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CONSTRUCTION DETAILS AFFECTING WALL CONDENSATION

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SYNOPSIS

Curtain walls often contain a cavity between the interior finish wall and a veneer. It is essential to prevent interior humidified air from reaching the cavity in order to prevent condensation and the associated accumulation of water or ice. Thoughtful construction details can provide the means of utilizing customary components and materials to control the air transport of interior moisture into the cavity. Unfortunately, unconstructible or poorly conceived details can render customary or specialized materials ineffective in preventing interior humidified air from reaching the cavity. The resulting condensation can lead to interior damage, saturation of structural and insulation materials, overtaxing of the wall drainage system, "weeping", ice build-up on the exterior, etc.

Case studies are presented to illustrate the manner in which construction details defeated the anticipated effectiveness of an exterior wall in controlling cavity condensation. The case studies represent condensation conditions which exceed the storage and drying capacities of the wall, resulting in observable distress. An instrumentation program was implemented to monitor the temperature and humidity conditions within the cavity of a masonry wall. The response of the cavity was then related to interior and exterior conditions so that dominant influences and interactions could be studied. Infrared thermography was also used to assess wall conditions, and the thermography results correlated with the instrumentation results. Investigative openings were made to expose the construction details for study, and to determine how they affected the cavity condensation conditions.

The observations and measurements from this program lead to simple detailing guidelines for the effective utilization of wall construction materials in controlling condensation within curtain wall cavities.

CURTAIN WALL DESIGN

Curtain walls on modern buildings have many functions. They must resist the penetration of the elements to the interior, retain the interior conditioned environment, and transfer wind loading to the structural frame. For humidified buildings in cold climates, an essential element in the retention of the interior environment is to prevent interior humidified air from reaching surfaces where condensation might occur, in order to prevent the associated accumulation of water and ice. When interior humidity reaches the cavity of a curtain wall and condenses, the accumulation of water can lead to interior damage, saturation of structural and insulation materials, corrosion, overtaxing of the wall drainage system, "weeping", ice build-up on the exterior, etc. It can also make controlling of the interior humidity difficult as vapor is lost to the cavity, and can make dehumidification necessary when the cold weather ceases.

Concern for the thermal performance and vapor control of curtain walls is apparent in the customary design procedures. It is assumed that the wall performs as a thermal conduction barrier for the purpose of calculating heat loss. In addition, vapor pressures are calculated based on a diffusion model. Resistance to vapor permeation of the various building materials are included in the calculation. Where necessary, a distinct vapor retarder element is added in order to prevent predictable condensation within the wall construction. Curtain walls can function reasonably as predicted on the basis of this model provided that the details are appropriate. Unfortunately, there are many examples of buildings in which the wall construction details result in behavior different from the thermal conduction and vapor diffusion model. Poorly conceived or unconstructible wall details can also lead to condensation problems within the wall.

MOISTURE MOVEMENT

There are two major mechanisms through which moisture from the interior conditioned environment can reach the internal components of a wall. The mechanism most often addressed in the design of a wall is diffusion, in which moisture in the form of vapor permeates the construction materials. The moisture moves from the interior, which is at a higher temperature and higher partial vapor pressure, towards the exterior, which is at a lower temperature and lower partial vapor pressure. When the materials of a wall do not have sufficient resistance to permeation, additional layers of material, such as plastic sheets, foil backing on wall board, foil facing on insulation materials, etc., are included to retard the permeation of vapor. A second mechanism for the introduction of moisture into a wall is the transport of vapor with moving air. This mechanism is capable of depositing large amounts of moisture in a cavity, and will lead to condensation problems even if a wall contains distinct vapor retarders. Humidified buildings in cold climates which exhibit condensation problems usually suffer from this second mechanism. The problem often results from wall construction details which render the vapor retarders ineffective, and permit interior humidified air to reach the cavity.

