Eliminating Humidity and Condensation Problems in University Dormitories – Case Study

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ABSTRACT
Krueger Hall, McFadden Hall and Rudder Hall are dormitories used for housing on-campus students of Texas A&M University (TAMU). These halls have suffered with humidity problems for many years. The Continuous Commissioning (CC^{SM}) group of the Energy Systems Lab in collaboration with the Utilities Office of Energy Management, the TAMU Physical Plant, was dispatched to perform Continuous Commissioning on these three dormitories in order to find viable solutions to the humidity issues. The CC group performed extensive field tests and analysis on building AHU systems, exhaust systems, building construction, and the Energy Management Control System (EMCS). This paper presents the investigation and follow-up efforts, which identified reasons and corrective measures for the high humidity levels in the living areas of McFadden and Rudder Halls, and condensation in the bathroom ceilings of Krueger Hall, transforming these inefficient, humid university dormitories into comfortable environments.

INTRODUCTION
One of the most difficult tasks in HVAC operation is proper control of humidity (Chen et al. 2000; Lewis, 2000; Gatley, 1992; Shakun, 1992). Poorly controlled humidity can compromise comfort, assist the growth of mold and other harmful particulates, and can even result in surface condensation (Joseph 2002; Harriman, et al. 1999). McFadden Hall, Rudder Hall, and Krueger Hall all exhibited symptoms related to high humidity levels for many years. A large portion of the observed problems was a direct result of uninhibited air infiltration into the building. In the case of Krueger Hall, the humidity expressed itself in ceilings and walls so damp that they actually "wept" into the living space. The condensation had persisted for many years. Though the rooms maintained reasonable humidity levels, the chases and crawlspaces were filled with saturated air that immediately condensed on living area surfaces. The other two dormitories suffered from extremely high moisture levels inside the living space resulting in very uncomfortable occupants.

The purpose of this paper is to investigate how university dormitories on the Texas A&M campus were affected by excessive humidity by verifying design and existing HVAC systems, diagnosing humidity problems, and then recommending CC measures implemented to deal with these problems.

Figure 1: Outlook of C. C. Krueger Hall dormitory on Texas A&M University campus

Table 1: Facility Information for Student Dormitories

	McFadden	Krueger	Rudder
Air Conditioned Area (ft^2)	62,160	112,140	67,290
Year Built	1979	1972	1989
Construction Type	Modular	Standard	Modular
O.A. Unit	Fan Coil Unit on the East and West sides of each floor (total 8 FCUs)	16 SDCV AHUs with mixing of outside and return air flow (Cooling Coil only)	Two AHUs: 100% outside air serving each floor
Room	Each room is furnished with its own thermostat and humidistat. The humidistat is basically an override device	Terminal Heating with Thermostat Control; The space above ceiling of bedrooms is isolated from other space as return air chamber to AHU.	Each room is furnished with its own thermostat and humidistat. The humidistat is basically an override device for cooling coil
Hallway and Landing for stairwell	Fan Coil Units on the East and West sides of each floor (total 8 FCUs)	No FCUs	4 FCUs on each floor in the hallways as well as one FCU at each landing for the two stairwells. These FCUs have both heating and cooling coils and maintain their setpoint by local thermostats.
Chase	16 continuously operated chase exhaust fans located on the roof. Each chase serves 2 bathrooms per floor, one on each side of the chase, from the first floor up through the fourth floor. The chases are also open to the crawl space	The Space above ceiling of Bathrooms is isolated from room (ceiling to flooring above) and a part of the Space is Utility Chase. The utilities penetrate the concrete flooring from the first floor through the fourth floor in utility chase	16 continuously operated chase exhaust fans located on the roof. Each chase serves 2 bathrooms per floor, one on each side of the chase, from the first floor up through the fourth floor. The chases are also open to the crawl space
Vent fans	Four vent fans for the building, two for the crawl space, one for the mechanical room, and one for the laundry exhaust	Four vent fans for the building, two for the crawl space, one for the mechanical room, and one for the laundry exhaust	Four vent fans for the building, two for the crawl space, one for the mechanical room, and one for the laundry exhaust
Original Control Schemes	OA FCUs were designed to deliver treated outside air to the hallways and then on into the rooms. The OA FCU's were sized to keep the building pressurized and maintain the proper indoor air temperature and humidity levels. Individual room thermostats and humidistats control the FCU in each room to maintain suitable room temperature and humidity levels. The chilled water and hot water pumps were set to run continually. The hot and chilled water was pneumatically controlled by return water temperature.	16 SDCV AHUs with mixing of outside air and return air flow would supply cooling airflow at 55 F to each room.	OA AHUs would be on at all times except during freeze or smoke alarms. The OA AHUs would maintain a 55 F plenum temperature if the outside air temperature is above 60 F. The CHW valves will be full open and the OA AHU's reheat valves will modulate to maintain the 55 F setpoint. If the outside air temperature drops below 40 F the OA AHU's preheat valves will modulate to maintain 65 F temperature in the plenum.

