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by M.C. Baker

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2.4 REHABILITATION AND THE BUILDING ENCLOSURE

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Abstract - The building envelope provides the separation between inside and outside environments and controls flows of mass and energy. Rehabilitation of buildings usually involves new interior conditions that will normally impose a more severe service environment for the building envelope than existed in the original building. The walls and roofs have to be designed to maintain the separation of the two dissimilar environments without deterioration and this should take precedence over restoration considerations. The paper deals with the upgrading of walls and roofs to increase airtightness, reduce rain penetration and conserve energy use. It discusses the effect of insulation and the location of insulation on the envelope performance and the types of wall and roof modification that are possible. Exterior cladding and insulation on the exterior of walls, controlled buffer spaces for walls, and exposed insulation in the protected membrane mode for roofs is considered.

RÉNOVATION ET L'ENVELOPPE D'UN IMMEUBLE

Résume - L'enveloppe d'un immeuble assure la séparation entre l'intérieur et l'extérieur et la circulation des masses et des énergies. La réhabilitation des immeubles implique en général la création de nouvelles conditions intérieures qui imposent normalement à l'enveloppe des contraintes d'utilisation plus sévères que ce qui existait dans l'immeuble à l'origine. Les murs et les toits doivent être conçus de sorte à maintenir la séparation des deux milieux (intérieur et extérieur) sans aucune détérioration, et ce principe doit précéder toute considération de réhabilitation. Cette communication traite de l'amélioration des murs et des toitures pour améliorer l'étanchéité, et conserver l'énergie. Elle aborde les effets des isolants et de leur position sur la performance de l'enveloppe, ainsi que les divers types de modification des murs et des toits possibles. Elle étudie enfin les revêtements extérieurs lourds, l'isolation des murs par l'extérieur, les espaces tampons contrôlés dans les murs et les toits à membrane protégée.

REHABILITATION AND THE BUILDING ENCLOSURE

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Exterior walls are usually considered to be the most important part of buildings, because it is the building facade that creates the streetscape or townscape to an observer at ground level. In many rehabilitation projects carried out on the basis of economic viability, it is general practice to clear out the entire interior of the buildings, leaving only the structure and some or all of the exterior walls and roofs. The exterior appearance of the facade or some restoration to the original appearance is usually what is desired and is retained. The interior conditions, however, are brought up to present-day standards in relation to usage, environmental conditions, services and appearance. The shell of the building, the former exterior enclosure or some part of it, has to form a part of a new energy conserving enclosure, whose function is to separate the new interior environment from any external environments resulting from local weather conditions. It is unlikely that much thought was given, during design and construction, to the environment modification function of the walls of older buildings now being rehabilitated, but such thought is required when changes are contemplated.

It is the intention of this paper to point out some of the factors responsible for the good performance of older buildings and to sound a warning in relation to rehabilitation. Any changes to the interior conditions or to the enclosure of such buildings will usually subject the enclosure to new temperature and moisture conditions. Basic principles of enclosure design are now generally accepted and understood and these will be indicated. It may be difficult to apply them to rehabilitated buildings, however, because of the restraints relating to restoration but, unless they are applied, problems may occur that can cause rapid deterioration of the elements of the rehabilitated enclosure.

TRADITIONAL PRACTICES AND PERFORMANCE

In Canada, until very recently, building practice generally followed traditional practices from elsewhere. For the most part, immigrants to Canada brought with them the building systems and styles used in their former homelands, although architectural fancy as well may sometimes have been involved. Not much regard initially would have been given to the different climatic conditions in Canada, and the problems of performance that might ensue.

Poor performance of a building would have indicated the need for change and slow adjustment in building practice occurred. Over the years architects and builders learned how to achieve a reasonable environment in buildings, and how to avoid difficult problems of weathering and visual deterioration. It should be noted, however, that what was tolerated as a satisfactory level of performance in the past, was much lower than that considered acceptable today. Many buildings were cold, damp and drafty and rain leakage of walls and roofs was not uncommon.

