled or heated before entering the space.

Exhaust air from the north and south offices is ducted to the atrium and released from its top. In both runs of ductwork this exhaust is assisted by a fan—a conventional move on the mechanical side, but somewhat unusual on the passive side. The fan assist to the passive system is designed to encourage the passive flow of air from the offices to the atrium; because the air must flow through such a small duct, the negative pressure in the ductwork helps to keep warm office air from escaping to the conditioned hallway. When the exhaust air reaches the atrium, it rises to the top, and is removed by an exhaust fan. Please see figure 1 for a diagram of the ventilation design.

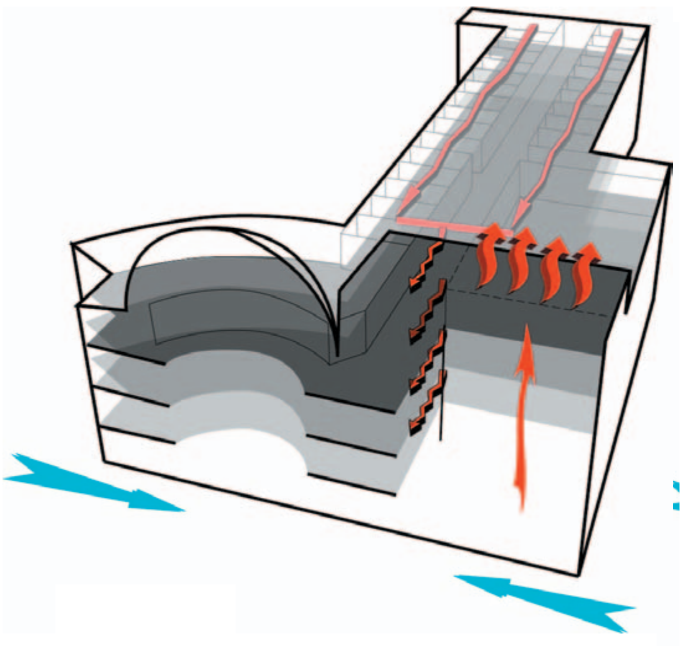

Figure 1: Ventilation design intentions

General questions to be answered:
Based on the reports of occupant comfort and our understanding of the mechanical systems, we set out to answer several questions about the building.
Are the passively cooled office within the ASHRAE Standard 55—2004 comfort zone?
How does this compare to the mechanically cooled offices?
How were the passive and active systems designed to work together?
How does air move within the atrium?
How does air move in the corridors, and how does this affect the offices?
Are people in the offices using their windows, fans, and doors correctly?

<u>2. HYPOTHESIS:</u>

Based on the feedback from the post occupancy evaluation and our preliminary visits to the building, we came to the following hypothesis:

The passive cooling strategy employed in the Lillis Building does not provide thermal comfort to the north side fourth floor offices.

<u>3. METHODOLOGY & ANALYSIS:</u>

In order to test this hypothesis, we undertook three smaller tests to determine what was happening in the building:

Study #1: North vs South Offices
In order to get a clearer picture of the thermal behavior of the offices, we placed temperature sensors in offices in the east wing of the fourth floor. We collected data for about a week, during which time the outdoor temperature ranged from about 35 degrees at night to 55 or 60 degrees during the day.

Questions:
Which of the north and south offices are within the ASHRAE comfort zone?
When and for how long are these offices within the ASHRAE comfort zone?
What differences in temperature trends exist between north and south offices?
Are occupants on the north side actually experiencing hotter temperatures, or do they believe they are warmer because they are expecting a mechanically conditioned space?

Hypothesis:
North offices are hotter than south offices.

Methodology:
Temperature sensors were placed in 6 offices of the east wing (see Figure 2) at varying distances from the atrium. Temperature readings are taken for 14 days.

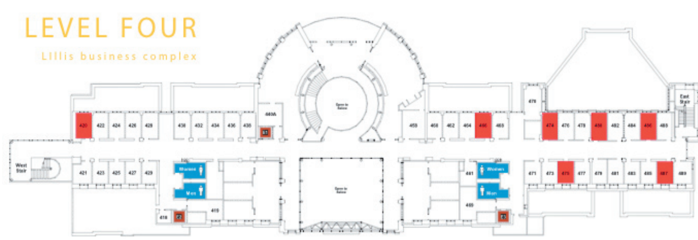

Figure 2: Location of test offices for Study 1 and Study 2

Observations:
As seen on the graph in Figure 3, the south offices had larger temperature swings, and lower minimum temperatures in the evenings. North offices had very mild diurnal temperature swings.

