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CONDENSATION PROBLEMS IN FLAT WOOD-FRAME ROOFS

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ABSTRACT

Flat wood-frame house roofs with insulation applied between joists are susceptible to condensation problems in cold climates. Investigation of difficulties experienced in a wood-frame row housing project in Eastern Canada showed that many interrelated factors contribute to the occurence of problems and demonstrated that control of air leakage through the ceiling is the one primary requirement for successful performance.

Les toits plats à ossature de bois avec isolant entre les solives posent des problèmes de condensation dans les climats froids. L'étude des difficultés suscitées par un ensemble de maisons en rangée à ossature de bois dans l'Est du Canada a indiqué les nombreux facteurs interdépendants qui sont mis en jeu et a permis d'identifier la régulation des fuites d'air à le plafond comme la principale condition d'une action efficace.

Introduction

The condensation of water vapour in roof spaces of houses during cold weather has long been recognized as a potential problem in Canada. Building practices developed to alleviate these serious problems have involved the use of vapour barriers in the form of a membrane (usually polyethylene 0.05 to 0.10 mm thick) installed so as to inhibit the flow of vapour from inside the house into the colder portions of the exterior enclosure in winter, coupled with measures to promote the removal of any vapour that does penetrate to the outside. These measures were introduced in recognition of the higher vapour pressures that existed in houses relative to outside and were initially based on a simple, steady-state diffusion concept.

The movement of moist air through unintentional openings as a parallel mechanism in the transport of water vapour has come to be regarded as more significant than vapour diffusion in Canadian buildings. The building features and construction practices incorporated into traditional designs have generally acted to minimize the problems resulting from condensation, except in those cases where some special feature or environmental condition disrupt the process.

In recent years, electric heating of houses has become more prevalent, eliminating the need for chimneys and the combustion air requirements associated with fuel-fired heating systems. This has generally tended to decrease the natural exhaust of air from such houses, giving rise to higher humidities in the living space. In addition, an increasing number of electrically heated row housing projects have utilized flat wood-frame roofs for reasons of economy or appearance. These roof systems do not offer the large attic space which exists between the insulated ceiling and roof structure that is present in the more traditional sloping roofs of houses in Canada.

A project near Ottawa incorporating these features, completed in 1963, consisted of 122 units, 10 with high pitched roofs, 55 with low pitched and 57 with flat roofs. Problems of excessive window condensation in cold weather and dripping of water from ceilings during winter thaws had been reported periodically by some occupants. In many instances the problems were attributed to abnormally high humidities in the houses as a result of reduced ventilation or high moisture gains from clothes drying indoors.

The persistence of problems even after attempts to reduce humidities, prompted a questionnaire survey by DBR/NRC in 1968. The survey results indicated that ceiling condensation problems had occurred in 28 of the 122 units; 21 cases in units with flat roofs, 6 in those with low sloped roofs and one case in the units with steeply sloped roofs. This indication that flat roofs were more susceptible to condensation problems was in keeping with a general indication from the housing industry and led to a detailed study of performance and construction features in a six-unit row house within the development (Figure 1).

Construction Features

Each housing unit had a plan dimension of 7.30 x 7.60 m with two storeys of finished space over a full and separate basement. The front and back walls were insulated wood frame with gypsum wallboard on the interior. Party walls were concrete block with gypsum wallboard on strapping. End walls were of concrete block with wood furring, insulation and gypsum

FIG. 1

Test Units

wallboard on strapping. End walls were of concrete block with wood furring, insulation and gypsum wallboard interior. Details of the roof construction are shown in Figure 2.

