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THERMAL PERFORMANCE EVALUATION OF BUILDING ENCLOSURE ELEMENTS

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THERMAL PERFORMANCE EVALUATION OF BUILDING ENCLOSURE ELEMENTS

The thermal performance of walls, windows, doors and roofs is described by a number of characteristics. Both opaque and transparent elements are described by the over-all resistance to heat transmission, the inside surface temperature characteristic and the differential thermal movement behavior of the elements. In addition, transparent elements such as windows and glazed doors are described by the solar transmission characteristic and the thermal breakage resistance of the glazing. The factors affecting the foregoing characteristics and the methods available for their evaluation are herein reviewed.

EVALUATION DU RENDEMENT THERMIQUE DES ELEMENTS DE L'ENCEINTE D'UN EDIFICE

On décrit au moyen de certaines caractéristiques le rendement thermique des murs, des fenêtres, des portes et des toits. Les éléments opaques aussi bien que transparents sont décrits en termes de la résistance globale à la transmission de chaleur, de la température de la surface intérieure et du mouvement thermique différentiel des éléments. De plus, les éléments transparents comme les fenêtres et les portes vitrées sont décrits en termes de la caractéristique de transmission solaire et de la résistance à la rupture thermique du vitrage. On passe en revue les facteurs qui influencent ces caractéristiques ainsi que les méthodes d'évaluation existantes.

Thermal performance evaluation of building enclosure elements

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The thermal performance of a building enclosure is dependent on the indoor and outdoor environments it must separate, and on the thermal characteristics of the building enclosure elements, that is, of the walls, windows, doors and roof. Thermal performance is of greatest significance for buildings that will be subjected to both hot summers and cold winters.

This paper is a review of the thermal characteristics of the building enclosure and the methods available for their evaluation. For ease of discussion, building enclosure elements will be categorized as being either opaque or transparent as the thermal characteristics of the two types of elements are different. Opaque enclosure elements include walls, doors and roof; transparent elements include windows and window-walls, glazed doors and skylights.

THERMAL PERFORMANCE CHARACTERISTICS

The thermal characteristics of building enclosure elements are listed in Table 1. The total heat flow through an enclosure element is directly proportional to the overall thermal resistance of the element and the average difference between the outdoor sol-air temperature and room air temperature. The total heat flow through the enclosure elements affects the cost of heating and cooling a building. Heat flow can be reduced by utilizing insulating materials in the opaque elements and by using multiple-glazing in the glazed elements.

The inside-surface temperature characteristic (the inside-surface condensation resistance) and the interstitial condensation resistance (the resistance to condensation within the enclosure element) pertain only to those buildings exposed to relatively cold winter conditions. Cold storage buildings are also affected, but will not be considered here.

The inside-surface temperature characteristic of an enclosure element depends on the minimum outdoor air temperature experienced by the element, its over-all thermal resistance, the air infiltration that takes place through the element, and the presence of high heat-flow paths or thermal bridges through the element. The surface temperature characteristic of an element affects not only its resistance to inside surface condensation, but also its resistance to dust marking on the inside surface.

Both these problems will add to the cost of building maintenance. Large expanses of cold inside surfaces will also affect thermal comfort by creating cold drafts and by subjecting the occupants to a low mean radiant temperature. Condensation and dust-marking problems can be minimized by using enclosure elements that contain no thermal bridges and that have a high resistance to both heat flow and air flow.

Condensation

The occurrence of interstitial condensation depends on the air tightness, water-vapour tightness and thermal resistance of the constituent layers, and on the location of these layers within the element. It also depends on the outward air pressure difference, water-vapour pressure difference and temperature difference experienced by the element. Interstitial and interpane condensation can reduce the durability of enclosure elements by subjecting them to prolonged wetting. Condensation occurring within an insulation layer can also reduce the thermal resistance of an enclosure element.

The worst manifestation of interstitial condensation is the destructive displacement or spalling of wall cladding materials caused by freezing of the condensation. Interstitial condensation can be reduced in heated buildings by providing a high degree of air and vapour tightness at the inner face of the enclosure element.

Differential Movement

Differential thermal movement of an enclosure element can occur in many forms. It can occur between the constituent parts of the element, between adjacent elements, and between the element and the main structure of the building. It depends, therefore, on the temperature gradient across the element and the annual temperature cycle experienced by the element. It is also dependent on the thermal expansion coefficients of the constituent layers, the mechanical connections between the layers, and the mechanical connections to adjacent elements and to the structure.

Differential movement can lead to structural damage of an element or its connections unless the movement is accommodated by slip connections or restrained by strong mechanical connections. Daily thermal movement can also produce objectionable noises due either to oil-canning of metal cladding or friction between moving parts.