FIELD SURVEY AND INVESTIGATION

The CC group performed a comprehensive survey on building air handling units (AHUs) and fan-coil units (FCUs), exhaust systems, and the building energy management control systems (EMCS). Facility information is presented in Table 1. Extensive airflow and water flow measurements were taken on each of the outside air AHUs and FCUs. Temperature and humidity loggers were placed in several spaces for monitoring humidity and space temperature conditions. Complete supply and exhaust airflow measurements were taken on all three dormitories in order to quantify building deficiencies.

Krueger Hall

Krueger Hall is a four-story dormitory using sixteen (16) single duct, constant-volume (SDCV) AHUs equipped with only cooling coils to provide cooling air throughout the building. Terminal hot-water coils in the rooms reheat the air according to each room's needs.

Krueger Hall has had the distinction of being a building so plagued by humidity issues that the ceilings in many of its bathrooms were "weeping" to the point of raining on the occupants. This condensation problem had no obvious cause because room humidity levels were not excessive. Removal of the lighting fixtures in one such bathroom revealed that the crawl space above the bathroom was filled with very hot (90°F), very humid (95%) air that was condensing on all available surfaces, then leaking into the bathroom below. Careful examination of the crawlspaces uncovered numerous pathways for this humid air through the large unsealed holes cut for piping. These gaps allowed the humid air access to the area above the bathroom ceilings.

All the building utilities are distributed throughout the dormitory in separate chases. The distributed utilities are domestic cold & hot water, sewage drain lines, chilled & heating hot water supply & return lines. The utilities penetrate the concrete flooring through metal sleeves at every level of the building, from the first floor through the fourth floor.

Each bedroom has an adjacent bathroom, from which it is separated by a cinderblock firewall. The bedrooms in Kruger Hall have plaster ceilings. The areas above the bedroom ceilings are isolated from the bathrooms by the cinderblock firewall which extend above the ceilings to the floor above. The space above each of the bedrooms is used as a return air plenum for their respective AHU. The bathrooms in Kruger Hall also have plaster ceilings with an open area above. This area was designed to be isolated from the bedrooms, and not be a part of the return air system.

Bedroom air condition

We initiated the survey taking one problem bedroom/bathroom (room 142) as a test subject. Measurements showed the temperature of the bedroom to be around 72ºF and relative humidity was less than 58%.

AHUs condition

The measured airside data for the AHU's shows that supply cooling airflow and return airflow were close to design conditions of 55ºF and 1" WC.

Air Conditions for the Space Above Bathroom

The temperature above the bathroom was measured at 80ºF and its relative humidity was 90%. Significant amounts of water were found condensing on surfaces. Small open areas (gaps) were noticed at various locations around the cinderblock firewalls. Utility piping through the floor was obviously not sealed properly. Figure 2 shows a glimpse of the condensation situation in the space above the ceiling in one particular bathroom.

Trouble Sources

Field surveys showed that the bedroom CAV boxes and AHU's were functioning as designed, so why was there water dripping from the ceiling of several bathrooms? Where is the hot and humid air (above ceiling in the bathrooms) coming from?

Figure 2: Condensation in the crawl space above the ceiling in bathrooms

Continued investigation uncovered that conditions in the basement crawl space (a subterranean area with dirt flooring) were identical to that in the space above ceiling in the bathrooms. Figure 3 shows the condensation in another area above a bathroom in Krueger. The condensing water is dripping from all available surfaces (concrete floor, pipes, cross beams, pillars, etc.). Similar condensation was observed in the basement. While in the basement it was also noted that the crawl space vents to the outside were shut completely.

