VAV Systems— What Makes Them Succeed? What Makes Them Fail?

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ABSTRACT

When variable-air-volume (VAV) systems work right, they provide excellent temperature and humidity control and in addition deliver outside air to conditioned spaces in amounts sufficient to satisfy ASHRAE Standard 62 and meet all criteria required for acceptable indoor air quality. The final benefit is lower utility cost when compared to a comparable constant-air-volume system.

However, the successful performance of VAV systems is often compromised by flawed conception, faulty design, defective installation, poor start-up, inaccurate operation, and inadequate maintenance. Field observations of underperforming VAV systems have uncovered problems due to mistakes that have been made through all the phases of system development.

It is recommended that most VAV systems be designed, installed, started, and operated under a comprehensive commissioning process. Experience has shown that careful monitoring of all phases of development and operation will ensure that there are minimal problems to plague the building owner and operating personnel once the system is in use.

This paper is written from the viewpoint of a former contractor who is now a professional engineer and who has designed, installed, started, and maintained VAV systems.

INTRODUCTION

When variable-air-volume (VAV) systems are at their best, they provide exceptional control of the occupied space environment. The temperature and relative humidity of the space is maintained at design settings, and the majority of occupants are comfortable and productive. At the same time, the conditioned air is filtered to a degree that enhances the quality of the spaces by providing a healthy working environment. In addition, building energy costs can be reduced 20% to 30% when compared to conventional constant-air-volume systems. This is due, in large part, to the fact that VAV systems run on an overall average of 70% of anticipated peak load. Interior zones average approximately 80% of peak loads, while exterior zones, due to constantly shifting solar and conduction loads, average approximately 60% of anticipated peak loads.

However, the successful performance of VAV systems is often compromised by flawed conception, faulty design, defective installation, poor start-up, inaccurate operation, and inadequate maintenance. When VAV systems are at their worst, they tend to drive occupant comfort and indoor air quality down to the lowest ebb possible. The systems operate with wildly swinging temperature and humidity ranges in the conditioned spaces, noise, frequent breakdowns, and high utility costs. Field observations of underperforming VAV systems have uncovered problems due to mistakes that have been made through all phases of system development, starting with the conception phase and continuing through the operation/maintenance phase.

WHEN VAV SYSTEMS ARE AT THEIR BEST, WHAT MAKES THEM WORK RIGHT?

The system designer has obtained all available data that relate to the owner's requirements. This provides the basis for accurate space-by-space heating and cooling load calculations that determine equipment capacity requirements and ventilation rates for all the conditioned spaces. This, of course, is a vital exercise in ensuring the success of not only VAV systems but any type of system that has been selected. Listed below are many, but not all, of the items that must be considered in preparing an accurate heating and cooling load profile of each conditioned space.

1. Owner's criteria for space temperature and relative humidity conditions.
2. Local weather conditions that the building will experience.

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3. Building materials to be incorporated into the construction of the building, including color and insulation values.
4. Building orientation on the site and layout of occupied spaces, windows and exterior doorways.
5. Occupant density and activity planned for each space.
6. Lighting and internal heat-producing loads, etc., planned for each space.
7. Time-of-day, day-of-week, and seasonal schedules of occupancy plus on-off schedules of lighting and internal heat-producing loads.

During the design phase of VAV systems, the designer must provide sufficient quantities of conditioned outside air to all occupied spaces to comply with the indoor air quality (IAQ) requirements of ASHRAE Standard 62. The designer must also provide sufficient quantities of conditioned outside air to satisfy the exhaust air requirements of the building. Often the quantity of outside air required to satisfy building exhaust systems exceeds the quantity of outside air required to satisfy the IAQ requirements of the building.