Discussion + Conclusion:
This study was inconclusive study: the north offices have a larger temperature variation, but

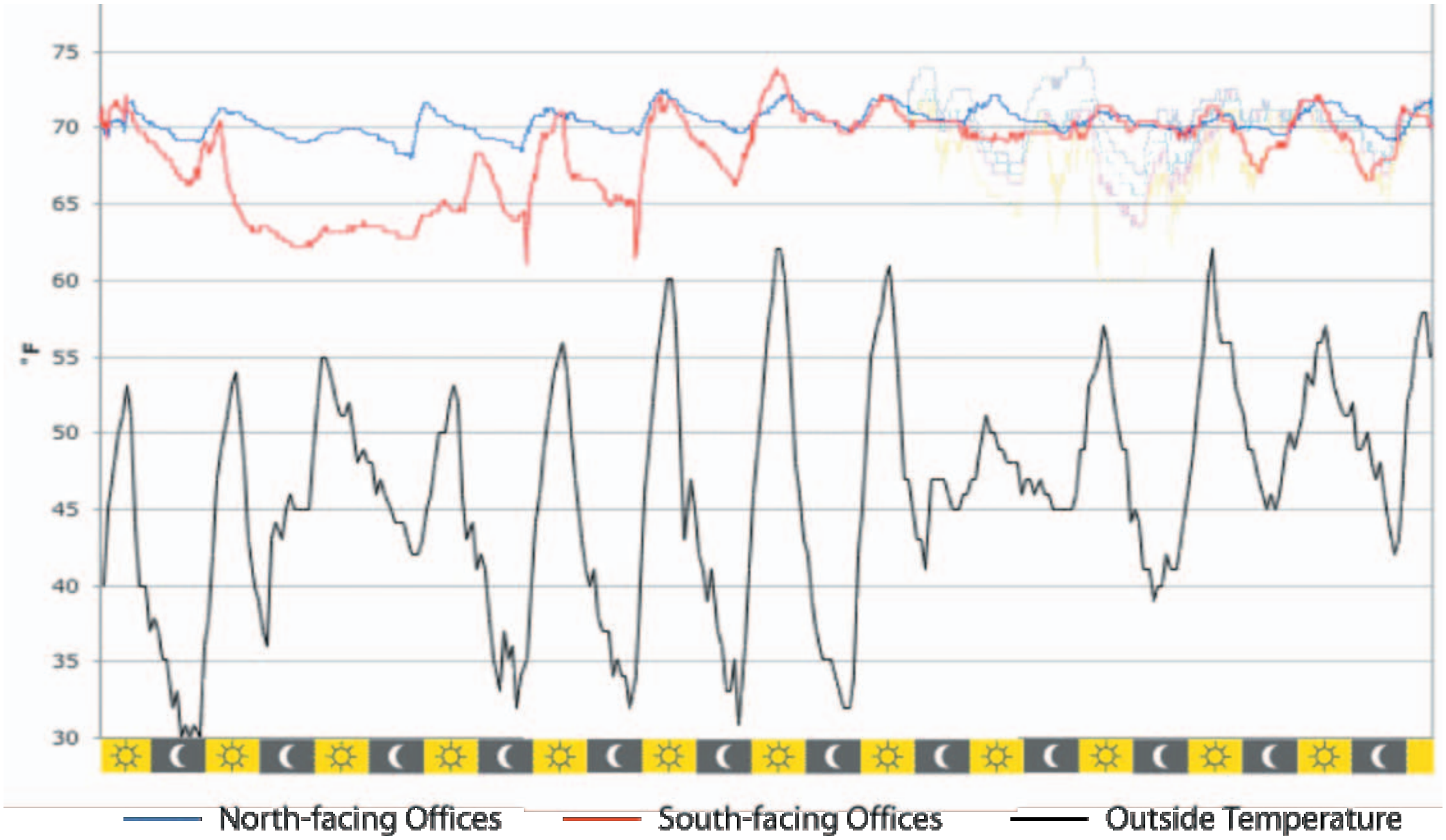

Figure 3: Averaged temperatures in North and South test offices

are still within the comfort zone. Further study of the temperature differences between north and south offices is warranted, particularly at the warmer times of the year. We speculate that the north offices would record higher average temperatures and higher temperatures spikes during the summer months, creating the relative "discomfort" of the occupants. This discomfort could be augmented by the transition from the mechanically conditioned hallway to the unconditioned office, and the expectation for offices to be cooled to the same level.