Buildings of masonry construction built for permanency in urban areas are the ones that have survived and are frequently involved in rehabilitation projects today. Masonry walls usually performed reasonably well because of their thickness. The reason for the thickness was mainly structural, i.e., to resist the loads and thrusts from heavy floors and roofs, but this also had an advantage in relation to thermal performance and rain penetration. The heavy walls had high heat and moisture storage capacity. They were generally constructed of relatively small units cemented together with weak mortar that gave reasonable uniformity and stability. Although cracking occurred in most buildings, it was usually confined to many small cracks at the joints. This probably did not allow much rain penetration except during prolonged wind-driven rain storms. Through penetration of thick masonry walls would normally not occur and the walls would dry out fairly quickly.

Although many masonry buildings of earlier times gave good performance, some of those built in the past fifty years have not fared so well. This is due mainly to changes in materials and in construction practices, the effects of which were not recognized by designers and builders. The introduction of building frames, for instance, was a great structural improvement: walls no longer had to carry heavy loads and so they could be thinner. This at the same time paved the way for the use of larger individual wall units of masonry or concrete that could be hung on the building frames. The larger units increased thermal and moisture movements which produced larger cracks at fewer joints, often extending through the thinner walls to allow rain penetration to the inside. In the earlier heavy walls, micro-cracking was more extensive but was well distributed and seldom extended through the walls.

The demand for more desirable occupancy conditions inside buildings brought about the increased use of central heating, ventilating and air conditioning. Insulation to control heat loss or gain became a necessity to increase the efficiency and reduce the cost of providing such services. The implications of the use of insulation in relation to building enclosure performance are only now being fully recognized and understood. Difficulties in performance due to the introduction of insulation were first recognized in residential construction. They occurred less frequently in public, commercial and industrial buildings because such buildings usually had low indoor humidities in winter. The provision of increased humidities in such buildings has now also changed that situation. Water vapour from inside the buildings can move outward into the materials and spaces in walls and roofs by diffusion or air leakage to condense on cold surfaces.

These factors can result in poor performance, e.g., leaking or walls and windows streaming with condensation which cause dismay to the building occupants or discomfort because the building is overheated or cold and drafty. Sometimes occupant discomfort is also accompanied by complete and drastic failure of elements or materials. Whole walls and roofs have to be repaired or completely replaced after short service lives (sometimes less than five years). Such failure is obviously related to haphazard design decisions without a knowledge of the principles of building and the properties of materials, and because of an improper match of systems and material properties to service conditions and requirements.

FUNCTIONAL REQUIREMENTS

Changes in building practice and the problems that resulted from them, particularly from the introduction of insulation, provided a stimulus for the development of building science. The science of air, heat and moisture flow in relation to building has been slowly developing for fifty years or more, but its application to building envelope design is fairly recent, perhaps only a little more than thirty years. The functional requirements of the building enclosure were clearly formulated for walls as long ago as 1952 in a paper by Dr. N.B. Hutcheon, a former director of the Division of Building Research. This information has also been widely distributed since 1963 as Canadian Building Digest 48, but the requirements are still not fully understood nor universally applied by designers.

The basic technical function of walls, windows, roofs and floors, referred to collectively as the building enclosure, is to protect the inside conditions from the uncontrollable weather conditions that exist outside. The enclosure is required to do this so that inside conditions can be controlled and adjusted in various ways to provide an environment suitable to the activities of the occupants or to assure that the building contents will remain in the condition desired. The building enclosure is thus a container of controlled space; it must perform as a selective separator between the different conditions and provide a barrier to flows of mass and energy. The flow of mass that it must stop or control is represented by air and moisture, and the flow of energy by heat and solar radiation. Economy, safety and aesthetics are other interrelated requirements; durability is the overriding requirement.

Failure to consider these functional requirements in the rehabilitation of buildings will almost certainly lead to unsatisfactory technical performance, as has already occurred in many buildings constructed in recent years. The situation is usually even more critical in relation to buildings being rehabilitated because of the added constraints that result from retaining some parts of the existing enclosure. This may greatly influence the solution, and will usually tend to prevent the fulfillment of some technical requirements. For the following discussion the main concern is with rain penetration and air leakage control as affected by the need for heat control.