The introduction of outside air quantities to each conditioned space must remain constant throughout the minimum-to-maximum range of variable supply air delivered to the conditioned spaces. The outside air must also be provided in quantities sufficient to keep the building under a positive air pressure in relation to the outside environment. This is to ensure that infiltration of untreated outside air is kept to a minimum. Currently, premium designs of VAV systems employ mechanical injection via a dedicated outside air fan. This strategy provides a controlled quantity of outside air that mixes with the variable return air entering the air-handling unit. (Note that in hot and humid climates, this outside air may be precooled and dehumidified before it is mixed with the return air as an added measure to control relative humidity levels in the conditioned spaces). This provides the constant volume of outside air required to satisfy the needs of IAQ, exhaust systems, and building pressurization during occupied and unoccupied modes. It has been found that complicated, and often badly designed, control strategies that manipulate dampers to mix outside air with return air fail to accomplish a dependable constant volume of outside air into the air-handling unit's intake.

Various strategies are employed for control of the supply air delivered to the variable-air-volume terminals. These include, but are not limited to, modulated flow of chilled water through the cooling coil, constant flow of chilled water through the cooling coil ("wild coil") coupled with face and bypass control, direct expansion coils that are kept constantly cold by specialized "bypass" control valves, and the use of economizer air when available. The correct strategy must be selected by the designer after careful consideration of its ability to deliver dependable and controllable conditioned air.

It is extremely important that all return air and outside air be cleaned by high-efficiency air filters before passing through the heating and cooling coils and then being delivered to the conditioned spaces. This is not only to protect the coils from accumulation of debris but to assure building occupants of working in an environment conditioned by clean, healthy air. To ensure compliance with ASHRAE Standard 62, many designers now select filters having a minimum efficiency of 60% to 65% (based on ASHRAE Standard 52-76) as the primary air-cleaning method employed in the air-handling unit. It is normal practice to reduce the replacement interval and expense of these filters by protecting them with a relatively economical prefilter section.

A VAV system, by design, delivers conditioned supply air to the spaces in quantities that vary as required to satisfy the space temperature setting. In order to prevent space relative humidity from exceeding the normal design conditions of 50% to 60%, the supply air temperature delivered to the conditioned spaces should be maintained at approximately 55°F without reset. This is normal when operating in hot and humid climates. In a climate that is not hot and humid, reset of the supply air temperature, up to 60°F, may be considered with the understanding that a higher supply air temperature diminishes the ability to remove moisture from the supply air before it is delivered to the conditioned spaces.

Delivering a variable volume of supply air to the conditioned spaces does have some drawbacks. During the early days of designing variable air systems, the air control terminal boxes were allowed to go to full shut-off. Although this was an effective way to reduce space cooling effect to zero, it caused the space occupants to suffer from stagnant air conditions and it became apparent that Standard 62 minimum ventilation air requirements were not being met. This has led to the current design consideration of limiting the supply air to a predetermined minimum ventilation air quantity that complies with Standard 62. Although this air quantity satisfies the minimum ventilation air requirement of the conditioned spaces, it also leads to overcooling the spaces due to the continuous delivery of air at a temperature of approximately 55°F. Thus, it has become necessary to reheat the air to a temperature that negates the cooling effect of the supply air and, in addition, to provide additional heating of the conditioned spaces as required to satisfy space heating temperature settings. Reheat, of course, is only provided to a reduced volume of supply air and is not utilized to heat the maximum air required for full cooling effect. Some exceptions exist, such as spaces that require maximum air delivery at all times.

Normally, supply air is delivered to spaces in a range between 0.8 and 1.5 cfm/ft2 of conditioned space. This quantity has been found to be acceptable by most space occupants, being perceived as above stagnation conditions and below drafty conditions. Some exceptions will require a higher air delivery, but it is normally not advisable to provide ventilation air that is below the minimum quantity stated above. It is of prime importance that conditioned air be introduced into the occupied spaces without causing a feeling of stagnation, dumping cold air directly onto the occupants, or causing drafty conditions.