Study #2: Office behavior variations

Given the dependence on appropriate user control in the passive cooling strategy, we decided to test the effect of different office configurations on thermal comfort. We studied the effect of fan and operable window usage on the observed temperature fluctuations over the course of a day. We tested a single office (see diagram) in several configurations.

Hypothesis:
Office configuration will determine thermal comfort within the north offices.

Questions:
Does opening the window cause the office to leave the ASHRAE comfort zone?
Does turning on the overhead fan cause the office to leave the ASHRAE comfort zone?
Does opening the door cause the office to leave the ASHRAE comfort zone? [Note: Not tested]

Methodology:
Temperature sensors were placed in an unoccupied north office. Temperature was measured in four locations in the office for 24 hours in each of several office configurations, as shown in figure 4. We tested for a full day in order to examine the effect of the office configuration on the effectiveness of the night flush ventilation in addition to the passive air movement during occupied hours. Each combination of window open/closed and fan on/off was studied.

Observations:
As seen on the graph in figure 5, the office fan creates a more homogenous temperature within the office. Opening the window provides for thermal comfort when the indoor-outdoor tem-

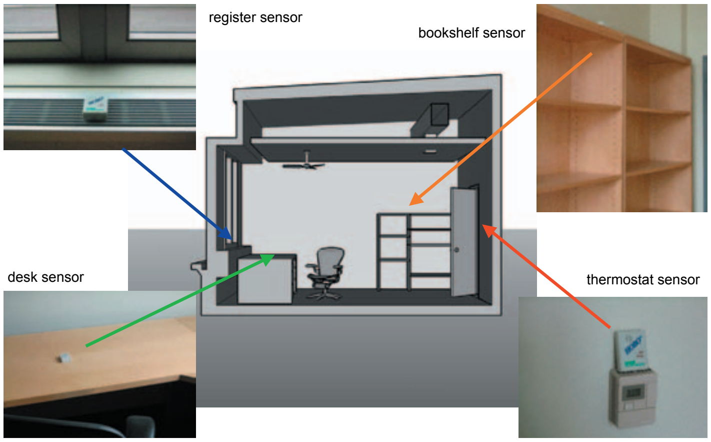

Figure 4: Location of sensors in study 2

perature differential is great, but we speculate that it would not do so if the indoor-outdoor temperatures were more similar. Opening the window had a great effect on the sensor near the window, but not as great an effect on the sensors further away. Cool air does not seem to travel too far into the office space.

Discussion + Conclusion:
Upon completion of the data collection, it was discovered that, unlike every other north side office, our test office is actually mechanically cooled. However, because the mechanical system was not significantly heating or cooling the building during our testing period, we can use the observations as a rough approximation of the effects on a typical passive office.

We were unable to conclude much about the effect of user control on the operation of the overall system. We find that running the ceiling fan does even out temperature differences in the office. If the outdoor temperature is cooler than the inside temperature and the window is open, the fan help distribute the cool air throughout the office. Further testing of the fan's effectiveness on warmer days is recommended.

An important corollary to observations about the configuration of the office is that the sensor which monitors the operation of the building is located where our "thermostat" sensor is located. This means that while an occupant sitting at the desk may feel cooled by an open window, the system may be recording a higher room temperature, especially if the fan is off.

