Commissioning and Envelope Leakage: Using HVAC Operating Strategies to Meet Design and Construction Challenges

David Sellers, Hannah Friedman, Larry Luskay, and Tudi Haasl
Portland Energy Conservation Inc.

ABSTRACT

Successful HVAC design and efficient operation are inescapably linked to a "successful" building envelope design. From the HVAC system standpoint, a successful envelope must resist the transfer of heat and moisture and minimize the exchange of air across its boundary. While intuitive, these goals are often relegated to second place in favor of creating an aesthetically pleasing structure or making an architectural statement. The construction industry often presumes that if no water penetrates the building envelope, then the integrity of the system is satisfactory. But, scientific analysis and practical experience demonstrate that infiltration can lead to frozen pipes, condensation, and occupant discomfort.

This paper contains an overview and examples of design and construction issues that lead to envelope leakage problems. The discussion includes identification techniques used to locate and quantify the leakage, operational ramifications associated with the leakage, and solutions to mitigate the leakage using HVAC operating strategies. For two of the examples, a test was performed based on ASTM-E-779-99 (Standard Test Method for Determining Air Leakage Rate by Fan Pressurization) to quantify the leakage rate and assess its impact on building pressurization. The results of these tests and other field experiences indicate that achieving a completely airtight envelope is practically impossible. Thus, the architectural design and construction details targeted at providing an airtight envelope need to be supported by HVAC design and operating strategies that will mitigate the impact leakage that will inevitably occur.

The Cause for Concern

Despite the attention that envelope design tends to receive, effective containment for the indoor environment is often not achieved. In reality, almost all building envelopes, while watertight, are not necessarily airtight. The problems that result from leakage are frequently compounded by current HVAC design and construction practice, where budgets and timelines dictate a more generalized, less detailed approach for developing and fabricating the systems that will control the indoor environment. Experience suggests that many parties involved in the design, construction and operation of buildings simply do not realize that the potential for problems exists; perhaps because they have not been exposed to an envelope problem with disastrous consequences (yet). When disaster does strike, those involved with the building quickly become informed of the issues, especially if disaster is in the form of IAQ problems and litigation. While the predicting leakage and the associated air flow patterns and pressure relationships can be quite complex, many of the problems and solutions appear obvious when viewed in hindsight (Armstrong et al, 2001).

The thermal and moisture protection provisions typically incorporated into a modern building would seem to offer the desired resistance to airflow. For example, one would expect a vapor barrier to also be effective at stopping airflow through the building shell, just as properly designed and implemented thermal breaks will prevent transfer. Problems tend to occur where architectural features and/or structural elements come together and create gaps in these barriers. These gaps and the mass flow that occurs through them are often hidden from direct observation. Designers and others familiar with load calculations will readily acknowledge that the loads represented by infiltration across a given boundary are frequently much more significant than the loads represented by heat transfer across the same boundary. Frequently, the HVAC design does not anticipate an envelope that is not airtight, and thus is not designed to handle the implications.

It is also important to recognize that some envelope leakage issues are created by intentional and necessary elements of the design. Lobbies, loading docks, garage doors, and other points of entry are prime examples. But despite the fact that these breeches of the envelope are known and obvious at the time of design, they frequently result in operational problems that are virtually identical to those created by their hidden and unrecognized counterparts.

Envelope Leakage Test Procedures and Research

There are several published procedures that are targeted at measuring building envelope leakage rates. The most readily available are the *ASTM E 779 – 99 - Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*. A similar standard exists under the Canadian General Standards Board titled, *Determination of the Overall Envelope Air Tightness of Buildings by the Fan Pressurization Method Using the Building's Air Handling System.* Both of these approaches use the building's HVAC fans or an independent test fan to pressurize the building with outdoor air, elevating the building pressure in increments and documenting the flow rate required to achieve each pressure.

In addition to the standards, a variety of other formal techniques have been explored and developed, all of which "utilize natural or controlled pressurization and depressurization to create airflow through the building envelope. A correlation between flow and pressure differential is derived from the results of a series of steady-state tests over a range of pressure differential values" (Bahnfleth, 1999). Upon a review of existing research on building leakage, most of the published data appears to focus on residential buildings rather than commercial buildings. ASHRAE Research Project 935 focused on developing "a method to evaluate the air tightness of the envelope of tall buildings that represents the best compromise between simplicity and accuracy" (Bahnfleth, 1999) and included data from trial applications of the methods they explored. In general, the research indicated that the ASTM and Canadian standards provided a good foundation for developing a leakage test as long as the nuances associated with applying them to tall buildings were taken into account.