Current state-of-the-art VAV systems are controlled by direct digital control (DDC) systems that employ microprocessor control panels and sensors for the space temperature, space relative humidity, supply air temperature, return air temperature, outside air temperature, and mixed air temperature. The control panels can be interconnected with a data transmission cable that can connect to a remote workstation manned by an operator. From this station, the operator can address each DDC panel to access current temperatures and relative humidity values of the conditioned spaces and the various air-handling units and central heating and cooling plants that serve the total HVAC system. The DDC control system has been found to provide accurate control of all system operations and is valuable as a means for troubleshooting temperature, relative humidity, or air delivery malfunctions. Data logging features allow for reviewing a history of zone conditions and system operations and predicting length of intervals between routine maintenance requirements.

Building owners are becoming more receptive to providing full or partial commissioning of the mechanical systems before taking occupancy of their buildings. They perceive a positive benefit in the use of the commissioning process to ensure full system operation once occupancy begins. They find that there are few callbacks for system malfunctions, and acceptable environmental control of the conditioned spaces is established quickly instead of after months of manipulation of the control adjustments and air distribution components. The owner and the design team have both found that the best assurance of system operational success is when design, installation, and start-up procedures are performed under the verification of a total project commissioning program.

No matter how successfully the design, installation, and start-up phases are performed, the end results can be completely ruined if the systems are not operated correctly or maintained and serviced under a preventive maintenance program. It is of prime importance that the operating personnel receive proper and sufficient training in operation, troubleshooting, and maintenance of all pieces and parts of the systems that serve the occupied spaces and the central heating and cooling plants. It is equally important that the operating personnel have sufficient ability and knowledge to comprehend the training sessions and be able to initiate and support the preventive maintenance program required for the systems.

WHEN VAV SYSTEMS ARE AT THEIR WORST, WHAT MAKES THEM SO BAD?

VAV systems fail to perform for the same general reasons that other HVAC systems fail. In addition, they have been found to be more sensitive than other systems. Any one of the failures listed below will cause a VAV system to underperform and create uncomfortable and/or undesirable conditions for the building occupants. If the system suffers from two or more of the following missteps, then it is very unlikely that the building occupants will ever be satisfied with their working environment.

VAV Systems Are Improperly Designed

1. The owner's intent was not known. Many times owners do not clearly convey to the designer what they expect to receive when the building and its mechanical systems are turned over to them.
2. The owner's intent was ignored by the designer, who may not have been convinced that the owner was sincere in conveying his/her intent and expectations.
3. The data used in heating/cooling load calculations were erroneous or the method of calculation was not performed correctly. This results in systems that are undersized or oversized and, in either case, unable to maintain comfort in the conditioned spaces.
4. Equipment and system components are improperly selected or configured, and the conditioned spaces do not receive the correct temperature or volume of ventilation air. This may occur when the owner decides to utilize spaces for purposes other than their original intent and the designer has not been informed during the design process.
5. The designer does not understand how temperature and humidity control systems must be selected and applied to properly operate the mechanical equipment, which results in uneven and erratic control of the conditioned spaces. Many times control systems, and their strategy, are not clearly and thoroughly described. The contractor is then left with the problem of determining how the various control sequences are to be attained. This leads to miscommunication and misapplication of controls and dooms the system's ability to properly condition the spaces.
6. VAV systems are often designed to be more complex than their competing alternatives. It has been found that with additional complexity and elements, there is a greater chance of making a mistake in design, construction, and operation. Increased complexity results in systems that are more sensitive to errors because there are more things that must work if the systems are to function properly. If there are more things that must work, then there is a greater chance they will fail.
7. The designer does not consider the operator's problems in operating and maintaining the systems once they are eventually placed into service. Many times the designer will ignore access requirements for service and maintenance as recommended by the equipment manufacturers. If the designer adds more complexity to the system, the more difficult will be its operation and maintenance.

VAV Systems Are Poorly Constructed

1. The contractor does not install equipment and system components in accordance with the construction documents.
2. The contractor substitutes equipment and/or materials that do not have the quality and features required to meet the

design intent. This must be controlled by the A/E's careful review of all submittals.