RAIN PENETRATION

The wetting of walls from rain penetration, unless it penetrates to the interior, is not of great consequence in countries with mild climates, and in such locales heavy masonry has performed satisfactorily for many centuries. In Canada, however, the freezing of water in wet masonry walls can cause and in many cases has caused serious and dramatic deterioration. That this has long been recognized as a problem is indicated by the many construction practices that have been introduced to reduce or prevent rain penetration.

Cornices and belt courses on traditional buildings are generally accepted as an attempt to reduce the amount of rain water contacting wall surfaces. Stucco and other renderings have also often been used in an attempt to produce a crack-free, monolithic exterior surface to reduce rain penetration. In areas such as along the Atlantic coast, where strong winds accompany rain storms, even these measures do not always stop rain leakage. More extreme measures such as covering the most exposed walls with overlapped weather boarding is sometimes found to be necessary.

The use of cavity wall construction which came to Canada from the United Kingdom is another example of wall construction to prevent rain penetration. This system is really two walls with an air gap between them. This breaks the capillary paths along which water can travel from outside to the inside. Water will usually penetrate the outer wall, but the inner wall will remain dry if the air gap or space is drained and ventilated and is free of water bridges.

It has also been common practice in Canada to separate interior finishes from exterior masonry walls by furring strips. It is believed that the purpose of this was to protect the interior finishes from moisture problems that could occur if rain penetrated all the way through the walls.

AIR LEAKAGE

Differences in air pressure between inside and outside cause air leakage which is a very prominent mechanism operating in buildings. Inward air leakage can cause cold drafts, and allow dust entry into a building; outward air leakage can carry water vapour into the walls and roofs to produce condensation. The provision of a structurally supported air vapour barrier on the warm side of the building enclosure is now considered essential to prevent a myriad of problems resulting from interstitial condensation. Parging and plastering on walls often provided reasonable airtightness in old buildings because the continuity was not broken by built-in wiring or other services and there was usually an easy passage for air leakage around windows and doors. This may well have helped in keeping the walls of such buildings out of trouble from vapour transfer and condensation.

It is important in the rehabilitation of buildings to stop outward air leakage from humidified interior spaces. Continuity of the air vapour barrier is all important, and all leakage paths at penetrations for electrical or other services connections must be sealed. Perfection cannot be achieved with normal good construction, however, and it is necessary to allow for the disposal of any moisture that gets past the air vapour barrier before it produces wetting.

INSULATED WALLS

With the increasing energy shortages and higher energy costs, energy conservation is now a prime factor in any building rehabilitation. The location of insulation in the enclosure system will have an important effect on all the other elements of the enclosure. To examine these effects, consider a typical uninsulated wall as might have been used in an earlier framed building, consisting of stone facing over terra-cotta back-up with mortar between and plaster finish on the inside.

The thermal gradients for winter and summer conditions for such a wall are indicated in Fig. 1. Under the winter conditions indicated the inside surface temperature will be as low as 13°C when the outside air temperature falls to -20°C. A relative humidity of more than 50% could be maintained with a 23°C inside temperature without danger of condensation on the inside wall surface. The average temperature of the terra-cotta will be about -4°C, and of the stone even lower than the outside air temperature when clear night sky radiation is considered. Most of the wall will be below-freezing temperatures when it is -20°C outside. The average seasonal range of temperatures for the stone may be as much as 82 deg. C and for the terra-cotta 48 deg. C but, because of the high heat capacity of the wall, temperature changes would be slow. With low interior humidities, there probably would not be much moisture moving into the walls from inside. If small masonry units are used, the thermal changes will not usually open up any large cracks to allow rain penetration.