By far, the most comprehensive data was found in the ASHRAE Journal article titled *Myths About Building Envelopes*, which documented the results of a DOE sponsored study of 139 commercial and institutional buildings worldwide (Persily, 1999). For the sample set, the average leakage rate varied from 0.1 - 6.8 cfm/sq.ft. The average leakage rate for the high-rise buildings in the data was approximately is 150,210 cfm at a 0.1 in.wc. test pressure. While the sample size was too small and not random enough to be statistically valid, some interesting and surprising trends were revealed, many of which fly in the face of conventional wisdom. Among the trends were:

1. There was no real correlation between building age and leakage rates;
2. There was no real correlation between building type and leakage rates;[1]
3. There was no real correlation between wall types and building leakage rates, although there was a tendency for framed walls to be leakier than other construction; and
4. The commercial buildings in the sample set were not significantly tighter than the US housing stock, which are somewhat leaky compared to European residences. (Murphy et al, 1991)

Examples of Envelope Leakage

Our experiences with operational problems related to envelope leakage began in the 1970's and is also illustrated with more detailed quantification during two recent commissioning projects. The following six examples demonstrate the operating problems that leakage creates, as well as the benefits of commissioning-driven efforts targeted at resolving these problems.

1960's Vintage Midwestern High-rise

Two operational issues encountered at a 1960's vintage high-rise in the Midwest were related to envelope leakage. The first experience involved extremely cold temperatures in the building lobby during the winter months. The original building design had incorporated an air curtain at the entrance that allowed the tenants to literally walk into the building from the street without having to pass through a door. Movable doors were provided for securing the building at night, but they were swung open during the occupied hours to allow free and easy access, and to lend a modern feel to the facility. Financial pressures and other restrictions imposed by the energy crisis resulted in a decision to shut down the air curtain and keep the night security doors in place during the cold winter months and the hot and humid summer months. As a result, during the winter months, the tenants complained about how cold the lobby was and about whistling at the elevator shaft doors.

As might be suspected, both problems were the result of the "stack effect" pulling cold outdoor air in through the lobby and up the elevator shafts. The Owner and consultant explored various options to resolve the situation, including reactivating the air curtain or operating the air curtain with the doors closed as a recirculating system. Ultimately, since the lobby in the building served only as a transitional space from the door to the elevators, the reduced operating costs outweighed the benefit of solving tenant complaints that existed only during extreme cold.

This high-rise also suffered from a less obvious problem during the hot and humid summer months. High velocity induction units equipped with a coil that could be served by hot water or chilled water conditioned the perimeter of the building. Since by design, the dehumidification needs of the space were to be served by the core constant volume reheat systems, the coils on the induction units were provided with drain pans to catch minor condensation, but they were not piped to a drain piping system. If the system was working right, there would be no significant condensation and thus nothing to drain. Unfortunately, when the Owner shut down the air handling and chilled water systems overnight during the summer months due to the energy crisis, the stack effect and envelope leakage caused the building to fill

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[1] Retail buildings tended to have more leaks than other types, and high-rises tended to be less leaky. Nonetheless, the leakage rates for any given building type were scattered across a wide range.

with humid air overnight. When the HVAC systems were restarted in the morning, the induction unit cooling coils were challenged with a significant dehumidification load in addition to the sensible load they were designed to handle. As a result, the drain pans overflowed, carpet and finishes were ruined, and mold and mildew began to develop.

A partial solution was implemented by modifying the secondary piping circuit serving the induction units so that they used return chilled water from the air handling systems rather than supply water from the chiller plant. This guaranteed that when the building was under control, the apparatus dew point of the induction unit coils would not be below the dew point of the air supplied from the air handling systems. Unfortunately, the envelope leakage that occurred due to stack effect overnight when the building was shut down meant that the building was not under control when it was started up and thus condensation still was a problem on the induction unit coils.

In the end, keeping the chilled water plant online overnight and running several of the core air handling systems on minimum outdoor air solved the problem. This approach provided enough positive pressurization to offset the stack effect and ensured that the building was maintained in a dehumidified state. Also, this approach actually used less energy than the consumption that resulted from the pull-down load when the building was restarted after being offline over a warm, humid summer night or weekend. And of course, the avoided IAQ problems and costs associated with replacing ruined carpet and finishes were an added bonus.

1980's Vintage Midwestern High-rise

During the first winter of operation of a 13-story high-rise in the Midwest, the mechanical design-build contractor was accused of failing to install adequate heating capacity and was threatened with legal action when indoor temperatures fell into the mid 50's°F during the first cold snap after occupancy. However, a simple inspection of the ceiling return plenum revealed a 40 foot long, 2 foot wide opening to the outdoors above the ceiling. The opening was part of an architectural soffit and reveal that simply had not been completed. As a result, it went unnoticed until Mother Nature provided a wake-up call. Simply closing and insulating the opening to meet the requirements depicted on the architectural drawings solved the problem and transformed the mechanical contractor from villain to hero in short order.

Rural Midwestern Regional Medical Center

In a medium sized rural midwestern medical center, designing the HVAC systems for a hospital project that expanded the lobby area provided the opportunity to address a net infiltration problem that had worsened as the complex had grown. The infiltration issues seemed to be related to minor supply/exhaust flow imbalances at multiple locations throughout the facility rather than any one particular imbalance. The successful resolution of the infiltration problem involved several important design elements:

1. The main entry doors were provided with vestibules designed so that when a group of people walked through, the automatic doors to the exterior of the building would be closed before the automatic doors to the interior of the building opened. The result was a buffer area between the building interior and the building exterior.
2. An additional independent constant volume system with 100% outdoor air capabilities was

dedicated to the vestibule and lobby area. The amount of outdoor air was controlled to maintain the vestibule at a slight positive pressure relative to the outdoors.