Figure 3: Condensation of the crawl space

The crawl spaces and basement are directly connected to a primary heating water loop tunnel underneath the building. The doors to this tunnel were discovered to be open during the investigation.

Causes Identified

We monitored heating tunnel with temperature and humidity data recorders. Plots in figure 4 show average dry bulb temperature was 103ºF, dew point temperature was 78ºF, absolute humidity was from 21 ~ 26 gm/m3 and average relative humidity was 48%. Hot air from the utility tunnel was flowing freely into the crawl spaces. We also monitored the crawl space. Figure 5 shows that the average dry bulb temperature was 78ºF and its dew point temperature was around 76ºF; the crawl space relative humidity range was from 80 ~ 90%. The various surfaces (beams, pillars, floors, pipes, etc.) had temperatures of around 73ºF. When the surface temperature of various surfaces was less than the dew point of the tunnel air (76ºF), condensation would occur in the surfaces in the crawl space. Hot and humid air was being pulled into the buildings through the utility piping chases from the first floor to the fourth floor. As this air traveled, condensation on surfaces occured. Figure 6 shows monitored space air conditions above the bathroom in room 142 during the test period from May 25, 2001 to May 31, 2001. It is clear that the crawl space air's relative humidity was close to 100% and the dry bulb air temperature was very close to its dew point of 75ºF.

We mentioned earlier that there were gaps in the cinderblock firewall between the attic spaces above the bedroom and the bathrooms. We also mentioned the crawl space vents were shut. The attic space, above the bedrooms, were used as a return air plenum.

A chain of events had occurred over time and the result was that the negative pressure from the adjacent bedroom return air attic space, through the cinderblock firewall gaps, was pulling the warm moist air from the crawl space up the chases into the attic space above the bathrooms and the moisture in the air was condensing on every surface below the airs dew point.

We now knew how and why this problem was occurring the next step was to implement a cure. To close all the gaps was not feasible, it would be nearly impossible to gain access to all the areas. Reversing the air flow to exit the attic space above the bathroom ceiling would solve the problem that had eluded everyone for years. We opened all the crawl space vents, closed the doors to the utility tunnels, and placed a temporary vent fan to pull the crawl space air out from under the building and into the surrounding atmosphere. Within a couple of days the moisture was gone from above the bathrooms and the problems were resolved. How simple and easy to correct once you discover the problem.

Actions Taken

- Opened all the crawl space vents.
- Fully shut both doors between primary hot water loop tunnel and the crawl space to isolated hot air from tunnel and the building.
- Installed a temporary ventilation fan to ventilate the crawl space temporarily until a permanent one could be purchased.

Results

The excessive moisture problem has been rectified and the now comfortable temperature and humidly level has eliminated complaints. Condensation is no longer an issue.

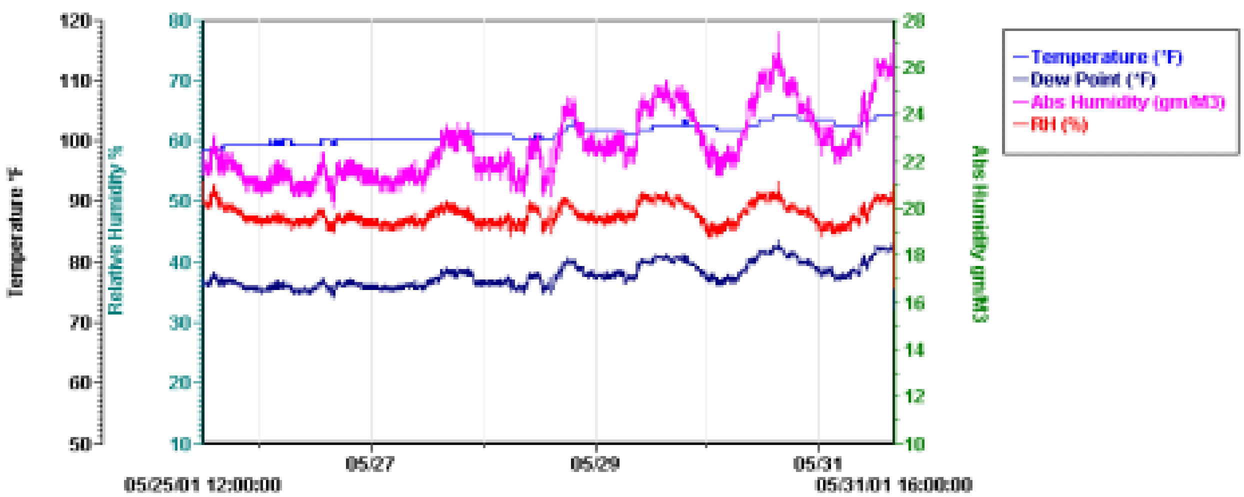

Figure 4: Monitored heating tunnel air conditions from May 25, 2001 to May 31, 2001