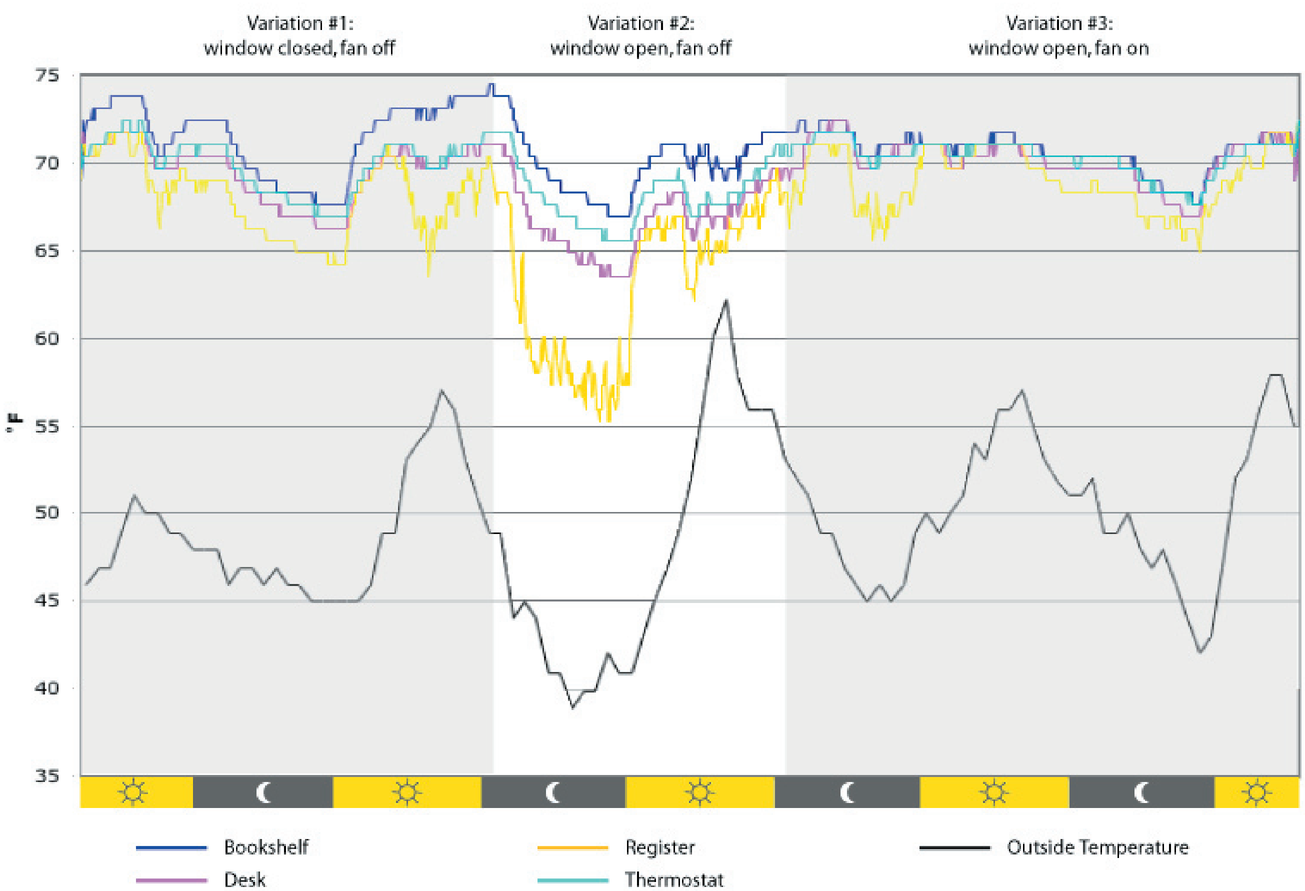

Figure 5: Graph of office temperatures in three different office configurations

We recognize that the system is designed to operate with the office doors closed, and wanted to test for the effect of opening the door on the thermal comfort in the office, but were unable to complete these tests for logistical reasons.

Sudy #3: Ventilation Examination

In order to get a better picture of how air was moving in Lillis, we undertook a few qualitative studies of air movement.

Hypothesis:

Air is moving down the corridors toward the atrium and upwards through the atrium.

Questions:

How does air move within the atrium?
How does air move in the corridors?
Is there different air movement on the first and second, as compared with third and fourth floors?
What does air movement in the corridor suggest about air movement in the ductwork?

Methodology:

Observe bubble flow paths in atrium and hallway. (See figure 6 and 7)
Observe movement of plastic strips on corridor telltale.