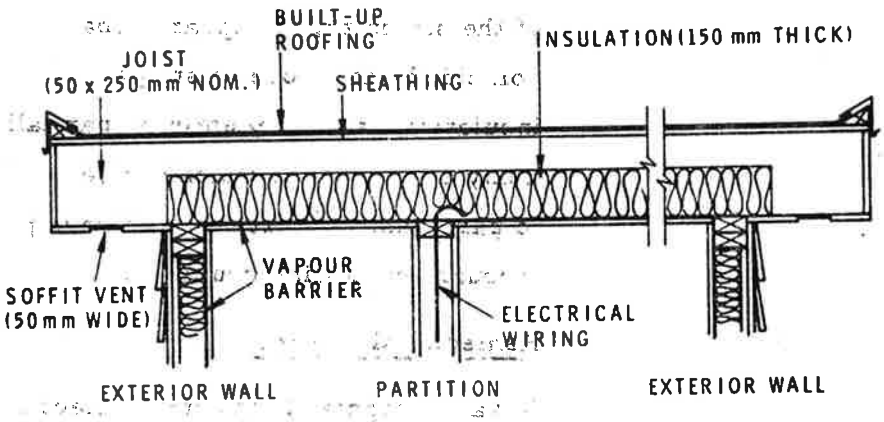

FIG. 2

Flat Roof Construction Detail

In principle the space above the roof insulation in each joist space was intended to be continuous and open to the soffit vents at the front and rear of the unit. In a number of joist spaces however, placement of insulation over nailing strips or cross bridging had resulted in blocking of this air space. The polyethylene vapour barrier, although intended to provide a continuous membrane under the insulation, was interrupted by the partition walls since these were used to support the roof joists in the initial erection process. Shrinkage of the top plates after application of the vapour barrier and wallboard, or other difficulties in securing the wallboard at this location, allowed an opening in the form of a crack that connected the interior of the partition to the roof space. Electrical wiring and plumbing services were also carried through these walls, allowing openings to the roof space. At party walls, the space behind furring strips and the masonry itself afforded similar passages of air and vapour movement.

When these "as-built" details were considered in relation to the pattern of staining that had occurred on the upper floor ceilings of the six units, it appeared that many of the major water stains coincided with those joist spaces where the air space above the insulation was completely or partially blocked (Figure 3). In many cases, the locations of severe staining were also adjacent to partitions or party walls where potential leakage openings through the ceiling could occur.

Remedial Measures

It was recognized that stack effect due to building heating produces an air pressure difference that promotes the flow of humid inside air through openings and cracks into the cold roof space, and that this effect could be greater in houses with no chimney (1). Remedial approaches designed to reduce the undesirable pres-

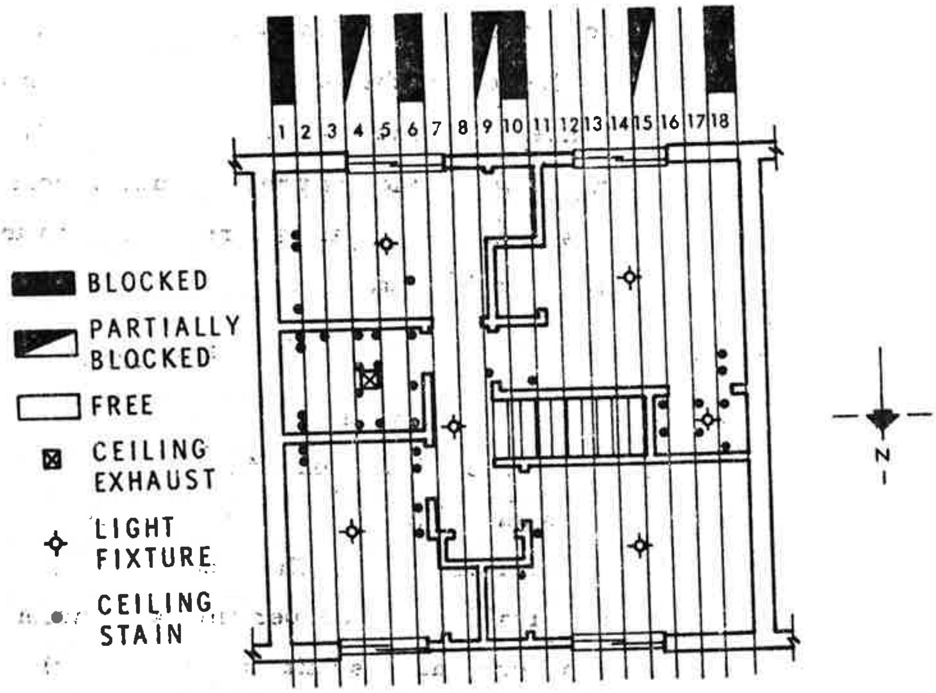

FIG. 3

Location of Blockage in Joist Space and Ceiling Stains in Row Housing Unit

sure difference across the ceiling were suggested and were applied in two of the six units; one involving pressurization of the roof space, the other using continuous exhaust from the living space. The remaining units were left unchanged.

Pressurization of the roof space in one unit was accomplished using a roof-mounted centrifugal fan discharging 0.059 m^3/s into a plenum under the soffit at the rear of the unit to supply air through the existing continuous soffit vent. The soffit vent at the front was covered and sealed. The flow rate was adjusted to produce a positive pressure of 2.5 N/m^2 as measured in one of the central joist spaces. Positive exhaust from the living space of a second unit, remote from the first, was provided by connecting the existing washroom exhaust ducts to 0.038 m^3/s fan located on the roof. Instrumentation was provided to record temperature and humidity in all six units and weekly measurements were made of pressure differences across the ceiling. Observations of ceiling conditions and window condensation were also carried out.