Moisture Redistribution

Another form of thermal movement is that due to moisture redistribution in a porous material under a temperature gradient. Moisture redistribution will produce a warp in an element in the opposite direction to that caused by differential thermal expansion or contraction. A wooden door panel or window sash will, therefore, warp in the opposite direction to a metal door or window under the same temperature gradient.

Warpage caused by either of these mechanisms can reduce the air tightness and ease of operation of operable windows and doors. These problems can be avoided by using weatherstripping that is able to accommodate large movements, and by providing ample clearance between operating parts.

The final two thermal characteristics — solar transmission and thermal breakage characteristics of glass — relate only to glazed enclosure elements.

Solar Transmission

The amount of solar radiation entering a building through a glazed element depends on the intensity of the incident solar radiation, the shading characteristics of interior and exterior shading devices, and the solar transmission properties of the glazing unit. The relevant properties of the glazing unit are the face temperature performance of complex elements.

The Architectural Aluminum Manufacturers Association has developed another laboratory method that is much simpler. This is the method currently being considered for standardization by ASTM as a comparative evaluation test[8].

Both the hot-box and AAMA methods, however, utilize test conditions that are not wholly representative of those found in real buildings and the test results may, therefore, give a misleading indication of the in-use performance of the elements tested.

Cold-Room Tests

A number of laboratories in North America have cold-room facilities that are more suitable for predicting in-use surface temperature performance. These facilities permit simulation of nearly all components of the actual construction that influence surface temperature, such as adjacent wall construction, interior shading devices, air leakage and heater terminal units.

The interstitial or interpane condensation resistance of an enclosure element is difficult to evaluate by computation as it depends on the heat, air and water-vapour flow characteristics of the assembled element which are interdependent. The resistance to interstitial condensation can be partially evaluated in a laboratory cold-room test, but only if realistic values of air temperature, relative humidity and air pressure difference are used.

It must be recognized, however, that this type of test is time consuming, especially for opaque elements where moisture storage capacity is an important factor.

Some aspects of the thermal movement experienced by an enclosure element can be calculated from the known thermal expansion coefficients of the constituent materials and the temperature range anticipated for the element. The movement accommodation or movement restraint to be provided by the mechanical connections can be determined in this way.

Noise generation or the effect of warpage on the air tightness and operability of an element cannot be computed. Testing in a cold-room facility that simulates conditions of use can provide some useful information regarding the warpage characteristic and the effect of warpage on the operability and air leakage characteristic of an enclosure element.

The expansion and contraction characteristic of plastic materials under partial restraint is another characteristic that is more readily determined by testing in a cold room or with heat lamps, than by computation. Testing, however, will probably be impractical for determining noise generation behavior. Noise generation depends on the real rate and range of cyclical temperature change experienced by the element as well as the aging of the moving parts; it is very difficult to duplicate the last factor in a laboratory test.

Solar Calorimeter

The solar transmission charac teristics for a number of glazing arrangements can be found in the ASHRAE Handbook of Fundamentals. Solar characteristics of arrangements not covered in the handbook can be determined experimentally and by calculation. Light transmittance of a glazed element can be measured with a photometer, and the total solar transmittance, absorptance and reflectance can be measured with a radiometer under natural sunlight conditions.

The shading coefficient of the element can be calculated from the measured solar properties and assumed thermal conductance values for the indoor and outdoor surfaces and the air space. The shading coefficient for a glazed enclosure element with an associated shading device is best determined by test in a solar calorimeter.

The thermal breakage characteristic of glass is the most difficult to evaluate, mainly because neither the edge strength of glass nor the thermal stresses in the glass can be predicted with certainty. One glass manufacturer has developed a computation method based on laboratory tests for selecting safe sizes of single heat-absorbing glass [4, 5]. To date, there is no similar procedure for determining the potential for solar breakage of sealed double-glazing units with an outer pane of heat-absorbing or heat-reflecting glass.

The breakage resistance of the inner pane of a sealed double unit under cold-weather conditions is equally difficult to predict. Some indication of the potential for this type of breakage can, however, be obtained by performing a surface-temperature evaluation test in a cold-room facility if the heater terminal unit and indoor shading device to be used with the glazed element are included as part of the test specimen [6].

SUMMARY

The over-all thermal performance of a building is described by the heat-flow, inside-surface temperature, interstitial-condensation, thermal-movement, solar-transmission and thermal-breakage characteristics of the building enclosure elements. It is the responsibility of the building designer to judge which of these are relevant to his building design.

Methods are available for evaluating most of these characteristics, but since there will always be some disparity between the test and in-use conditions, the designer must still exercise care in translating the test results into a prediction of in-use performance. The designer must rely entirely on the information contained in the technical literature and on his own judgment in predicting those aspects of thermal performance that lack an evaluation method.

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