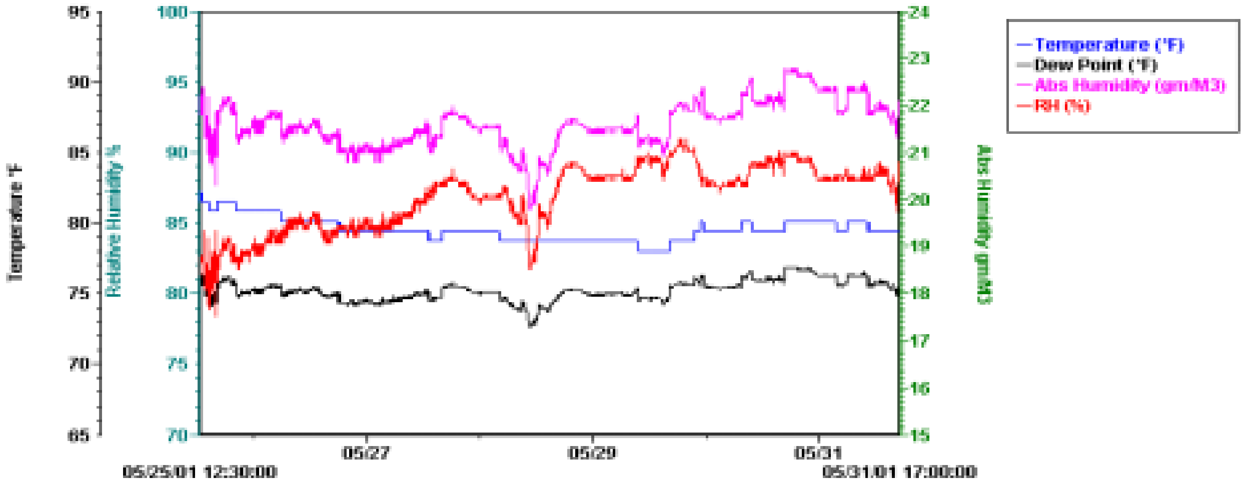

Figure 5: Monitored crawl space air conditions from May 25, 2001 to May 31, 2001

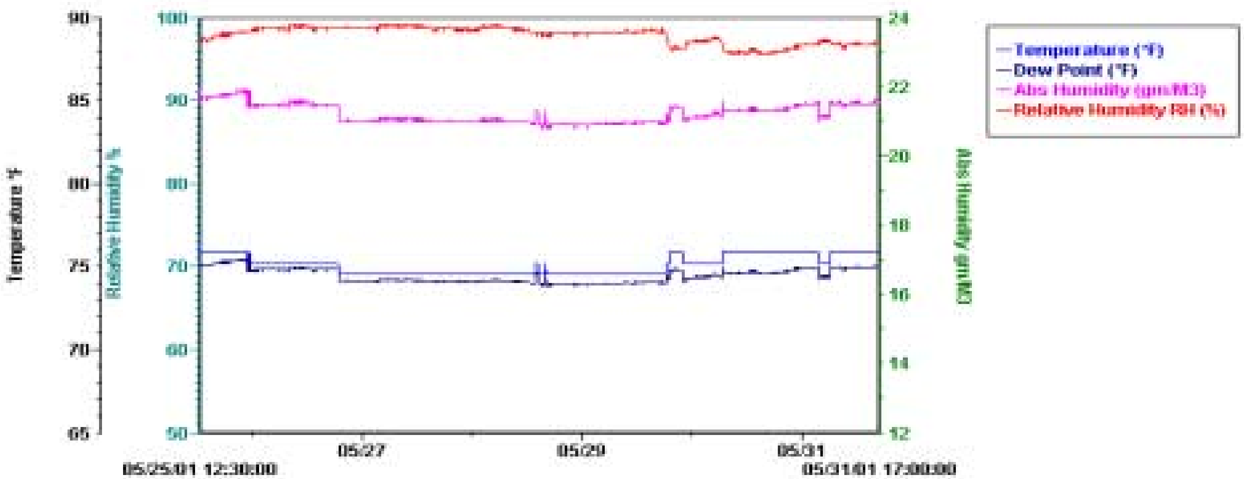

Figure 6: Monitored space air conditions above bathroom of room 142 from May 25, 2001 to May 31, 2001