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CONSTRUCTION DETAILS

Even when wall materials are carefully selected, and the condensation performance of the wall is carefully calculated on a basis of a thermal conduction model, condensation can result if wall construction details are not considered in their entirety. It is common practice in design offices for wall details to be segregated by disciplines such as architectural, structural, and mechanical/electrical. During the shop drawing process, it is common for details to be segregated by trades and suppliers such as structural steel, structural concrete, miscellaneous steel, curtain wall, and interior finishes. This segregated approach to details often results in neglecting the issues of the interfacing of materials, the tolerances for the erection of the various materials, and the overall constructibility of the detail. Figure 1 illustrates how the segregation of details by discipline can lead to problems at the edge of a slab. The structural detail is drawn with the spandrel beam and floor slab, but without the curtain wall. The architectural detail is drawn with the curtain wall, but without the adjacent structural elements. The isolated structural detail suggests that there is free access for the installation of fireproofing, while the isolated architectural details suggests that there is free access to the curtain wall for the installation of drywall up to the underside of the slab. It becomes apparent that this is not the case when the two details are combined. It is almost impossible to properly install drywall screws on the interior because of interference with the spandrel beam. Likewise, it is almost impossible to properly tape the drywall joints when they are adjacent to the structural beam. Depending on construction sequence, it might be impossible to properly install the fire protection on the structural steel beam. Only by combining the structural and architectural details, either by actually drawing them together or by deliberately conceptualizing them together, can these interferences be predicted. If the interior drywall cannot be completely screw attached to the its substrate, and the joints cannot be completely taped, an air path is created which will permit interior humidified air to flow into the cavity. Even if foil-backed drywall is specified and used, the air path will permit this vapor retarder to be violated, and can lead to condensation problems. Figure 2 shows an incomplete installation of interior drywall, in which there are no screws installed and no tape applied above the level of the bottom flange of the adjacent spandrel beam. There is little that the drywall contractor could have done to complete the installation. In this case, the use of foil-backed drywall did not provide condensation control for the wall because of the resulting air paths.

Spandrels above window heads, and diagonal kickers for spandrel hangers, are other locations where an air seal is rarely achieved. Figure 3 shows a representative detail in which miscellaneous steel must be integrated with the interior finishes, the window installation details, and the structural scheme. The diagonal kicker, which is necessary for structural reasons, penetrates the interior drywall and creates a hole in the vapor barrier, as well as an air path to the cavity. In addition, avoiding interference between the hanger and the exterior sheathing on the cavity side of the wall is critical for preventing interior conditioned air from reaching the cavity. Customary construction tolerances make it predictable that at some locations the hanger will be in the same plane as the exterior sheathing, or on the cavity side of the exterior sheathing. Achieving an air seal under those circumstances is virtually impossible. An example of the penetration of a diagonal kicker through the interior drywall, and the difficulty of achieving an air seal, is shown in Figure 4. The infrared thermography image in Figure 5 shows local hot spots where the spandrel hangers and kickers occur above the windows.

There are several other details repeatedly used in commercial construction which can lead to condensation problems. For example, it is common for an interior back-up wall of concrete block to be installed from the top of the slab to the under side of the spandrel beam above, and between the structural columns. If an air seal sufficient to compensate for construction tolerances and block shrinkage is not detailed between the back-up and the structural steel elements, an air path exists from the interior to the cavity beyond the block. In such a situation, as shown in Figure 6, condensation problems have been observed.

Another frequently occurring detail is the use of metal furring as part of a plaster wall installation, as shown in Figure 7. Metal furring was used on the concrete spandrel beam to create a suitable substrate for the installation of metal lath. Plaster was then applied to the lath to a level above a suspended ceiling. This produced a good-looking finish on the interior, but also created an air path between the metal lath and the concrete beam from the interior into the cavity beyond the beam. Interior conditioned air can flow freely around the concrete beam, carrying with it interior humidification. Condensation problems in buildings with this detail have been observed.

Because of the requirements for fire rating, stairwells in commercial buildings are often enclosed in concrete block. Even in buildings which have received careful attention to vapor control in the occupied space through the use of foil-backed drywall, foil-faced insulation batts, etc., the stairwells often receive only a single coat of paint. The permeation of concrete block, even with a single coat of paint, is substantial. Interior humidified air can easily permeate the block to the cavity beyond. It is unrealistic to expect that insulation board simply adhered to the exterior face of the concrete block will provide a functional vapor barrier beyond the block, and condensation within a masonry cavity is predictable. It is also common for the concrete block in a stairwell to be installed against the underside of the spandrel beam. When the concrete block shrinks, a gap opens up at this joint and permits air transport of interior humidified air into the cavity. In general, stairwells do not receive the attention to vapor control that the occupied spaces do, and have been observed to be a source of condensation problems in commercial buildings.