3. The pressure sensor controlling the outdoor air dampers on the lobby/vestibule system was arranged to sense the velocity pressure associated with wind acting on the face of the vestibule at the exterior doors.
4. All supply air from the constant volume system was delivered to the lobby, and the return air was taken from the vestibule. If the vestibule doors to the lobby were closed, the lobby would pressurize, which caused barometric dampers in the lobby ceiling to open and dump the air to the return inlets in the return vestibule. If the vestibule doors to the lobby were open, the supply air flowed out of the lobby through the lobby doors to the vestibule return inlets. If the vestibule doors to the outside were open, the vestibule return inlets essentially became outdoor air intakes, pulling the air that entered the vestibule into the air handling systems, tempering it and dumping it into the lobby.
5. A section of finned tube radiation with a self-contained control valve was installed in the knee space of the receptionist's desk. In addition, the desk was designed to provide a solid wall from the floor to the work surface on the front and sides. The supplemental heat and desk design were intended to provide an added measure of protection for the staff working round the clock in the immediate vicinity of the entry doors.

Over several years following construction, the new system provided a significant improvement in comfort in the lobby area over many operating conditions. The heating element at the receptionist desk proved to be beneficial to the staff working there on days when the weather was extreme and door use was heavy. Conversations with the facilities engineering group revealed that the approach has persisted in maintaining comfort conditions in the lobby (Cook, 2004).

Major Urban Midwestern Regional Medical Center

After the experience with the rural medical center, the design concept and lessons learned were applied to the lobby area of a laboratory and outpatient surgery expansion at a major urban medical center. The facility suffered from a similar flow imbalance problem as was experienced in the previous example. Initially, a similar design approach was developed. An independent air handling system was provided for the lobby area with supply air distribution on the occupied side of the entry door and return inlets in the immediate vicinity of the entry doors.

However, contrary to the recommendations of the HVAC designer, a vestibule was not installed, primarily due to the lack of space and the anticipated benefits of the alternative, automatic revolving entry door. Budget constraints resulted in the need to bid the lobby system as an additive alternate. While the Owner recognized that it was very likely that the proposed independent system would provide significant benefit in the outpatient surgery lobby, the plan was to accumulate operating experience with the completed addition and then add the system if it proved desirable, funding it from the operating budget rather than the construction budget.

Approximately one week after the first significant cold spell after occupancy, the designer was asked to investigate the possibility of providing the independent system functionality to the lobby using capacity in laboratory air handling system. After analysis, it was concluded that diversity designed into the laboratory air handling system could be used to serve this constant volume zone, meeting the needs of the lobby area without the added expense of an independent air handling system. The modifications were quickly implemented and a major reduction in complaints was noted. This experience tends to support the appeal of a properly designed independent, dedicated lobby HVAC system.

1990's Vintage Pacific Northwest High-rise

An existing high-rise courthouse in the Pacific Northwest was recently retrocommissioned by the authors. The facility is 300 feet tall, 560,000 square feet, and was constructed during the late 1990's. The building's ventilation and cooling needs are served by four double duct VAV air handling systems with a design capacity of 460,000 cfm and a typical operating point of 50% to 75% of the design capacity. The building incorporated an abbreviated commissioning process implemented during the later phases of construction, but did not include design phase commissioning and very little construction observation.

The systems are equipped with economizer cycle that positions the relief dampers via the same signal that positions the outdoor air and return air dampers. This approach, when applied to VAV fan systems, poses significant operating challenges. The economizer process is a temperature control function that brings in outdoor air beyond what is required for ventilation to reduce the cooling load on the central plant. This extra outdoor air creates the need for a relief air system.[2] The traditional approach has been to drive the relief dampers using the same signal that is used for the outdoor air and return air dampers. This approach works reasonably well when the systems are constant or near constant volume systems, the building is not complex, and the building is reasonably airtight. However, if VAV systems are employed and/or the building is leaky or is part of a large complex, decoupling the relief damper control from the economizer control will provide better performance.

One of the most persistent complaints voiced by the operating staff was that the building was plagued with comfort and operational problems due to a lack of heat in the winter months, including frozen pipes. The staff suspected that this was attributable to a leaky envelope having discovered and repaired major breaches in the envelope on several occasions. As a result, a test targeted at identifying the building leakage rate was warranted.