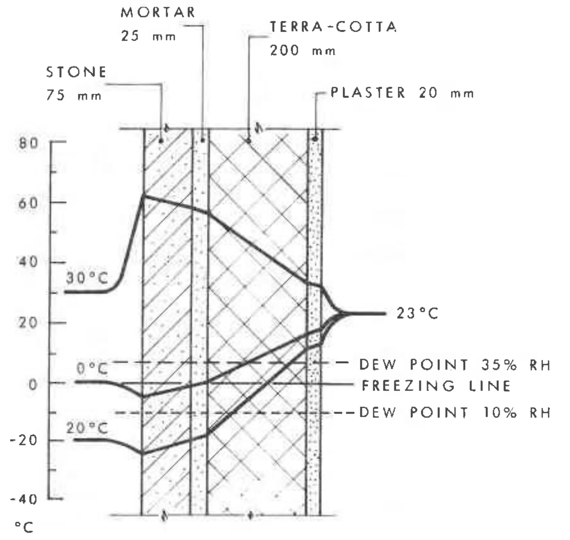

Figure 1. Thermal gradients, winter and summer conditions for masonry wall with no insulation.

When 75 mm of insulation is placed on the inside of the wall (Fig. 2), the inside surface temperature will be raised to 20°C. This would allow, for the same inside and outside winter conditions, a relative humidity of close to 90% with no surface condensation. The average temperature of the terra-cotta would drop to -20°C and that of the stone facing sometimes to below outside temperature, at night. Most of the masonry wall would be very much below freezing at -20°C outside temperature, and on a clear cool night all of the masonry might be below freezing even when it is only 0°C outside. Variations in temperature through the wall, however, are less than they were in the uninsulated wall. The average seasonal range is increased: the stone may be about 86 deg. C and the terra-cotta close to 80 deg. C. Such temperatures and temperature differences can cause serious disruption if there is moisture present. There is more chance of moisture being present in this wall construction because rain may penetrate deeper into the wall. As long as the moisture conditions are not changed inside there will still be little moisture transfer from inside and, of course, a good air vapour barrier can be applied with the new insulation and internal finish.

If 75 mm of insulation were placed on the outside of the wall, covered with a light rain screen, as shown in Fig. 3, the thermal conditions for the wall would be greatly improved: inside surface temperature would be about 21°C, the average temperatures in the masonry wall during winter would not drop below 15°C, and the average seasonal range would be not more than about 15°C. Such a wall would be ideal, but it is not often that it would be acceptable in rehabilitation, because it would require the existing facade to be covered by a new rain screen cladding.

Another possible design is one that uses a "buffer" zone in the wall: a space between a new interior wall and interior surfacing and the old wall, ventilated with low humidity air and heated (Fig.4). The new interior wall will be required to resist the passage of air and vapour, but will not be

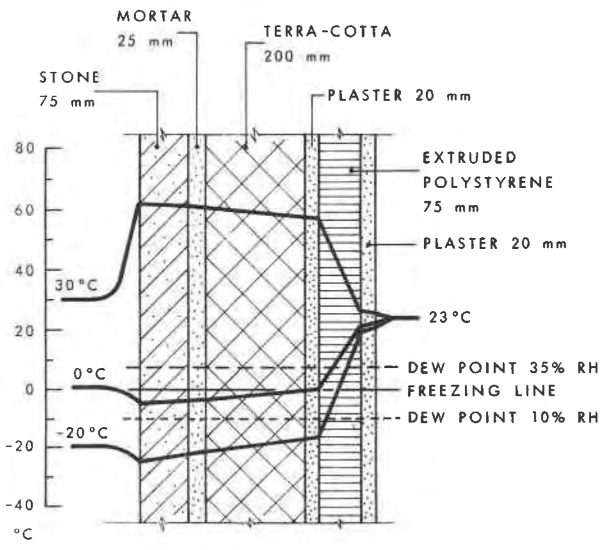

Figure 2. Thermal gradients, winter and summer conditions, for masonry wall insulated on inside.