McFadden Hall

McFadden hall is a four-story dormitory built using modular type construction. There are fresh air FCUs in the hallways on the East and West ends of each floor, which are designed to provide treated outside air to the building. Every room is also furnished with a FCU, which draws in the treated hallway air to maintain individual room temperatures and humidity via thermostats and humidistats. In this case, humidistats are located in the plenum space in the return air path. The humidistat is basically used as an override device, overriding the command from the thermostat to the chilled water coil in the event that the room humidity level is higher than the room humidity set point. We observed most every humidistat was not functioning and could not be calibrated. Because of the humidistat problems most every cooling coil was full open and the reheat coil had to overcome the cold air to attempt to meet room set point. This resulted in excessive energy consumption. It also resulted in high humidity and low room temperatures if the reheat coils had problems, which several did.

McFadden Hall has had chronically high levels of humidity and many comfort complaints. The building was also found to be negatively pressurized. Further investigation uncovered that all outside grills to the OA FCUs were deliberately obstructed and the duct had been cut to allow the unit to recirculate its supply air, it was no longer a 100% outside FCU as designed, the FCU's basically circulate only inside air.

Additional inspection of McFadden revealed humidity levels in the bedrooms that were significantly higher than the hallway. Some bedrooms had humidity levels as high as 80% while the adjacent hallways were closer to 50%.

Examination of the bathrooms also uncovered very low airflow. The measured exhaust airflow in the bathrooms was frequently less than 5 cfm. Several exhaust fans on the roof, which served these bathrooms required servicing. Inspection of the chases revealed the interior hallway chase access doors were too small to seal off the chase from the space air. The top of every chase door had been cut down about 3 inches to allow for a condensate drain line from the FCU's to enter the chase and gain access to a drain.

Air Balance Verification

- ***Fresh Air Intake***

The building measurements and designs were compared with the fresh air intake and exhaust requirements from the ASHRAE standard 62-1989 for a dormitory-type facility. According to ASHRAE standards, each room requires 30 cfm (cubic-feet per minute) and each bathroom requires 35 cfm of fresh air. Each bedroom FCU serves a bedroom/bathroom combination, therefore these amounts total to 65 cfm of fresh air to each room FCU. Because the rooms and bathrooms are combined, the 35 cfm for the bathroom can come from the bedroom's allotment of 65 cfm, making the necessary cfm per bedroom FCU 40 cfm. Each dormitory also has additional exhaust from laundry and mechanical rooms that need to be made up by supply air. Table 2 shows how much fresh air is required for each dormitory to account for rooms, bathrooms, mechanical, and laundry rooms. The "Design" row indicates the original engineer's design cfm for the building. The "Measured" row reflects the results the building survey. "Calculated," which is detailed later, is derived from ASHRAE standards concerning dormitory buildings.
ASHRAE Requirements for Fresh Air Intake:
The existing design fresh air (10,400 cfm) intake is 26% higher than the ASHRAE requirements for fresh air intake (8,255 cfm) by about 2,145 cfm.

- ***Exhaust Air***

For the building exhaust, there are 16 chase exhaust fans. Each chase exhaust fan is designed for 244 cfm of exhaust. Therefore, the total design exhaust air is 3,904 cfm (244 cfm x 16). Fourteen (14) of these chase exhaust fans serve 8 bathrooms each, while 2 exhaust fans serve 7 bathrooms each.