If in fact the building envelope was as leaky as the evidence suggested, then decoupling the relief damper systems from the economizer control signal and providing control based on building static pressure might provide some significant benefits in terms of energy, operations and maintenance costs, and comfort. Specifically, the building leaks might provide most of, if not the entire, relief path required by the economizer process. The procedure finally implemented was designed to test the viability of this control modification. Relieving through the cracks rather than the relief louvers would have several benefits, including:

1. The infiltration load would be converted to an exfiltration load. As a result, tenants in the vicinity of the perimeter would not experience the cold drafts associated with air infiltrating into the building through the leaks.
2. The perimeter heating load associated with infiltration would be eliminated. Instead the internal gains in the building would be used to offset the perimeter loads; essentially providing a simple heat recovery process.[3]

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[2] Frequently, the relief stream is called the exhaust air system, but should not to be confused with the toilet exhaust and other process exhaust functions that will occur regardless of the status of the economizer process.

[3] Extra outdoor air is brought into the building by the economizer process because the internal gains in the building result in a net cooling load in the core, even though ambient conditions impose a net heating load on the

3. The return fan energy would be reduced since, if properly controlled, the return fans would not have to move the exfiltrated air back to the relief dampers.

Based on past research for all building types (Persily, 1999), it was predicted that test would show that between 41,600 cfm and 1,918,000 cfm of outside air would be supplied to create a test pressure of 0.1 in.wc. at the ground level. The average leakage rate for the high-rise buildings in the data set is 150,200 cfm at a 0.1 in.wc. test pressure. Budget constraints and the realities of working with a real building precluded running a full ASTM E 779–99 test to document the building leakage rate. An abbreviated procedure was developed that could be run in 4-6 hours to provide a reasonable assessment of the leakage rate through the envelope. Like the ASTM test procedure, the abbreviated procedure used the supply fans to pressurize the building and then checked the pressure at several levels. However, it was not as rigorous since pressures were not checked on every level and on every building face.

For the test, the return fans were shut down, the return and relief dampers were forced closed, and the outdoor air dampers were forced open (all verified visually). As a result, the supply fan systems were operated in a 100% outdoor air mode with no relief system other than the cracks in the envelope. Differential pressure with respect to the outdoors was documented at the lobby level, on the 9th floor and at the 16th floor at each fan speed. A related paper includes a detailed discussion of this test procedure (Sellers et al, 2004). During the test, it was apparent that it would be difficult to positively pressurize the lobby at all, let alone to 0.1 in. wc. Therefore, we simply ratcheted the fan speeds up in large increments in an effort to find the speed at which positive lobby pressure was first achieved. With ambient conditions only in the low 50's°F during the test, the stack effect was not excessive. The results are shown in Figure 1.

The pressure test resulted in an estimated leakage of 100,000 cfm, much higher than even anticipated. The lobby could not be positively pressurized, even with the supply fans bringing in about 200,000 cfm of outdoor air. The peak speed was limited at 70% by high discharge static pressure limit switch set point being reached at one air handler. Further, the maximum pressure on level 16 was just starting to generate whistling through the cracks at the doors.

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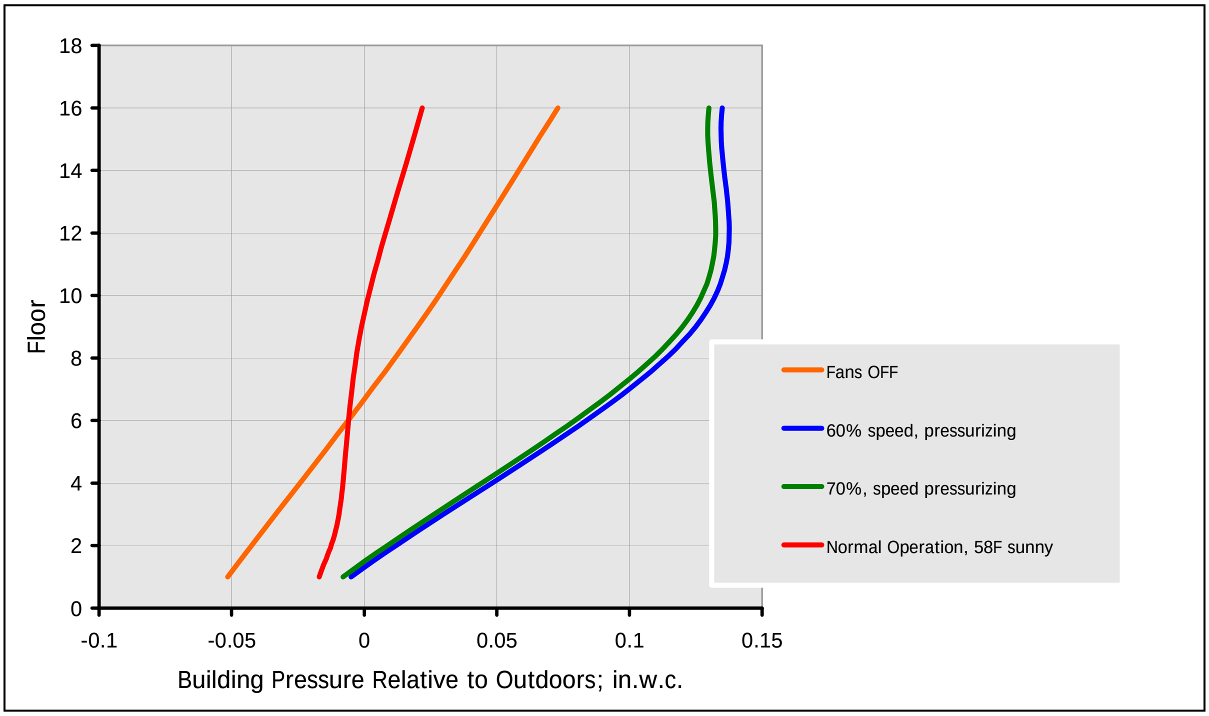
perimeter zones. The cool air delivered to the interior zones is heated by the internal gains to the space set point. Rather than using the return fan to move this air back to the relief dampers and ejecting it from the building, the building is allowed to pressurize, which forces this air out the cracks in the envelope, offsetting the infiltration of cold outdoor air with exfiltrated relief air heated by the building internal gains.