PERFORMANCE MEASUREMENTS

A building in the upper Midwest was instrumented to monitor the performance of the wall during the winter season. The typical wall cross section is shown in Figure 8. The details of the wall construction included the problems illustrated in Figures 1 and 3. The instrumentation program included thermocouples to measure the brick surface temperature, the cavity temperature, and the interior temperature. Relative humidity was monitored in the cavity and the building interior. Differential pressure transducers monitored the pressure difference between the interior and the cavity, and between the interior and the exterior. A portable weather station installed on the roof of the building monitored exterior air temperature, wind speed, and direction. The instrumentation program was conducted for approximately two months during the winter season. Data was acquired for both heating cycles and cooling cycles of the building operating system. Condensation performance was suspected as a problem because of the construction details observed, as discussed above. In addition, where exfiltration paths existed, such as at weep holes in the masonry or at sealant failures, condensation on the face of the brick was apparent, as seen in Figure 9. At times, during the early thaw of spring, the building surface was observed to be wet and dripping, and was described by the Owner as "weeping". When temperatures dropped well below freezing during this period, icicles formed on the face of the masonry. These phenomena occurred when there was no rainfall or snowfall immediately prior to these observations. Wall temperature measurement data for a 150-hour segment of the data record is shown in Figure 10. Measured relative humidity data, and differential pressure data for the same time period are shown in Figures 11 and 12. Calculated specific humidity for the same time period is shown in Figure 13. The temperature data in Figure 10 exhibits two interesting phenomena. During periods when the outside air temperature was lower than the interior temperature, and the building was being heated, the surface temperature of the brick was measured to be lower than the outside air temperature. A comparison between the predicted behavior of the wall on the basis of a conductive heat loss calculation, and measured temperatures and relative humidities, is shown in Figure 14. The cavity temperature and the brick surface temperature are approximately 15 percent lower than the outside air temperature. The relative humidity measured in the cavity at that time was 100 percent. Condensation had been occurring in the cavity for some length of time, and evaporation of the condensate lowered the surface temperature of the brick. Essentially, during the heating cycle at night, the building behaved as an evaporative cooling tower. This phenomenon has also been observed on other buildings with instrumentation programs incorporating heat flux transducers. Measurements were obtained which indicate that heat appeared to flow from the exterior to the interior during periods when the outside temperature was very low. Evaporative cooling, with perhaps some radiant cooling, accounts for the apparent reversal of heat flow.

When the exterior air temperature was higher than the interior, and sun heating of the brick occurred, the cavity temperature was measured to be lower than the air temperature, while at the same time the brick surface temperature was predictably higher than the air temperature. A comparison during this period between the predicted behavior on the basis of conductive heat loss calculations, with measured temperature and humidity data, are also shown in Figure 14. Cavity temperatures lower than would have been predicted by conductive heat loss calculations during the cooling cycle of the building operating system are attributed to the circulation of cooled interior air in the cavity and the daily evaporation cycle of moisture trapped in the cavity. This daily evaporation cycle is best illustrated by the calculated specific humidity plots in Figure 13. Even though the relative humidity stayed at 100 percent during this time period, the specific humidity varied on a daily basis. This change of total amount of moisture in the air produced a cooling effect on the cavity.

The temperature and relative humidity measurements indicate that interior conditioned air is circulating in the cavity, and that condensation is occurring. The lack of isolation between the interior and the cavity is also demonstrated by the differential pressure data shown in Figure 12. There is very little difference in pressure between the cavity and the interior, indicating an essentially unobstructed exchange of air. Additional differential pressure measurements were made during manual operation of the ventilating fans of the building HVAC system. Fans were turned off and the pressures were monitored for 20 minutes; fans were then turned on and the monitoring continued. The operation of the fans created no noticeable differential pressure between the interior and the cavity, confirming the existence of large air flow paths.

CONSEQUENCES

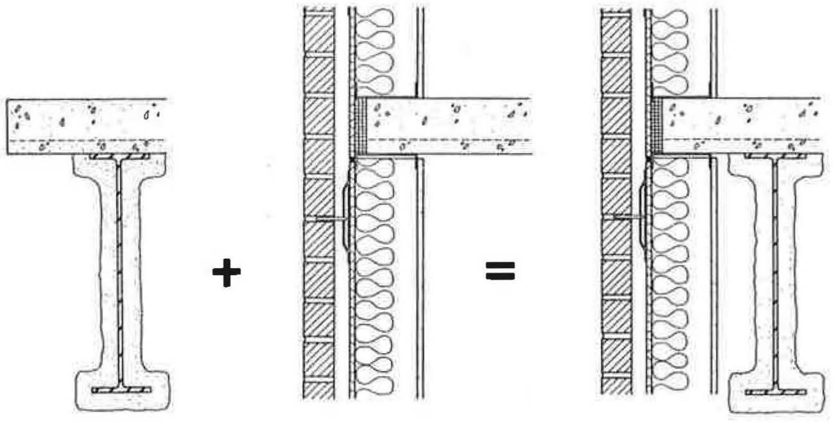
The data discussed in the previous section explains observed condensation occurring in the building monitored for thermal and humidity performance. The condensation of interior humidified air in the cavity of this building is attributed to construction details which permit interior air to circulate into the cavity. The construction details failed to address the interfacing between the various components of the wall, resulting in unconstructible details. The wall had poor thermal performance and condensation problems even though materials normally thought of as vapor retarders were incorporated into the wall.