VAV Systems Are Not Properly Started, Adjusted, and Balanced

1. The equipment start-up and checkout procedures are incomplete and many control functions are not verified. This creates the possibility that equipment and systems will not respond correctly when critical control sequences must occur. This generally happens when systems go through mode changes such as outside air control during economizer modulation or when air-handling units require temperature and air volume reset. Many times the systems are placed into operation without verification that control strategies operate in accordance with the design intent. The lack of a thorough commissioning procedure during this phase will invariably lead to poor system performance after building occupancy occurs.

VAV Systems Are Not Properly Operated and/or Maintained

1. The operating personnel do not receive proper and sufficient training in the operation and maintenance of the systems.
2. The operating personnel do not have sufficient skills and knowledge to comprehend the complexity of the systems they must care for.
3. The operating personnel do not pursue an active program in preventive maintenance of the systems. As a result, frequent breakdowns and poor control of the conditioned spaces are incurred.
4. The system may receive well meaning but misguided operation and maintenance attention. In this case, the operating personnel respond to what they perceive to be system problems with what they believe to be cures. These might, in fact, be incorrect and lead to many more problems. A lack of technical knowledge and troubleshooting guidance could lead to this result.

WHEN VAV SYSTEMS ARE AT THEIR WORST, WHAT IS THE RESULT?

Dry-Bulb Temperature Is Not Maintained

The system fails to keep the space dry-bulb temperature in the range necessary for occupant comfort. This can mean that the temperature of the complete space, or part of the space, will be outside the acceptable range all or part of the time. It could also mean that, although the temperature stays within an acceptable range, it changes rapidly enough to be noticed by occupants and cause a perception of discomfort.

Humidity Is Not Maintained

The system fails to maintain space humidity within acceptable limits. As with dry-bulb temperature, this may only occur part of the time (i.e., under certain loading conditions). Poor humidity control can have another, and previously unforeseen, consequence. It can promote the growth of mold, mildew, and other living organisms that lead to poor indoor air quality.

Air Motion Is Objectionable

The system may fail by causing either too much air motion, causing occupants to experience drafts, or too little motion, causing occupants to experience the feeling of stagnation. At low airflow, the system may exhibit "dumping" from misapplied supply air devices.

Noise Variances Are Objectionable

Although often closely associated with air motion, noise must be considered separately. Objectionable noise can occur even when air motion is acceptable. Either general sound levels, or changes in sound levels, can be objectionable to the occupants.

Indoor Air Quality Is Not Acceptable

The system may fail to keep room air sufficiently "clean." This can happen in several different ways. The total quantity of ventilation air brought into the air-handling unit may, under some loading conditions, be inadequate. Although the total quantity of ventilation air is acceptable, the ventilation air delivered to a specific space may be inadequate at some loads. In addition, if each space receives its required ventilation air quantity, the effective ventilation may be less due to poor air mixing and short-circuiting. The designer may have selected an air filter system having insufficient efficiency to clean the conditioned air to a suitable level, or the operating personnel may replace acceptable air filters with those having less efficiency. Finally, airflow variations can also cause filters to work less efficiently in cleaning up recirculated air. The end result of all these failures is the same: indoor air contains pollutants at levels of concentration above that which is conducive to occupant health and comfort.

High Operating Cost Is Experienced

The final failure is the only one that has nothing to do with occupant comfort. This is when it is found that the system has become excessively expensive to operate and maintain, which may take the form of either high utility cost or high maintenance cost. The defect that leads to this condition may have its origin in any or all phases of design, construction, or operation/maintenance.

WHEN VAV SYSTEMS ARE AT THEIR WORST, WHAT HAS BEEN OBSERVED?