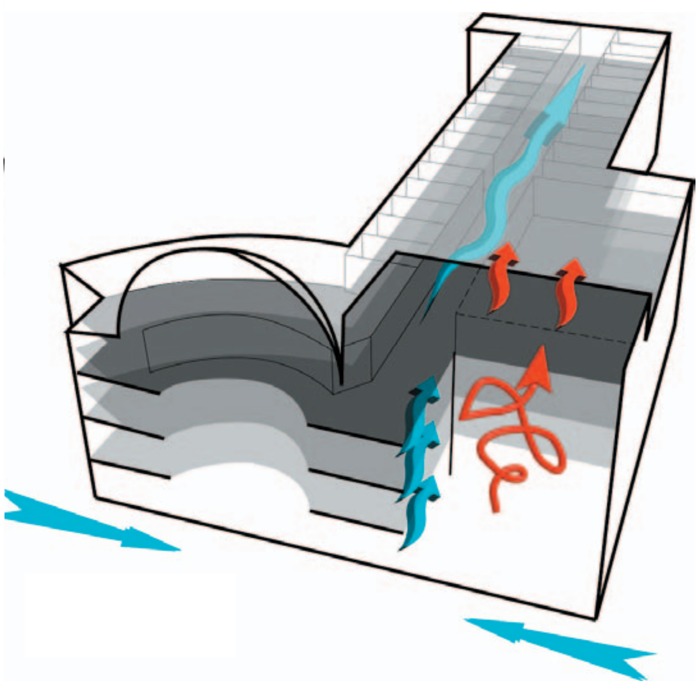

Figure 8: Observed air flow paths

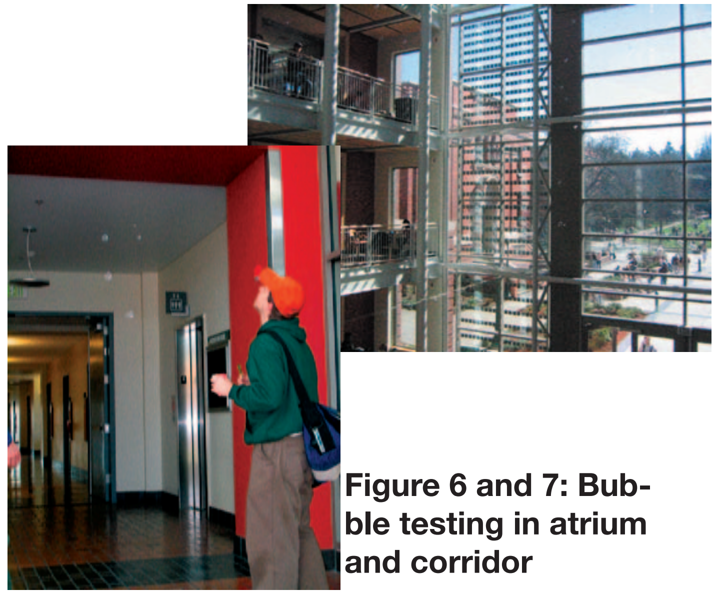

Figure 6 and 7: Bubble testing in atrium and corridor

Observations:

On the fourth floor of the east wing, we observed that air flowed from the atrium, down the hallway toward the fire stair way, and to a lesser degree, the air return, at the east end of the hallway. We repeated this test on all four floors of the east wing of the building, and observed the same behavior. The larger air returns on the first and second floors did appear to draw more air than their counterparts on the third and fourth floors. See figure 8 for a diagram of our observations.

We checked the air flow in the main corridor with the doors to Gilbert (an adjoining, older building) open and closed, and did not notice a change in airflow between the two configurations.

We observed air both rising and falling within the atrium space, depending from where it originated. We speculated (and confirmed with temperature readings at each floor) that temperature stratification in the atrium was occurring. From the second and third floor, bubbles quickly rose upward through the atrium until they got to the level of the fourth floor, where they began to drift laterally, and then fall. From the fourth floor the bubbles slowly dropped into the atrium space. Some bubbles released from the fourth floor made their way toward the third floor corridor, at which point they were sucked down the length of the hallway.
Bubble tests at the outlet of the office-duct transfer fan indicated that it is indeed evacuat-

ing air into the atrium space, although we did not measure air temperatures within the atrium or of the air being evacuated from the office exhaust system. We also did not measure whether the evacuation fans were running at this time to exhaust air from the atrium. We highly recommend gathering this data in future experiments.

Discussion + Conclusion:
While not conclusive, the evidence points toward the ventilation patterns in the atrium and the corridors not supporting the stack effect in the atrium.

The influence of air pressures from the transfer fan outlet points, opening/closing exterior doors on the main floor, and opening/closing doors at the junction with Gilbert, Chiles, and Peterson may have some influence on the movement of air within the atrium, and certainly on the ability of the mechanical system to achieve a certain pressure in the atrium.