The condensation predicted by the measurements was observed during investigative openings. The interior side of the brick veneer was observed to be wet, the insulating materials and gypsum sheathing were saturated at various locations, and corrosion had begun on the sheathing screws and on the tracks and runners of the metal stud system. The condensation problem resulting from poorly conceived details threatens the longevity of this wall construction.

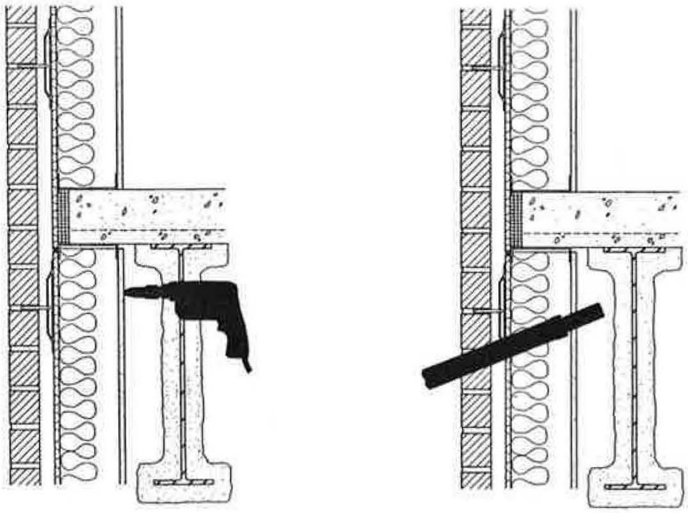
CONCLUSIONS

The wall details illustrated above, and the data acquired by monitoring the performance of a building, indicate that the lack of attention to wall construction details can lead directly to condensation problems. It is possible to incorporate materials in a wall whose normal function is to retard the transmission of vapor from the interior, and to have those materials rendered ineffective by poorly-conceived details.

Condensation problems in commercial wall construction can be avoided by specifically addressing both the permeation of wall materials and the transport of interior moisture by air moving into the cavity. Conceptually, this can be done by incorporating a vapor retarder and an air barrier in the wall design. It is not considered necessary that separate construction materials be used for these barriers. Normal construction materials can function as vapor and air barriers if they are detailed properly, and if normal construction tolerances and material interfaces are addressed during the design.



STRUCTURAL DETAIL ARCHITECTURAL DETAIL COMBINED DETAIL



INTERFERENCE FOR INSTALLATION OF DRYWALL SCREWS AND TAPE

INTERFERENCE FOR INSTALLATION OF FIREPROOFING

Figure 1

Example of problems resulting from failure to integrate architectural and structural aspects of a detail.

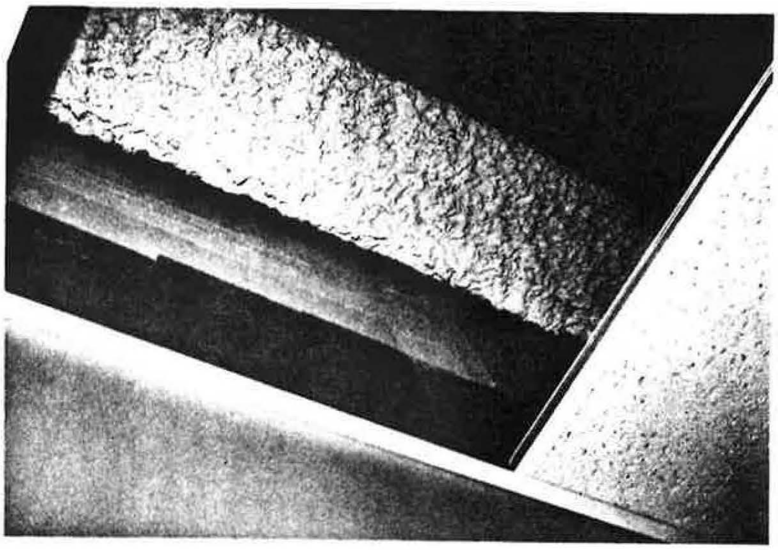


Figure 2

Incomplete installation of interior drywall due to interference from an adjacent structural beam.