Figure 1. Building Pressurization Test Results



Source: PECI

The shape of the pressure curves tends to indicate leaks at the 8th floor mechanical room and the top of the building. During the test, significant air flows were observed at the return shafts and into the building mechanical rooms, which are also return plenums. Since the return fans were off and the relief dampers were closed, the only cause for this flow could be significant leaks within the mechanical rooms. Subsequent investigation revealed the following findings:

1. A major leakage path existed in the upper level mechanical room. The air handling units furnished for the project were large, custom units. The space above the unit (between the top of the unit casing and the structure) was closed off via a sheet metal plenum wall, separating the equipment room/return plenum from the outdoor air intake system. However, the unit was mounted on rails that held the bottom of the unit approximately 4 - 6 inches off of the equipment room floor. Thus, the return plenum was short circuited to the intake system via the gap under the unit.[4]
2. A terminal unit serving the lobby area was discovered to be highly dysfunctional. Due to a problem with the auto-zero function, the unit controller thought it was driving its primary air damper fully open and delivering 1,300 cfm to the lobby. In fact, the damper was only being opened partially, with a maximum delivery rate of 300 - 400 cfm. This error was compounded by a calibration problem in the flow controller.

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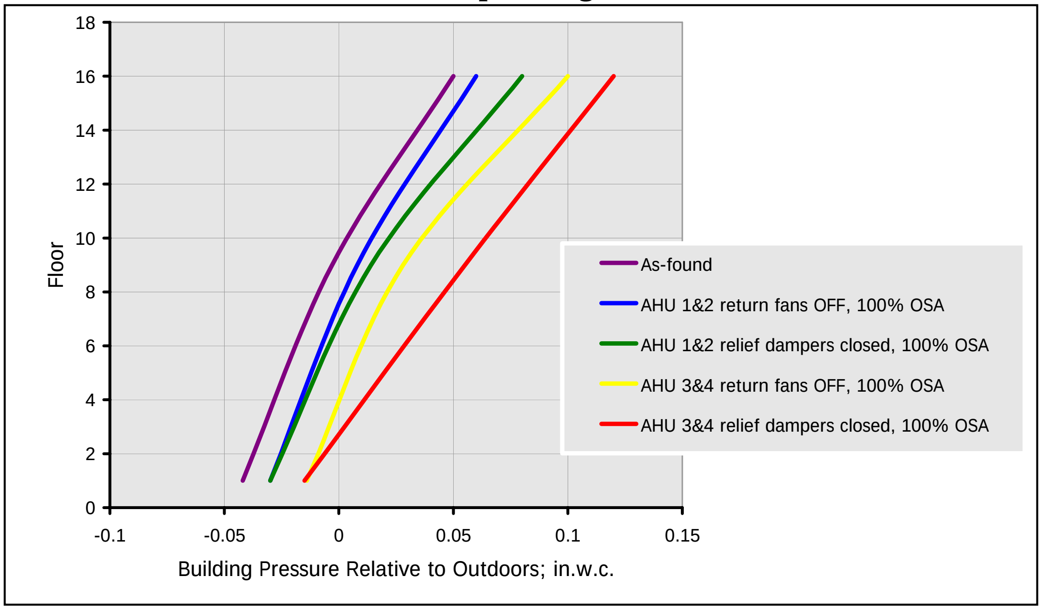
4 This deficiency also increased the entering air temperature several degrees above ambient when operating on the economizer cycle, compromising its effectiveness and forcing the operating staff to bring chillers on line when they should have been able to handle the loads with outdoor air.

A few months later, a second pressurization test was performed to test the effect of turning off the return fans and closing the relief dampers under normal operating conditions. This test would tell us whether the return fans could be permanently shut off, and the relief dampers could be broken out from the economizer control process, and instead be controlled based on building pressure. The building was kept in a normal operating mode on a day when it was operating at 100% outdoor air. In increments, the return fans were shut down and the relief dampers were closed. Figure 2 documents the test results.