Table 2: Airflow (cfm) Verification

	Type	McFadden
O.A. flow (AHUs/FCUs)	Design	10,400
	Measured	0
	Calculated	6,283
O.A. flow (room and bathroom requirement)	Design	10,400
	Measured	0
	Calculated	5,080
Chase exhaust flow (room and bathroom)	Design	3,904
	Measured	5,629
	Calculated	4,445
Exhaust flow (laundry room, etc.)	Design	1,203
	Measured	N/A
	Calculated	1,203
Total exhaust flow	Design	5,107
	Measured	10,736
	Calculated	5,648
Total intake of crawl space	Design	2,963
	Measured	N/A
	Calculated	2,963
Total exhaust flow out of crawl space	Design	4,518
	Measured	N/A
	Calculated	2,963

ASHRAE Requirements for Exhaust Air:
According to ASHRAE standards, each bathroom requires 35 cfm of exhaust air. Since there are 127 rooms in McFadden Hall, the total exhaust air requirement is 4,445 cfm. The design exhaust air (3,904 cfm) was lower than the ASHRAE requirements for exhaust air (4,445 cfm) by about 541 cfm.

- ***Recommended Fresh Air and Exhaust Air Requirements***

Based on our investigation, and ASHRAE Standards, we recommend implementing new fresh air and exhaust air cfm settings for this building.

For the dorm rooms and bathrooms, there is only one supply diffuser to each set. There is no diffuser directly supplying air to the bathrooms. Therefore, the supply air from the FCUs is delivered to the bedroom directly and part of this air is then exhausted out through the bathrooms through the chase exhaust fan.

For this dormitory, it is recommended that instead of supplying 82 cfm for each room (10,400 design cfm / 127 rooms), the outside and exhaust airflow should be modified so that each room gets 40 cfm of fresh air and each bathroom exhaust 35 cfm. This amount of fresh air will satisfy the fresh air and exhaust requirements called for in the ASHRAE standard 62-

1989 for a dormitory. In addition, an extra 1,203 cfm needs to be supplied in order to account for the laundry room exhaust. Therefore, the amount of outside air to the building should be balanced to supply a total of 6,283 cfm (40 x 127 + 1,203).

As mentioned earlier, the existing design fresh air intake was 10,400 cfm. Based on ASHRAE standard 62-1989, the fresh air intake in this building should have been 8,255 cfm (based on 65 cfm /room; 30 cfm for the bedroom plus 35 cfm for the bathroom). However, we recommend fresh air intake be further reduced to 6,283 cfm, which is 40% less than the original design fresh air intake of 10,400 cfm. This is due to the fact that there is only one supply diffuser to each room and there is no diffuser directly supplying air to the bathrooms. The supply air from the FCUs will be delivered to the room and part of this air will then be exhausted out through the bathrooms via the chase exhaust fan.

Similarly, the exhaust air should also be modified. Out of the 16 chase exhaust fans, 15 chase exhaust fans should be modified to exhaust 280 cfm each (35cfm/bathroom x 8 bathrooms) while one chase exhaust fan should be modified to 245 cfm (35cfm/bathroom x 7 bathrooms). Therefore, the total exhaust air from this building through the chase exhaust fans should be modified to 4,445 cfm (127 rooms x 35 cfm).

The total fresh air requirements are described as follows:

1. Fresh air for rooms (127 rooms x 40 cfm / room)
= 5080 cfm
2. Fresh air intake for Laundry room exhaust
= 1203 cfm
Total Fresh Air Intake
= 6283 cfm

Similarly, the exhaust requirements are determined by the following:

1. Bathroom exhaust (127 rooms x 35 cfm / room)
= 4445 cfm
2. Laundry room exhaust
= 1203 cfm
Total Exhaust Air
= 5648 cfm

Based on the above analysis, by accounting for the laundry room exhaust air, the building should receive 6,283 cfm of fresh air. Approximately 35 cfm will be exhausted out of the bathroom, approximately 9 cfm from each room will flow into the hallways and exhausted out of the laundry room exhaust fan, while the remaining 5 cfm per room will keep the building under positive pressure. This figure amounts to a total of 635 cfm extra supply air or approximately 10% more than design exhaust air.

- ***Existing Airflow in Crawlspace***

According to the original design specifications, the two crawl space vent fans exhaust 4,518 cfm from the crawl space, while the mechanical room vent fan exhausts 1,760 cfm into the crawl space, and the laundry room vent fan exhausts 1,203 cfm into the crawl space. Since the bathroom chases are open to the crawl space, the difference of 1,555 cfm (4,518 – 1,203 – 1,760) of air is being drawn in from the bathroom chases into the crawl space and out via the crawl space vent fans.

- ***New FCU's were Installed***

For proper humidity control it is essential that the fresh air AHUs/FCUs' cooling and heating coils have enough sensible and latent capacities to cool and dehumidify, as well as, heat the raw outside air.