VAV systems are expected to provide occupants with a comfortable and healthy environment. Owners expect them to provide dependable operation and low energy consumption. Unfortunately, after start-up, many VAV systems flounder and cause dissatisfaction and problems for all parties, including the owner, design team, contractors, occupants, and operators.

When dissatisfaction and problems are addressed, it is often found that they stem from negligence on the part of one or more of the above parties. The following observations were made during visits to buildings in response to occupant or owner complaints.

1. Most of the VAV boxes would not move in response to their thermostats. Their linkages were such that they tended to bind when the actuator stroked. The linkages had been field-modified to provide a minimum of 25% airflow.

a. Previous routine maintenance did not discover this problem.

2. The design specified that the supply fan's inlet guide vanes be controlled by a static pressure sensor located two-thirds of the distance from the supply fan to the end of the longest supply air duct run. A high air pressure limit was specified to be located at the discharge of the supply air fan. Instead, the static pressure sensor was installed at the discharge of the supply air fan.

a. This variance had not been picked up during the system's start-up phase.

b. Previous routine maintenance did not discover this problem.

3. The air-handling unit controls are unnecessarily complex. Some of the control systems were totally inoperable.

a. The designer did not heed the requirement for applying the "KISS" procedure in the interest of ensuring constructability and maintainability. The problem was further compounded by a vague sequence of control description in the temperature control specifications.

b. The operating personnel had very little understanding of how the system was supposed to work. When the control systems became inoperative, they were unable to diagnose the problem and make corrective adjustments and repairs.

4. The supply air fan and return air fan were designed to be controlled by the same supply air static pressure sensor. The economizer modulation works totally on the basis of mixed air temperature.

a. It has been proved (by painful experience) many times that the return air fan must be controlled separately from the supply air fan.

b. Successful control of the economizer system depends on a combination of inputs from various sources, including, but not necessarily limited to, the supply air temperature, outside air temperature, and return air temperature.

5. The original design specified an enthalpy-based changeover for the economizer system. The changeover point was erratic and became nonfunctional after a short period of operation.

a. There is general industrywide agreement that enthalpy changeovers tend to be high-maintenance items that require frequent calibration and, many times, do not function as intended.

b. Failure of the economizer can sometimes go undetected for a long length of time and lead to higher utility costs.

6. The static pressure controls on the supply air fan have been disconnected. The control on the return air fan remains connected and operable.

a. This apparently was done within the system's first year of operation due to problems from association of the operation of VAV boxes with "pressure-dependent" control systems. This was a well-meaning, but misguided, attempt at solving the problems. The "repair" led to high static pressure at the inlet to the VAV boxes and resultant air noise when the boxes throttled in accordance with their space temperature control systems.

b. The continued control of the return air fan resulted in uncontrolled differential pressure of the conditioned spaces in relation to the outside air pressure. This led to infiltration of untreated outside air, high space humidity, and poor indoor air quality.

7. The belts are missing on the return air fan. The fan is free-wheeling in the airstream. According to the operating personnel, this situation has existed for a long period of time.

a. This is an obvious lack of a preventive maintenance program.

b. An analysis of this event may lead to the conclusion that the system does not require a return air fan.

8. The perimeter baseboard heat is controlled by separate thermostats. The temperature settings of these often overlap the temperature settings of their respective VAV boxes.

a. Normal practice is to control both components from the same thermostat in a sequence that prevents simultaneous operation of heating and cooling.

b. When the heating component is operated unnecessarily, there is waste and higher utility costs of both heating and cooling energy.

9. The filters are very dirty; some have collapsed.

a. This is an obvious lack of a preventive maintenance program.

b. This will lead to higher utility costs.

10. The system has a number of long runs of flexible duct. Numerous air leaks were found in the flexible ducts and their related duct fittings.

a. Acceptable design practice is to not allow the use of flexible ducts upstream of, and connected to, the inlet connection of the VAV boxes. This will prevent unanticipated extra air pressure drops.

b. Acceptable design practice is to limit the length of flexible ducts connected to supply air devices to a maximum of six feet. This will prevent unanticipated extra air pressure drops.

c. A commissioning procedure may have caught this during the design or start-up phase.

d. The duct leaks should have been discovered during the testing and balancing work prior to owner acceptance.