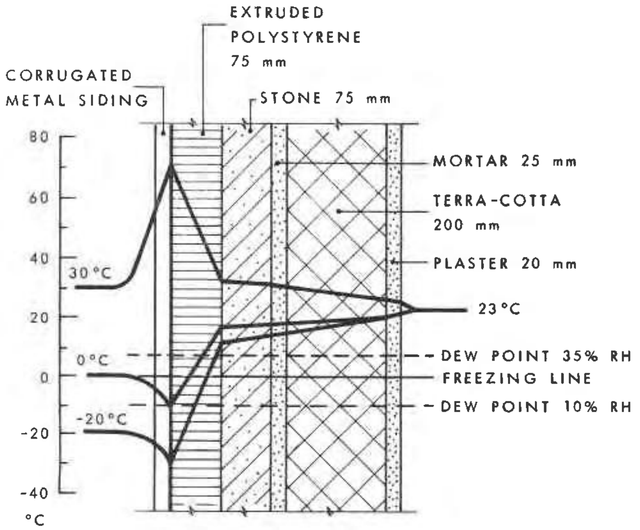

Figure 3. Thermal gradients, winter and summer conditions, for masonry wall insulated on outside.

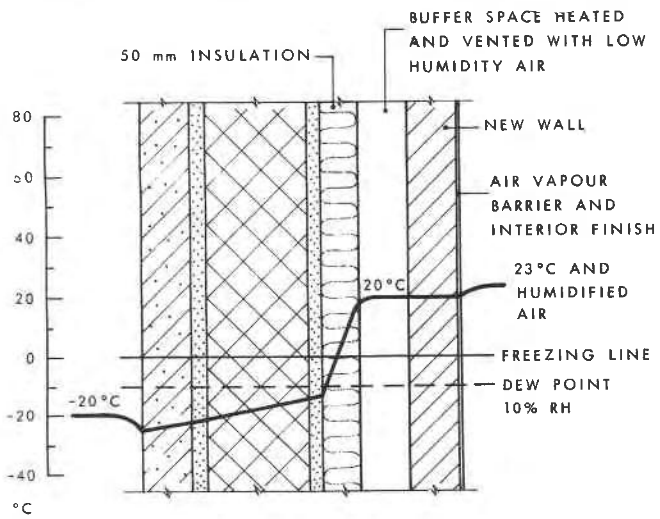

Figure 4. Thermal gradients, winter conditions, for masonry wall with buffer zone.

subjected to a temperature gradient. Any moisture from inside that might leak into the space will be removed by the ventilating process so that the outside wall is not subjected to any outward moisture movement. With insulation on the inside of the outer wall, however, the masonry will still be very cold and could suffer from rain penetration.

The air space provided can be as little as is required for proper air movement in relation to heating and ventilating, or it can be wide enough to perform as a corridor or other usable space within the new building. There is also the possibility of keeping the buffer zone at some temperature between inside and outside conditions as a compromise to ease the separation functions of each. In some instances, it may be possible to use the outer wall merely as a screen with the new inner wall taking care of the main environmental separation function. The basic consideration in all systems is to keep the old wall dry.

INSULATED ROOFS

Roofs are considered to be the building element that provides the best potential for thermal upgrading of a building without disrupting the building. If the building has an attic or loft space, this is certainly true and thermal upgrading is easy as indicated in Fig. 5. It merely involves adding insulation or additional insulation above the ceiling, which does not change the basic arrangement of the system and has little effect on the other elements. The basic features of this system that allow it to perform satisfactorily are an air vapour barrier at the ceiling inward from the insulation and ventilation of the roof space to dispose of any moisture that gets past the air vapour barrier. If these do not exist in a building being rehabilitated, they must be provided.

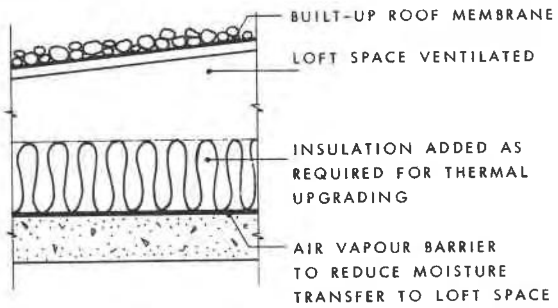

Figure 5. Upgrading of attic or loft space roof systems.