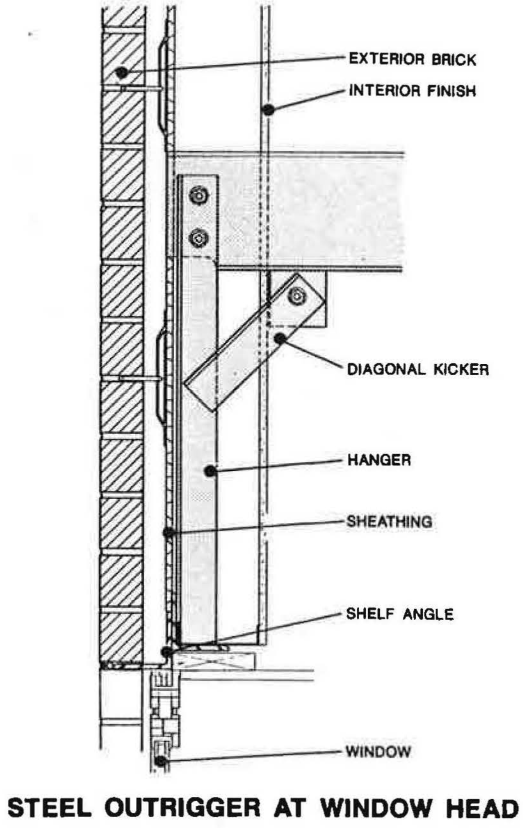


Figure 3

Steel hangers and diagonal kickers over window heads make it difficult to achieve an interior air seal.

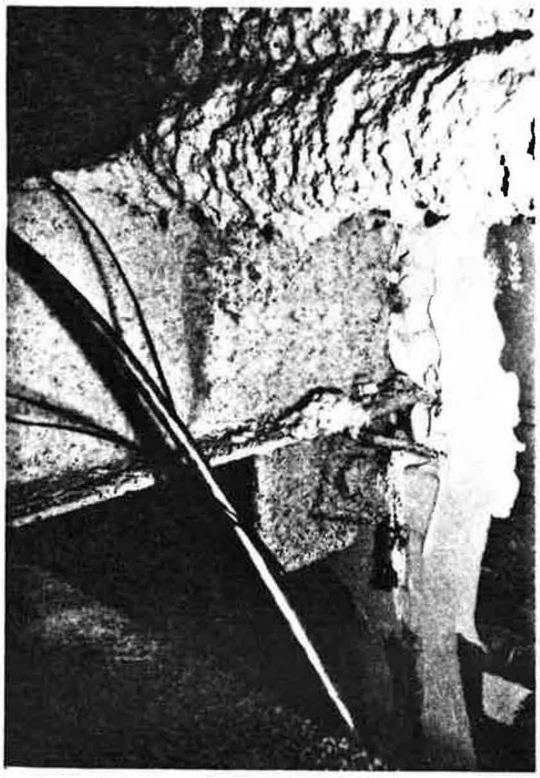


Figure 4

Penetration of a diagonal kicker through the interior drywall. It is difficult to achieve an air seal from the interior at these penetrations.

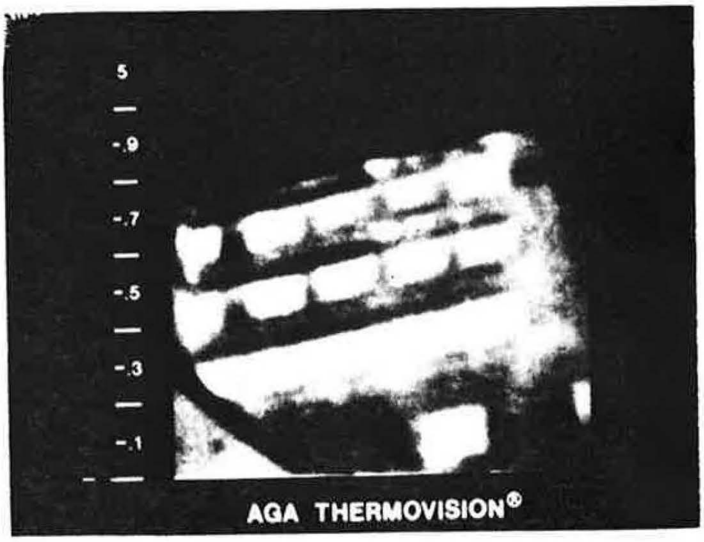


Figure 5

Infrared thermograph illustrating cavity heating and condensation at the location of hangers and diagonal kickers above the windows.