Figure 2. Building the Impact of Shutting Down Return and Relief Systems Under Normal Operating Conditions



Source: PECI

Shutting down the return and relief systems tended to shift the neutral plane downward and positively pressurizing most of the building. However, compared to shutting off the return fans, closing the relief dampers had comparably little effect on shifting the neutral plane downward. This implies that the hole in the building created by the relief dampers is insignificant relative to the building leakage rate. This is a very significant issue that could lead to catastrophic moisture problems in hot and humid environments and frozen pipes in cold environments. Essentially, the building is operating at 100% outdoor air, even when in recirculation mode (the leaks become an outdoor air intake). The building will tend to run as a 100% outdoor air system until the leaks are identified and eliminated. Depending on the location of the leaks, operating the return fans when the systems are not in an economizer cycle may shift the pressure gradient to minimize the impact of the leaks.

The results of these tests have led us to experiment with running the building with the return fans turned off, and with the relief dampers still controlled by the same signal that controls the outside air dampers. Turning off eight 40 hp return fans has helped improve pressurization, but the leaks still exist and infiltration still occurs on the lower floors during cold weather. In a less moderate climate[5], this solution may not be appropriate. In fact, IEQ and problems with building finishes would probably have forced a solution earlier.

In this case, the leakage rate is so overwhelming that it is impractical to modify the HVAC configuration and operating strategy to compensate. The root problem – excessive leakage – needs to be addressed. Further pressure testing is necessary to pinpoint where the major leaks occur. This is in contrast with the next example, where the HVAC operating strategy was adjusted to compensate for the leakage, improve comfort, and save energy.

Pacific Energy Center

In recent months, the abbreviated ASTM E 779–99 based procedure was performed at the Pacific Energy Center (PEC) as field exercise incorporated into a training class. The PEC occupies a 1950's vintage low-rise that was remodeled in 1991 to convert it to a training facility operated by Pacific Gas and Electric (PG&E). A 26,500 cfm economizer equipped variable volume air handling system serves the facility. Relief dampers on the unit are controlled by static pressure in the building lobby, and the relief fans are cycled if necessary. Performing the pressure test at this building would verify that separating the relief function from the economizer function is a desirable approach for maintaining comfort and potentially improving efficiency by controlling the building's pressure.

There are several significant differences between the courthouse in the previous example and the PEC. The most obvious is that the PEC is a relatively simple building approximately 40 feet tall, whereas the courthouse is a complex high-rise over 300 feet tall. Thus, it was anticipated that the stack effect would be much more pronounced in the courthouse. The wall system in the courthouse is a curtain wall with an extensive array of joints and a significant amount of glazing on all faces. The PEC is a poured concrete structure with high performance glazing installed in cast-in-place openings in the roof and front and rear facades. The sides of the building are common with the adjacent buildings and thus contain no penetrations.

For this test, we were able to take advantage of some of the PEC's lending library tools to log pressures continuously through out the test cycle. Flow measurements were taken manually with a Shortridge® multimeter using the Velgrid® attachment at the filter bank. The test data are depicted in Figures 3 and 4.