11. The system is significantly oversized (a revised cooling load analysis indicated an excess cooling capacity above 50%). The system was observed to be operating at the bottom range of its designed air volume delivery.

a. This is a problem caused by the designer by using faulty data in calculating the cooling loads, making bad assumptions about system requirements, or botching the cooling load calculations.

b. Operating an oversized system can lead to high humidity in the spaces and, consequently, produce poor indoor air quality.

12. Not only has the air-handling unit been sized without using diversity correction, but its scheduled airflow exceeds the total maximum scheduled output of its respective VAV boxes.

a. This is an obvious design error.

13. The VAV boxes were originally designed to go to complete shut-off.

a. The designer ignored the need for ventilation air during periods of low cooling loads.

b. Even though the sensible cooling load may be satisfied, a latent cooling load may still exist. Thus, a loss of space humidity control will probably occur and the occupants will experience a cool and clammy environment.

c. A shut-off of ventilation air to the space will expose the occupants to a condition of air stagnation (poor indoor air quality).

14. The inlet guide vanes of the supply air fan had a broken linkage.

a. The linkage was provided by the contractor. The linkage was undersized for the load imposed on it by the fan's inlet guide vanes.

b. The inadequate linkage assembly was accepted by the A/E observer during construction.

c. The linkage broke soon after the fan was placed into operation. This was not discovered by the operating personnel due to the lack of an organized preventive maintenance program. The personnel also failed to identify the problem even though a severe "hunting" condition was encountered in the pressure of the supply air distribution system and numerous occupant comfort complaints were registered.

15. Almost all the VAV boxes were malfunctioning due to incorrect space temperature settings.

a. Temperature settings should have been verified during the system start-up phase. It is possible that under a commissioning procedure, this would have been corrected as a standard checkout of the thermostats and/or DDC control panels.

b. Incorrect temperature settings will guarantee that the system will not provide occupant comfort.

16. An air-handling unit was found with an open access door on its mixed air section. The mechanical equipment room is used for paint and chemical storage.

a. The operating personnel failed to properly fasten the door shut, and it swung open during a fan shutdown period.

b. The operating personnel were responsible for the storage of paint and chemicals in the mechanical room. This is a bad practice and should be avoided. Any chemical fumes drawn into the air-handling unit could present serious health and safety conditions in the conditioned spaces.

17. The cooling plant is in need of repair. The occupants have registered complaints of the spaces being too hot.

a. This is a problem that often is not caught by the operating personnel. A quick observation of the cooling coil temperatures would lead them to a very quick answer to the problem.

18. Objectionable noise from the air-handling unit is being transferred into the occupied spaces.

a. The designer was not properly sensitive to the noise criteria established for the project.

b. This situation should have been caught during the start-up phase and/or the testing and balancing work. It is possible that under a commissioning procedure, this would have been found and corrected.

19. There are a number of significant discrepancies in the testing and balancing report that never seem to get resolved.

a. These should be addressed by the A/E and the TAB contractor, and additional testing and adjusting should be provided to determine if the discrepancies are a result of design or construction.

b. An unbalanced system will never perform as designed.

20. The VAV boxes serving the conditioned spaces were all designed and scheduled to provide 275 cfm. The boxes that were submitted, approved, and installed were too big.

a. The submittals were not properly reviewed by the A/E. This is a common mistake in thinking that bigger is better. The submittals should not have been approved.

b. The oversized boxes should have been caught during the testing and balancing work due to their design operation being at the bottom of their capacity range.