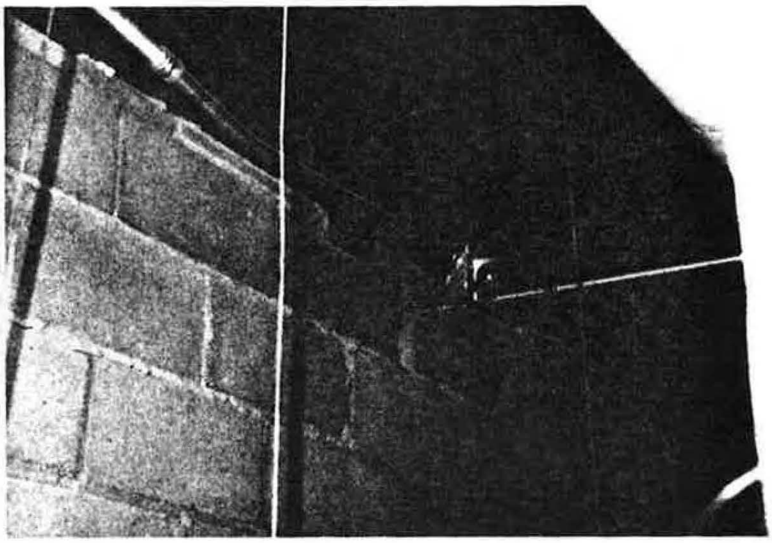


Figure 6

Concrete block back-up wall with no air seal at the underside of the spandrel beam.

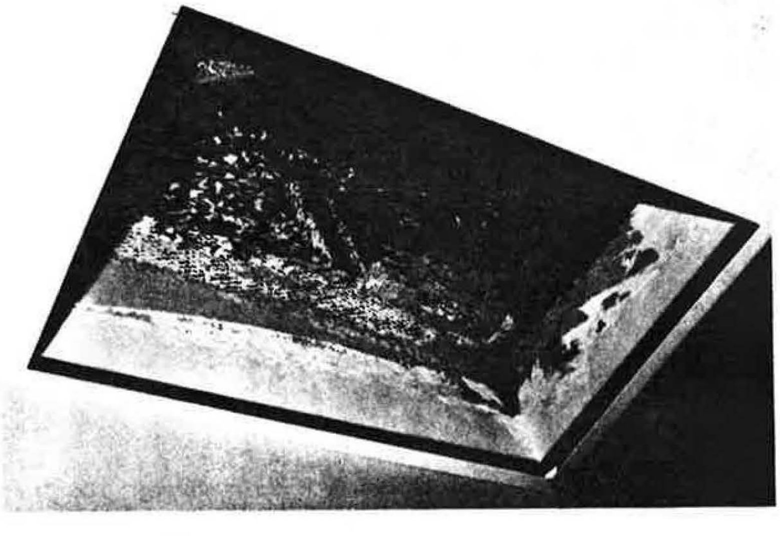
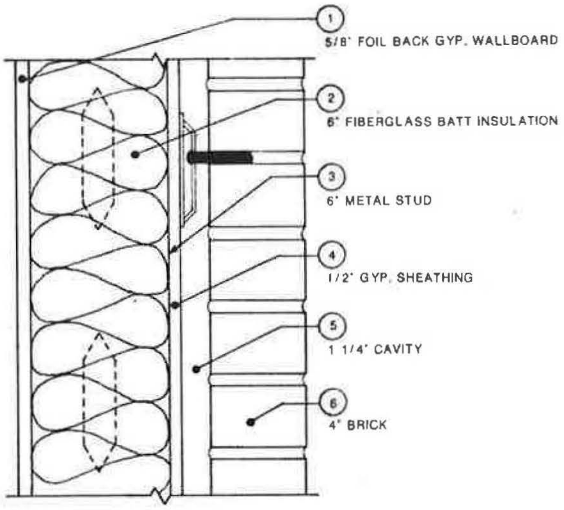


Figure 7

Furring used as part of a plaster wall installation, creating an air path around the concrete spandrel beam into the cavity.



WALL CONSTRUCTION

Figure 8

Typical wall construction of building monitored for condensation performance.