A reduction of total outside air intake was recommended from the original design of 10,400 cfm to 6,283 cfm, which should be divided equally among the 8 fresh air FCUs at 785 cfm each. The owner decided to replace the existing FCU's due to the condition of the existing FCU's. The old duct was replaced and new hardware cloth was installed. New DDC controls were added as well. Tables 3 and 4 show the coil capacities at these conditions for McFadden Hall.

Since there were no balancing dampers installed on the chase exhaust fans new reo-stats were installed on the exhaust fan motors to allow for air balancing. The outside airflow and exhaust flow were adjusted based on recommended airflow rates. Air balance was performed on each chase exhaust fan.

Unfortunatley the individule bathroom exhaust ducts did not have balancing dampers either. Chilled water and heating water balances also were performed.

Table 3: Cooling coil capacities for McFadden Hall

Cooling Coil						
Unit Type	Entering DryBulb Deg F	Entering WetBulb Deg F	Leaving DryBulb Deg F	Leaving WetBulb Deg F	CHW GPM @ 45 F	Press. Drop Ft. of Water
FCU-D	100	80	53	51	22.11	10

Table 4: Heating coil capacities at different conditions for McFadden Hall

Heating Coil						
Unit Type		Entering DryBulb Deg F	Leaving DryBulb Deg F	Total Capacity BTUH	HW GPM @ 180 F	Press. Drop Ft. of Water
FCU-D	P. H.	0	50	70.200	7.02	10
	R. H.	50	110	84.240	8.42	10

Actions Taken

- Replaced the chase access doors with larger doors to eliminate gaps reroute the condensate drain lines.
- Installed new FCU's with new duct work, hardware cloth, and DDC controls.
- Installed reo-stats on the exhaust fan motors.
- Repaired the crawl space exhaust fans.

Results

With the new FCU's now pulling 100% outside air, the chase exhaust fans balanced, the crawl space fans working, and chase doors replaced, the building was now positive in pressure and the humidity and condensation problems vanished. Humidity levels in the bedrooms and bathrooms returned to acceptable levels and complaints ceased immediately.

Rudder Hall

Rudder Hall is also a modular style dormitory with four floors. Two fresh air (OA) AHUs on the ground floor condition all of the outside air for the FCUs throughout the building. Each floor employs four hallway FCUs and two additional FCUs per floor on the stairwell landings. Each room also contains a FCU designed to control space temperature by drawing in hallway air. All of these FCUs have heating and cooling coils.

As for the exhaust systems there are 16 continuously operated chase exhaust fans. The fans are all located on the roof. From the first floor, up through the fourth floor, 14 of these chase exhaust fans serve 8 bathrooms each, while 2 chase exhaust fans serve 7 bathrooms each. The chases are also open to the crawl space.

There are also four vent fans for Rudder Hall; two for the crawl space, one for the mechanical room, and one for the laundry exhaust. All four vent fans run continuously. The two vent fans for the crawl space discharge air from the crawl space to the outside area, on the west side and on the south side of the building. The laundry vent fan draws air from the laundry room and discharges it into the crawl space. The mechanical room vent fan draws air from the north side of the building, through the mechanical room, then into the crawl space.

The chilled water and heating water pumps for Rudder Hall are constant speed. Exclusively pneumatic devices control this building's HVAC system. There is currently no DDC system in the dormitory.

Rudder Hall occupants had complaints similar to McFadden Hall - excessive humidity and condensation throughout the year. There were also frequent complaints regarding lack of adequate control over temperature.

During the inspection, both of the outside air AHUs designed to dry out the outside air and provide the building with positive pressure were discovered to be off due to component failures. The exhaust fans for the bathrooms and laundry, however, were all still operating normally. Even with the AHUs off, airflow was detected through the units due to the negative pressure in the building. This air entering the building through the off-line AHUs was then being cooled significantly by the chilled water coils - which were fully open in failure mode. Meanwhile, untreated outside air was infiltrating the building through every door, crack, and crevice imaginable. It was then condensing upon the ductwork containing the cool air from the AHUs and dripping into the hallway.

Air Balance Verification

The manufacturer, who furnished the original cooling coils, was contacted to obtain the design specifications on the coils and to provide load characteristics of the coils with varying specified load profiles. Table 5 shows the coil capacities at these different conditions for Rudder Hall.