Observations

Observations were begun in November 1968 but no visible evidence of condensation difficulties was apparent in any of the six units during the midwinter thaw that had precipitated problems in previous years. The occupants of a unit in an adjacent, identical block did experience a recurrence of ceiling moisture problems and this unit was subsequently included in the study.

Measurements of air pressure differences across the ceiling of the control units indicated that when the outside temperature was -18°C under conditions of no wind, there was a positive air pressure difference due to stack effect equal to approximately 3.75 N/m^2. This acted to promote air movement up through the ceilings. This difference decreased at higher outside temperatures and under wind conditions but not to the point where reversal occurred for any appreciable period of time. Operation of the 0.038 m^3/s exhaust fan in the one unit reduced this pressure difference by almost 2.5 N/m^2 and thus could lead to reversal when outside temperatures rose above -12°C.

In the fall of 1969, the roof space pressurization system was transferred to the unit in the adjacent block that had experienced ceiling condensation difficulties and all of the six units in the test building were returned to normal operation. During the winter of 1969-70 reports of ceiling condensation were received from the occupants of four of the units in the original test building. The unit in the adjacent block with roof space pressurization did experience an isolated condensation problem in a closet adjacent to a party wall. A pressure difference traverse across the ceiling indicated that roof space pressurization decreased from the centre and that reversal occurred near both party walls, indicating the effect of interconnection to the roof spaces of adjacent units. It was also observed that some surface condensation had occurred on an interior wall near the soffit supply plenum where roof space pressure was high which resulted in a flow of cold air downward from the roof space into the wall.

During the winters of 1970-71 and 1971-72 the roof space pressurization system was modified by opening the previously sealed soffit vent on the side of the unit opposite the air supply plenum so that the system would operate as a roof space forced ventilation system delivering approximately 0.095 m^3/s of outside air continuously. Observation of conditions in the roof space indicated that heavy frosting of the underside of the roof sheathing occurred in two of the spaces blocked by insulation and near the vent opening of the exhaust soffit. During both winters, however, no condensation was visible from inside the housing unit.

Discussion

Although conclusive evidence as to the degree of success of the remedial measures in preventing condensation problems in all such units was not obtained from the study, the experience, observations and measurements made provided a basis for practical analysis as to the causes of the problems and the potential of control measures. The observation of "as-built" details in construction in this and other projects had shown that a substantial number of leakage openings occur in the ceiling systems of Canadian wood-frame houses. Measurement of the actual leakage openings in single-family houses of similar ceiling construction has since indicated an aggregate opening area, 0.02 per cent of the total ceiling area. Based on this leakage opening and measured air pressure differences caused by stack effect, with inside conditions of 30 per cent relative humidity and a temperature of 21°C, at an outside temperature of -18°C there is a potential for transfer of water into the roof space of 6.8 kg per day.

In flat roof systems such as described, this moist air comes in contact almost immediately with the cold underside surface of the roof where the moisture can condense as frost. This is in marked contrast to the situation in a sloping roof with attic space above the insulation. Here the moist air rising through localized openings can mix with the larger volume of air, most of which enters from outside at a low moisture content, offering a potential for dilution before it comes in contact with condensing surfaces. Most of the surfaces available are sloped to the eaves and under subsequent melting conditions, the moisture can migrate by gravity to the eaves, or evaporate in the process, rather than dripping directly onto the ceiling as would be the case in a flat roof. The moisture removal potential of a flat roof of the type described can thus be much less than that of the traditional sloped roof with an attic space.

If the influence of air pressure differences due to stack effect is accepted as the primary mechanism acting to move water vapour into the roof spaces of houses in winter, any system that acts to decrease this pressure difference, such as roof space pressurization or living space exhaust, should help to reduce or solve the problem. This approach, however, has disadvantages, e.g., increased electrical power and maintenance requirements, potential higher heating costs, and possible surface condensation problems within the house where reversal of air flow occurs. Increased ventilation of flat roofs by injection of outside air tends to raise the pressure in the roof space to a degree dependent on the resistance to "out-flow" and increases the rate of removal of moisture. Application of this method to the unit described appeared to be as effective as pressurization without creating the problem of localized cold interior surfaces.

The most obvious approach to solving the roof space condensation problem is to increase the air tightness of ceiling constructions. For new construction, efforts in this direction have been taken in Canada (2). Other changes in practice with respect to application of barriers to air flow in construction operations or relocation of electrical distribution and wiring could be warranted.

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