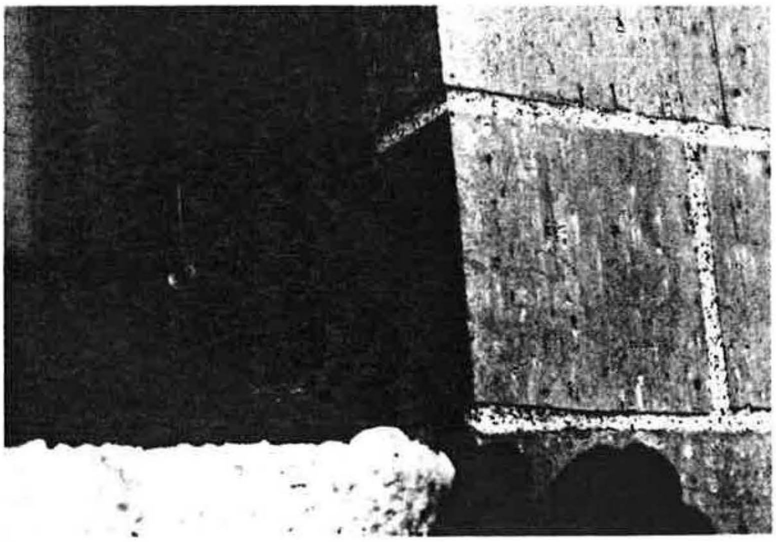


Figure 9

Condensation on the exterior of moisture transported by air exfiltrating from the cavity.

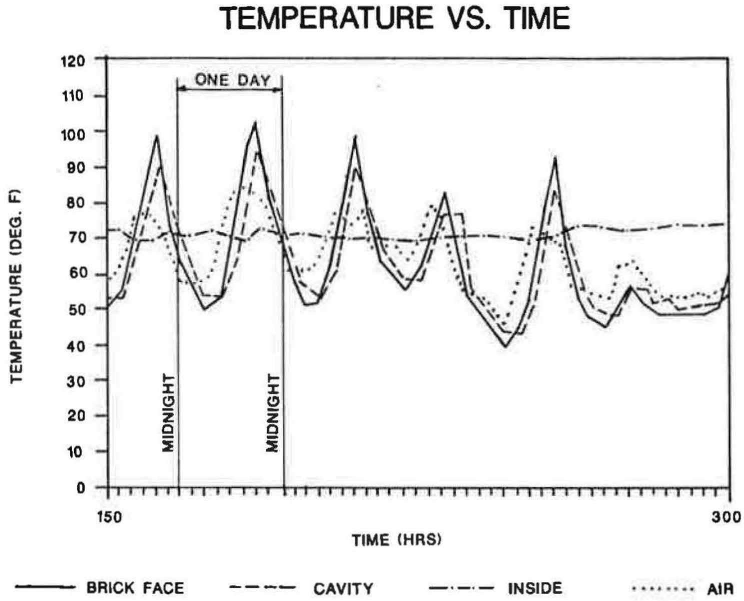


Figure 10

Measured wall temperature data.

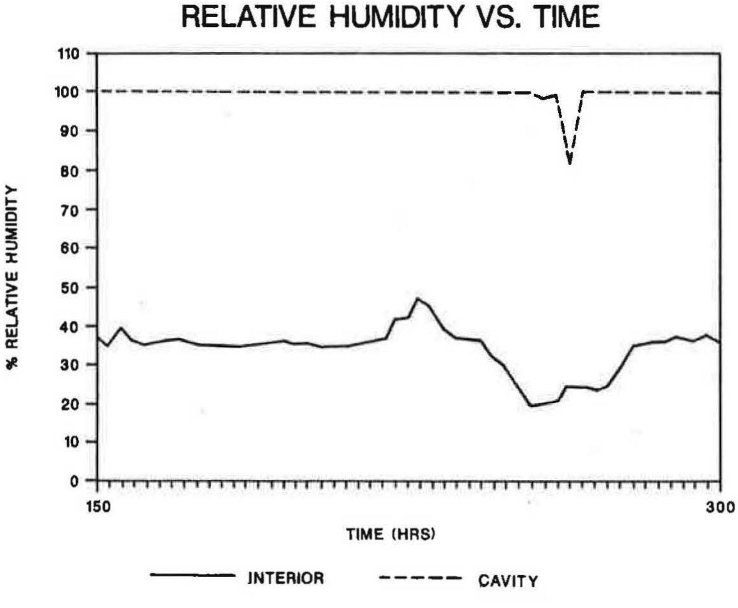


Figure 11

Measured wall relative humidity data.