Table 5: Coil capacities at different conditions for Rudder Hall

Entering DryBulb Deg F	96*	96	96
Entering WetBulb Deg F	76*	76	76
CHW Temp Deg F	44	44	47
CHW GPM	40	40	40
Air Flow CFM	4000	3220	3220
Leaving DryBulb Deg F	55.2	52.7	55
Leaving WetBulb Deg F	54.8	52.4	54.7
Sensible Capacity MBTUH	181	155	146
Total Capacity MBTUH	291	255	235

96ºF DB and 76ºF WB is 1% design conditions for College Station, TX

For the outside intake and exhaust airflow of Rudder Hall, the same calculation and analysis procedures detailed for McFadden Hall were followed. Each room will receive 51 cfm (6,438 / 126 rooms) of fresh air. Out of this 51 cfm, 35 cfm will be exhausted out of the bathroom, 11 cfm per room will flow into the hallways and exhausted out of the laundry room and janitor room exhaust fans, while the remaining 5 cfm per room will keep the building under positive pressure. This amounts to a total of 630 cfm extra supply air or approximately 10% more than design exhaust air.

As mentioned above, we recommended that the total outside air intake be reduced from 8,000 cfm to 6,438 cfm, which should be divided equally among the two outside AHUs at 3,219 cfm each. From the manufacturer's table above, the existing cooling coils should have the capacity to meet the sensible and latent load requirements until supply CHW temperature exceeds 47ºF, provided the coils are clean and flushed, air filters are clean, coils have proper flow, etc.

CC FOLLOW-UP

Based on the investigation and measurements, the following measures were recommended and ultimately implemented:

1. All the chilled water coils for the AHUs and FCUs had their surfaces cleaned and the internal tubes back flushed. All strainers were removed and cleaned. All filters were replaced with new filters. The coil performance data suggests that the OA AHU will be able to meet the expected loads satisfactorily. However, the outside air AHUs were not able to cool the air to the desired cold air temperature of 55ºF. This resulted in humid air being supplied to the plenum.

2. The airflow to each plenum was balanced such that each floor receives equal amounts of cold and dry fresh air.

3. The exhaust flow was adjusted for each chase exhaust fan based on recommended airflow rates. All these fans are the same size, therefore, the variations in flow may be due to varying degrees of slack in the fan belts.

4. The building supply air was reduced based on recommended air flow rates. This measure will insure the building stays under positive pressure, and does not pull in untreated outside air through the exterior doors, windows, and cracks.

5. The crawl space vent fans airflow was adjusted based on recommended air flow rates. The crawl space vent fans, the mechanical room vent fan, the laundry exhaust fan, and janitor exhaust fan were repaired and turned on.

6. Once the outside air intake was reduced, the chilled water and heating water control systems were modified as to allow the coils to effectively maintain a discharge temperature of 55ºF under the new loads.

7. Installed a DDC control system. The new DDC system should have the capability for remote programming, alarming, and monitoring of indoor comfort conditions and interface with the existing campus Energy Management System.

CONCLUSIONS AND RECOMMENDATIONS

Over the course of commissioning these three dormitories, one problem stood out as the primary root of excessive humidification: infiltration. Any outside air that enters a building apart from through a dehumidifying coil can carry with it unwanted moisture. Without properly stopping the infiltration or any mechanism to wring out the air already in the building, humidity problems will continue to plague any building. Tight controls need to be placed on physical variables that can contribute to humidity in the air, such as open tunnel doors, open windows, and uninsulated gaps and cracks in the building's construction.

The second most critical issue for dealing with the high humidity problems in these dormitories is establishing effective airflow pathways. These pathways are essential in order to prevent areas from stagnating, maintain proper ventilation, and to eliminate airflow bypasses. Additional problems such as excessive CO_2 levels can develop if this issue is ignored. Pathways are formed by generating positive pressure and then allowing the air to flow towards zones of lesser pressure. Controlling these pathways to our advantage requires that no opportunities for bypass exist. For that reason, negatively pressurized chases need to be properly insulated to insure that only intended pathways are present and outside air-handling units ought to have sufficient access to outside air. Furthermore, adequate attention ought to be paid to proper air-balancing throughout the building.

Finally, the installation of a DDC control system that is remotely accessible can serve to enhance the controllability of a building and allow for rapid detection and diagnosis of building problems.

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