We could not draw many conclusions from this set of observations. Because the corridor is mechanically cooled, it is not part of the passive system controlling the north offices and the atrium. Though the flow of air through the ductwork serving the offices runs in the opposite direction of the flow down the hallway, this does not clearly indicate a failure of the stack effect in the atrium. However, we speculate that the air returns at the east end of the hallways do pull some warm air east down the hallway, hence working somewhat against the stack effect. We further speculate that some of this air travels down the hall, down the stairwell to the first/second floor where it is picked up by the return and ducted to the atrium for exhaust. This implies that air is traveling in a loop through the building, rather than being exhausted to the outside. We assume that pressure equalization is achieved when the main exterior doors to the atrium are opened, a common occurrence at most times of the day.

4. CONCLUSIONS:

It seems from the combination of studies we have undertaken that our hypothesis is correct, and the atrium is not working effectively as a stack in the winter to ventilate the offices on the top floors of the building. If true, the intended flow of air within the building is not being achieved, causing some users to feel uncomfortable. However, beyond seeming to confirm this hypothesis, our data raised more questions and suggested many follow-up studies concerning the design and operation of the building.

Though not directly related to our stated hypothesis, we conclude from our observations that the mixed-mode system does not seem to be an equal partnership of passive and mechanical systems. The mechanical system does appear to dominate the passive system, and will override the passive cooling mechanisms in an office if, say, the occupant leaves the office door open. Occupants might leave a door open with the expectation that there would be cross-ventilation or increased air movement. We wonder if it is possible to “fool” the mechanical system into not overriding the passive system, and hence save on energy. [?] We don’t believe that educating the occupants about the system would lead to them sitting in their offices with the door closed.

Recommendations:
Because our studies yielded inconclusive results, we have several recommendations for further study of the overheating offices in Lillis:

1. We recommend that the study be performed in summer when the north side offices are operating in full passive mode, so that temperature fluctuations at the problem times can be recorded directly.

To further characterize occupant effects on the system performance, we recommend the following:

2. We recommend that the individual north office configuration study be conducted again on a truly “typical” passive office. Effects of open doors should be studied. Because we observed north office doors open often, and we know the system is designed to run with closed doors, we think it important to know the effects of this behavior on the larger system.

3. We recommend a user survey to determine the occupants' understanding of the building systems, particularly the passive systems directly affecting the north office occupants. We observed few architectural cues setting the north and south offices apart, and little about the space to indicate that adaptive behavior is required to maintain comfort in the offices. That is, arriving in an office from a conditioned corridor does not necessarily prepare an occupant to open a window to cool off. In fact it may dissuade them from doing so, and encourage them to open the door to the cool hallway instead. As discussed above, this would force the mechanical system to work harder than designed, and effectively override the passive system in the office.

The occupants of the north side offices have changed since the building was programmed and designed, and may not have a clear understanding of the way the system was designed to run. Indeed few modern buildings are designed to operate as Lillis is! We want to see how effective any educational programs about the building have been.

We recommend several studies be undertaken with the Building Management involving the Siemens building management system or the architectural features of the building:

4. We recommend investigation into the effect of lowering the building's set-point from 78 degrees to 76 degrees. This involves an investigation into the amount of thermal mass in the building, and analysis of whether this amount is appropriate to the heating loads of the building.

5. We encourage an investigation of the exhaust air from the atrium. This would involve testing airflow rates at the exhaust vents from the offices, and from the atrium to the outside, the extent of operation of the fan-assist, and the extent of operation of the smoke-evacuation fan in the atrium. These should be correlated to temperatures outside, in the offices, and at various heights in the atrium.

6. We recommend a study of ways to isolate the atrium from the corridors, and hence achieve some pressurization of the atrium.

7. We recommend developing some sort of cues for north office occupants regarding the operation requirements of their offices. Architectural ways should be developed to indicate to them that adaptive behaviors are required to achieve thermal comfort, and that these adaptive behaviors are different from those of their counterparts on the south side. As a very specific recommendation, despite its being on the north side, Office 420 should not have an operable window because it is not a passively cooled office.

5. ACKNOWLEGEMENTS

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We appreciate the flexibility and helpfulness of the office occupants on the fourth floor. We'll get to the bottom of this yet!