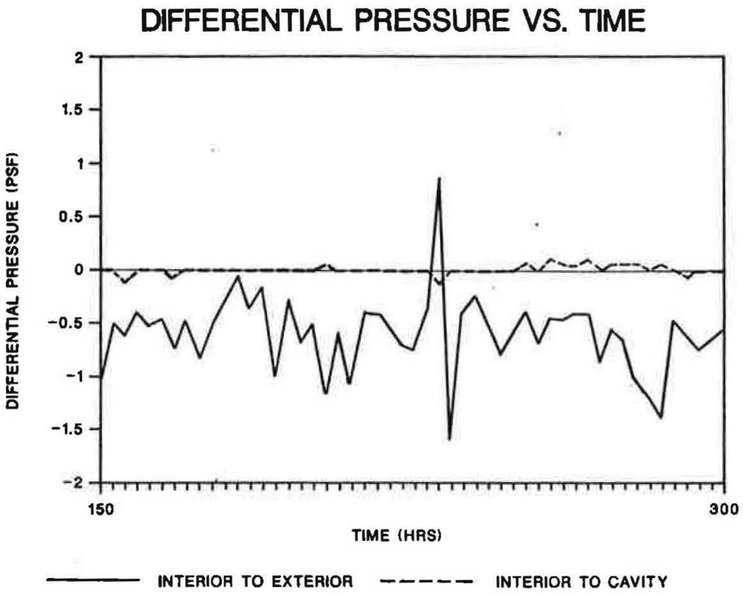


Figure 12

Measured differential pressure data.

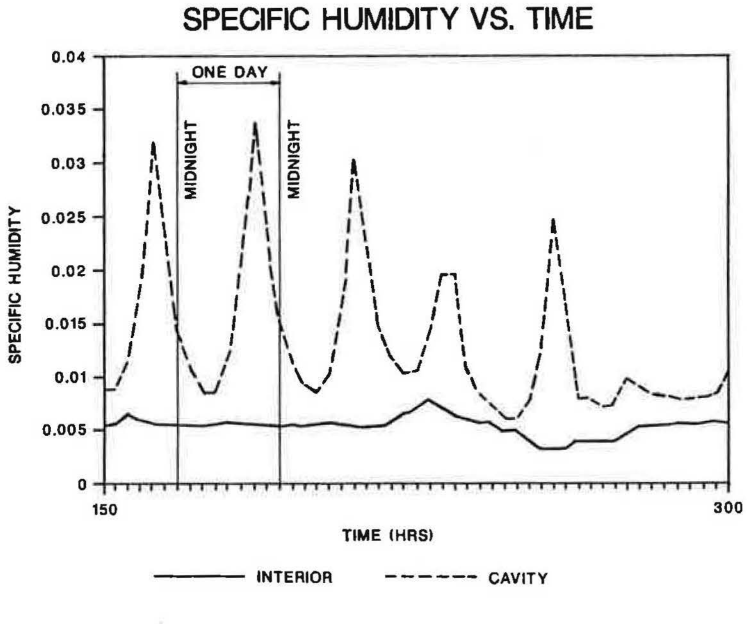
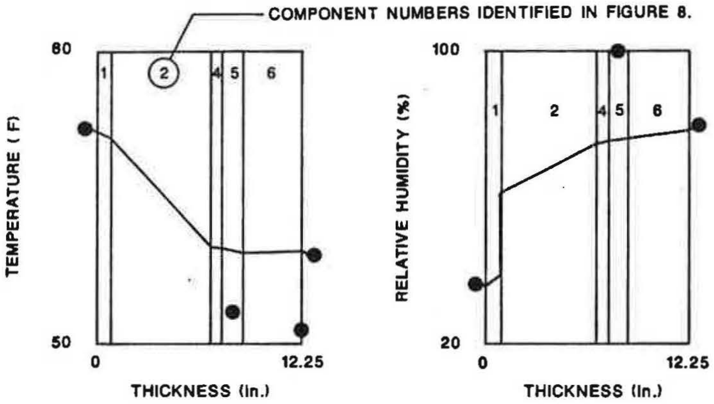
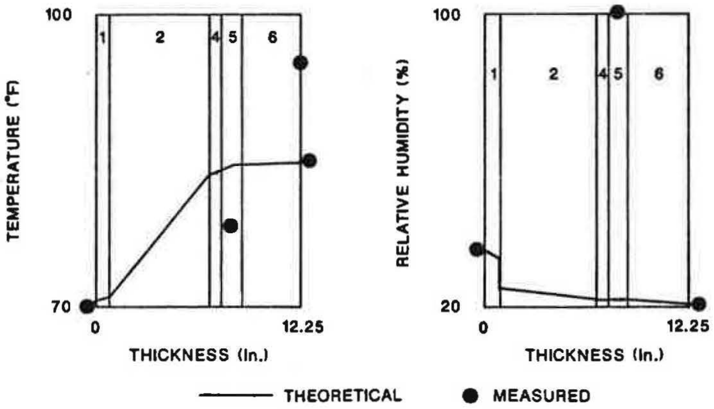


Figure 13

Calculated specific humidity data.



HEATING (Hour 174, 6 am)



COOLING (Hour 183, 3 pm)

Figure 14

Comparison of behavior predicted by conductive heat loss calculations with measured temperatures and humidity data.