21. The TAB report noted that testing and balancing work was performed during the heating season and the contractor was unable to check out the cooling mode. The report states that the cooling mode will be tested and balanced during the upcoming cooling season.

a. The testing and balancing of the cooling mode was never provided. There was no follow-up on the A/E's part or the contractor's part to ensure that this work would be accomplished. It appeared that the importance of this work had been forgotten.

b. The importance of the work was finally remembered after many comfort complaints were registered by the occupants during the cooling season.

22. The operating personnel are using chilled-water temperature reset to control system capacity. (Note that this is in a hot, humid climate.)

a. The personnel are operating under an incorrect notion of the importance of chilled-water temperature reset. Resetting the temperature of chilled water upward can have disastrous consequences with respect to humidity control and indoor air quality. In a VAV system, raising chilled-water temperature also increases the required airflow and, therefore, wastes energy.

23. The air-handling unit controls are direct digital controls (DDC) and not understood by the operating personnel, who have virtually no information to help them understand the system.

a. The complexity of the controls is beyond the capabilities of the operating personnel. This situation is made worse by the fact that there are no operating and maintenance manuals available to them and they had not received proper training. This was a result of a hasty and ineffective start-up procedure conducted by the contractor. A commissioning procedure would probably have been very effective in providing proper and sufficient training

b. Without an understanding of the control systems, the personnel had no way of dealing with operational problems as they were encountered. As a result, their actions would often tend to make the situation worse, not better.

24. Cooling capacity control of the air-handling unit is via a three-way control valve at the chilled-water coil. The outside air is introduced, untreated, into the mixing box. (Note that this is in a hot, humid climate.)

a. The designer did not give proper consideration to system performance at light loads, which may cause system loss of humidity control during light load conditions.

25. The static pressure in the supply air duct has been set too high through a lack of understanding of the system by the operating personnel.

a. The high static pressure results in a waste of fan energy and, by its subsequent overcooling, a waste of cooling energy.

26. The outside air dampers have been completely closed. The exhaust air systems remain in operation.

a. This was done by the operating personnel in the mistaken belief that by eliminating the introduction of outside air into the systems, they could increase their cooling effect in the conditioned spaces and at the same time reduce heating and cooling energy. In fact, this action placed the building under a severe negative pressure in relation to the outside air, and large quantities of raw untreated outside air were infiltrated into the conditioned spaces. This created conditions of high humidity in the spaces, which led to mold and mildew growth and a big indoor air quality problem.

27. The air-handling unit's outside air is in excess of design requirements.

a. This was done by the operating personnel in the mistaken belief that they would cure occupant complaints of "stuffiness" in the conditioned spaces. In actuality, it was found that this situation had been caused by an erroneous setup of the control strategy.

b. The additional outside air has overtaxed the cooling coil's capacity and resulted in loss of both temperature and humidity control. This has lead to poor indoor air quality and waste of heating and cooling energy.

CONCLUSIONS

When VAV systems are at their best, they provide excellent temperature and humidity control of the conditioned spaces. When VAV systems fail to operate as designed and/or intended, proper temperature and humidity control of the conditioned spaces is not achieved and the cost of system operation may increase to an unacceptable level.

It appears that VAV systems are susceptible to adverse and often violent reactions to one or more failures of the following elements when putting a new VAV system on-line:

1. Concept
2. Design
3. Installation
4. Start-up and Testing, Adjusting, and Balancing
5. Operator Training
6. Operation and Maintenance

It has been found that problems leading to adverse reactions can, in most instances, be anticipated and corrected (1) through a careful analysis of the concept and design elements as they are formed and implemented, (2) by careful monitoring of the installation and start-up phases before the system is turned over to the building's operating personnel, (3) by careful selection of the operating personnel to ensure they have the knowledge to properly operate the VAV system, and (4) by training the operating personnel to properly maintain the system during its use.

It is recommended that most VAV systems be designed, installed, started, and operated under a comprehensive commissioning process. Experience has shown that careful monitoring of all the phases of development and operation will ensure that there are minimal problems to plague the building owner and the operating personnel once the building is in use.

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