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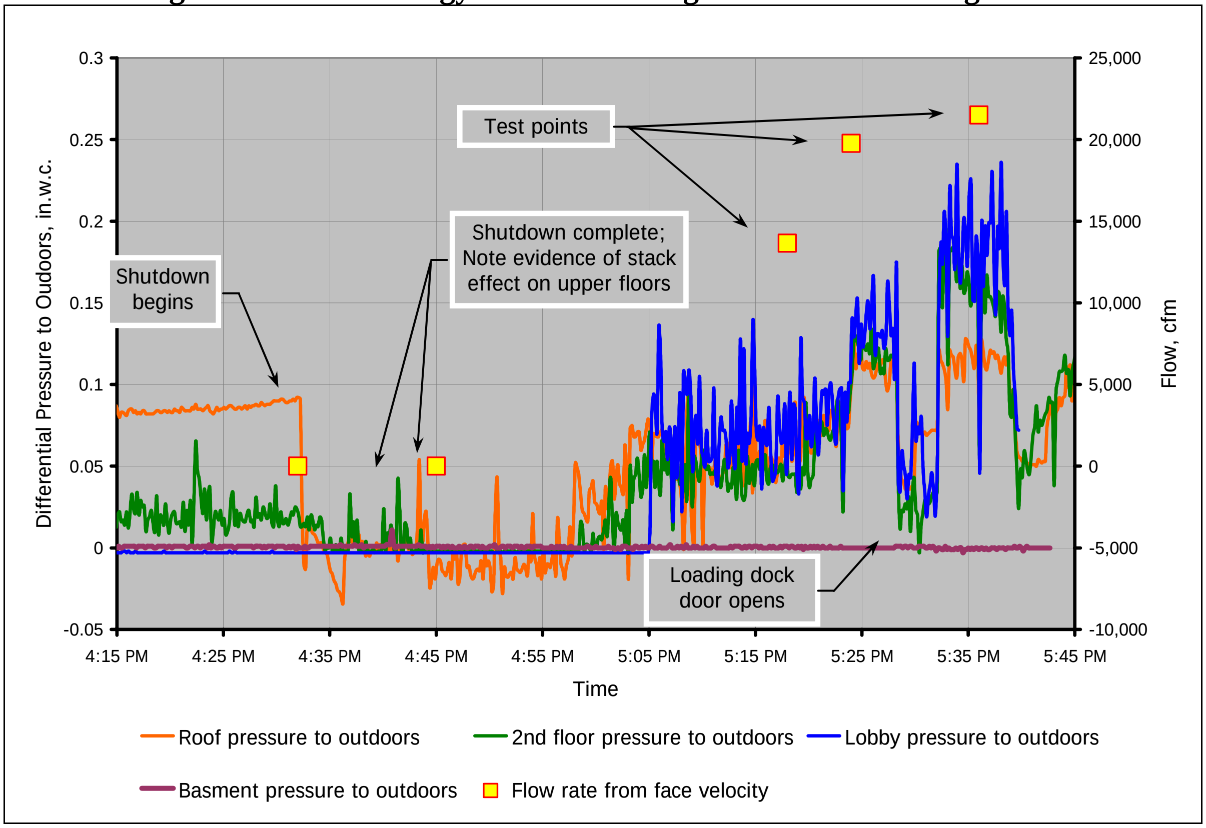
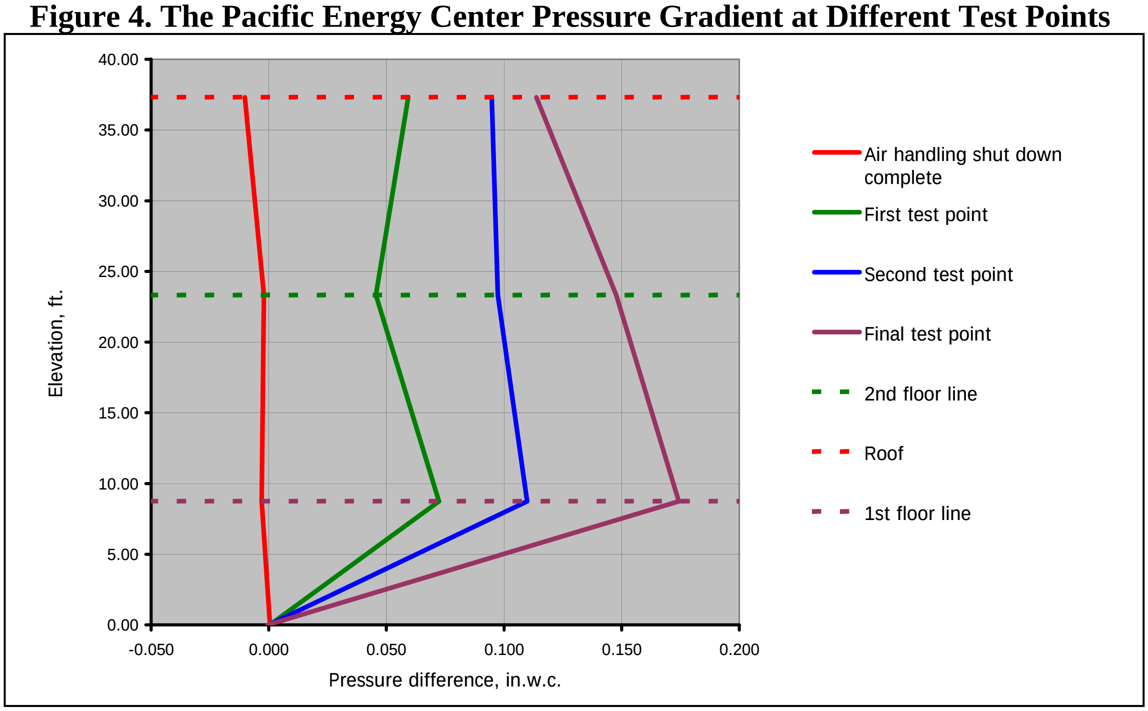
[5] Portland's climate is such that integrated economizer equipped air handling systems spend many of their operating hours at or near 100% outdoor air. Approximately 4,700 hours per year are between 55 and 75 °F and approximately 7,300 are between 40 and 75 °F. Wet bulb temperatures at the warmer dry bulb temperatures are moderate. As a result, systems seldom approach minimum outdoor air in the winter and the integrated economizer function keeps the units on 100% outdoor air for much of the summer. However due to the infiltration providing uncontrolled outside air to the building, overcooling the spaces, and forcing the discharge air temperature to reset to its maximum value, the air handlers at the courthouse go into full recirculation mode even when outdoor temperatures are not extremely cold.