Whether the roofing will have to be replaced will depend on its type and condition. Since most roofing of the bituminous type applied in this century has a ridiculously short life, it is probable that such roofing would have to be replaced. If of metal or similar longer lasting materials, it may be possible to save the roofing, if it does not interfere with the provision of a complete roof system. If the roofing must be replaced, the longer lasting roofing systems should have preference over the short life bituminous, or new rubber and plastic systems.

Insulation added to a flat or near flat roof without ventilated attic space (compact flat, Fig. 6a) has an effect on the other elements of the system. When added to the underside of the structural deck, it will make the deck and the roofing outward of the insulation colder. When added above the deck and roofing, the thermal environment for the existing system will be improved. The extent of the worsening or improvement of the environment will depend on the presence, location and condition of any insulation in the existing system. Although insulation can sometimes be added to the inside for thermal upgrading, Fig. 6b, the new temperature conditions created in the system have to be carefully considered, and it will usually be better to add insulation on the outside.

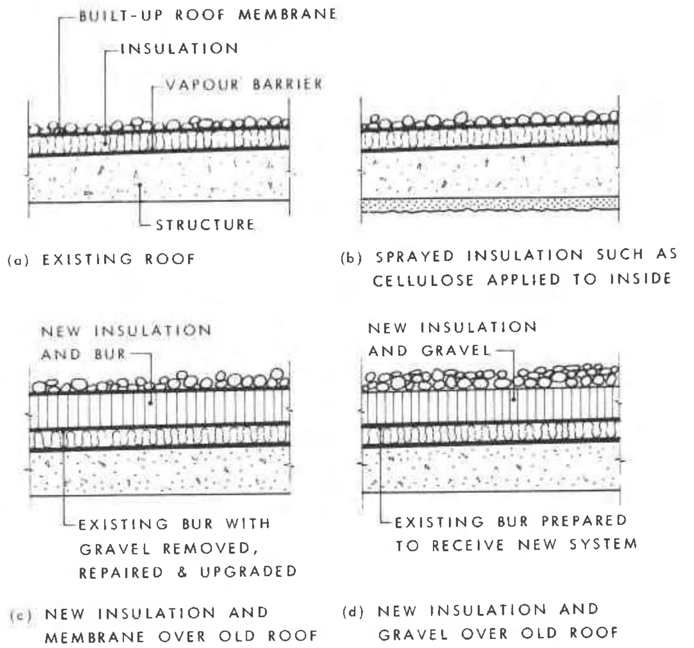

Figure 6. Upgrading of compact flat roofs.

If an existing waterproof roof system is in good condition, a new system can be applied directly over it after the existing membrane has been prepared to receive it, Fig. 6c. Such preparation usually includes removal of gravel surfacing and possible upgrading of the membrane, and might also include the provision of slopes to drains if that is possible. New insulation and roofing over the old system will protect the existing membrane from the weather and provide a better thermal environment for it so that its life expectancy is increased.

Another possibility that may be the best one in many cases, is to merely add insulation over the upgraded roofing membrane in a variation of the protected membrane roof mode, Fig. 6d. In this case, it would also usually be necessary to remove the existing gravel, apply additional waterproofing and, in some cases additional felt reinforcing, followed by application of extruded polystyrene insulation and ballast as required for the system. The insulation is normally fully adhered to the membrane, but in some instances may be loose laid and ballasted against flotation and wind uplift, if structural considerations allow this.

CONCLUDING REMARKS

Rehabilitation of buildings usually requires new interior environmental conditions that will normally impose a more severe environment on the building envelope than existed in the original building. The walls and roofs must be designed to maintain the desired degree of separation of the two dissimilar environments, and this will usually include thermal upgrading. The main factors to be considered, if deterioration of the rehabilitated enclosure is to be avoided, are air leakage and rain penetration control.

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