Figure 3. Pacific Energy Center Building Pressure vs. Leakage Rate



Source: PECI

Figure 4. The Pacific Energy Center Pressure Gradient at Different Test Points



Source: PECI

The test revealed that the building leakage rate is about 75% of what might be anticipated from data in the DOE/ASHRAE study, which projected a leakage rate of 2,300 to 26,000 cfm at 0.10 in.w.c. During the test, we measured a leakage rate of 19,000 cfm with the lobby pressurized to 0.11 in.w.c. This amount of leakage was surprisingly high given the concrete construction, the lack of openings in two faces of the building, and the attention to energy efficient windows and skylights at the facility.

The results also validated the existing relief damper control strategy as being a sound method of minimizing infiltration and relief fan energy. Operating experience has shown the facility staff that maintaining a lobby pressure of 0.05 to 0.10 in.w.c. will provide a comfortable environment at the reception desk with out objectionable noise or blowing the doors open.[6] Extrapolating the test data indicates that approximately 12,000 to 18,000 cfm will be required to maintain the desired pressure range. Many of the units' operating hours occur with flows in this range on an economizer cycle utilizing a significant amount of outdoor air, resulting in a need to relieve this air. The existing operating strategy uses the building leaks as the relief path, enhancing comfort and minimizing relief fan operation. However, if the building was located in a climate with less economizer hours or if the VAV fan system had higher turndown, there may not be enough air brought into the building to pressurize the lobby, and thus infiltration could occur.

Conclusion and Recommendations

Past experience and recent test data indicate that air leakage through the building envelope can be a significant factor impacting comfort, energy consumption, and other operational issues. Experimentation and testing reveal that design and commissioning efforts targeted at minimizing those impacts can have a positive effect in many areas. In fact, there are ways to exploit the leakage to minimize the perimeter load and save fan energy, as was the case at the PEC. But in some instances, such as the courthouse, the leakage is so overwhelming that there is no practical way to modify the HVAC systems to mitigate the problem. In these situations, there is little recourse other than to identify and repair the leaks if the issues associated with them are to be resolved. It is likely that a combined course of action under-which identification and repair of major leakage is supplemented with HVAC operating strategy modifications will be the most viable.

Thus, designers would do well to assume the buildings they develop will leak despite their best efforts for airtight design and construction, to anticipate the leakage, and to develop HVAC design and operating strategies that can accommodate it. Construction personnel should continue to make every effort possible to minimize the potential for leakage because even with due diligence, perfection will not be achieved. Commissioning agents can use the lessons learned to adjust existing HVAC systems to mitigate the leakage related operational problems they encounter and guide the development of improved HVAC strategies during design phase commissioning. Overall, key factors to consider include:

1. Decouple the temperature control and building pressure control functions associated with the economizer. Consider controlling the relief dampers and return fans based on building pressure.

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[6] During the test, we discovered that the doors tended to blow open at test pressures of approximately 0.20 to 0.25 inches w.c. and that we had to restrain the doors to complete the test.

2. Provide vestibules on lobbies, arranged with an air lock between the interior and exterior of the building under normal traffic flow rates.
3. Provide supplemental heat and draft protection at workstations located in the lobby.
4. Provide an independent HVAC system for the lobby in high-rise and complex buildings that is tailored to meeting the requirements of the lobby, including pressurization.

While a completely leak-free building may not be achievable, a building that is comfortable and mitigates the impacts of envelope leakage via the design and operation of the HVAC systems is both achievable and desirable.

References

Armstrong, Peter R., P.E., Donald L. Hadley, Robert D. Stenner, Ph.D., and Michael C. Janus, P.E. 2001. *Whole-Building Airflow Network Characterization by a Many-Pressure-States (MPS) Technique*, ASHRAE.

ASHRAE. 2001. *ASHRAE Handbook of Fundamentals, Chapter 26, Ventilation and Infiltration*. ASHRAE.

ASTM. 1992. *ASTM Standard E 779*:(Standard Test Method For Determining Air Leakage Rate By Fan Pressurization, Philadelphia: American Society for Testing and Materials.

Bahnfleth, William P., Ph.D., P.E., Grenville K. Yuill, Ph.D., P.E., and Brian W. Lee. 1999. *Protocol for Field Testing of Tall Buildings to Determine Envelope Air Leakage Rate*, ASHRAE Transactions, V. 105, Pt. 2.

Cook, Joe. 2004. Memorial Hospital of Carbondale Facilities Engineering, Personal communications.

Murphy, W.E., Ph.D., P.E., D.G. Colliver, Ph.D., P.E., and L.R. Piercy, P.E. 1991. *Repeatability And Reproducibility of Fan Pressurization Devices in Measuring Building Air Leakage*, ASHRAE.

Persily, Andrew K., Ph.D. March 1999. *Myths About Building Envelopes.* ASHRAE Journal.

Ross, Donald, E. 2004. HVAC Design Guide for Tall Commercial Building. ASHRAE.

Sellers, David, P.E., Hannah Friedman, Larry Luskay, P.E., Tudi Haasl. 2004. *A Test Procedure for Assessing Envelope Leakage in Commercial Buildings: The Issues, the Process and the Results*. Presentation at the 12th National Conference on Building Commissioning, Portland Energy Conservation Inc. (PECI).