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Thermal Bridges in Buildings

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Please note

Walls and roofs designed today often incorporate details that have a lower resistance to heat flow than the main construction. In general, these details are thermally weak because high-conductivity structural elements project partly or wholly through materials of lower conductivity; in this Digest they are referred to as "thermal bridges."

Thermal bridges can seriously interfere with the performance of buildings. The temperature of the inside surface over a thermal bridge is lower than that of the adjacent construction during the heating season, and may even be lower than that of double glazing; consequently, it may be impossible to maintain the desired relative humidity without surface condensation (**CBD 42**). The difference in the temperature gradient through the bridge and adjacent construction will cause thermal stressing that may result in structural damage. The corresponding exterior surface temperature over a thermal bridge is higher than that over the adjacent wall. This can result in increased wetting of the wall by melting of wind-driven snow, thereby increasing the possibility of damage on subsequent freezing. Thermal bridges result in higher building heat losses, although this is not usually regarded of itself as a major problem. In designing a curtain wall to meet a specified maximum over-all heat transmission requirement, however, thermal bridges at structural ties and joints are usually the major obstacle. The lower surface temperatures over thermal bridges can also lead to dust marking.

Thermal bridges are often formed by steel or concrete beams and columns incorporated in exterior wall or roof construction. Insulation applied to the interior surface of a wall is bridged by floor slabs and partitions; if these project on the exterior of the wall they form "fins," which provide a large surface exposure area for heat loss. Metal ties in cavity walls are another type of thermal bridge commonly found in masonry construction. Serious problems may also occur at metal window frames and sash (**CBD 4**) and at metal curtain wall mullions, which either partially or completely bridge the wall and often present a fin exposed to the outside.

Problems with thermal bridges can be readily overcome where insulation is placed over the entire exterior of a building, enclosing all structural elements and excluding only a rain-screen cladding (**CBD 40**), which requires a minimum of structural support. In most conventional construction, however, many thermally weak configurations occur. To provide a basis for recognizing and minimizing the problems presented by thermal bridges, this Digest will deal with a few examples and illustrate factors that influence their thermal performance.

Analysis of Thermal Bridges

Figure 1 represents a dense concrete structural member (thermal conductivity, k, of 12 Btu per (hour) (sq ft) (°F per in.)) that bridges a lightweight concrete wall (k 2.4), except for the interior plaster coating. The temperature gradients through the structural member and through the adjacent wall have been calculated on the basis of one-dimensional heat flow, as outlined in **CBD 36**; that is, it is assumed that there is no interchange of heat between the member and the adjacent wall. For a 100°F temperature difference between inside and outside air there is a calculated difference in temperature between the inside surface over the thermal bridge and that of the adjacent wall (TD_c) of 18°F. It will be noted that the bridge is colder than the wall toward the inside and warmer than the wall toward the outside; heat must flow, therefore, from the wall to the bridge on the warm side and from the bridge to the wall on the cold side (see arrows). The calculation, however, does not take account of this lateral heat flow and thus there is an error in the calculated temperatures.

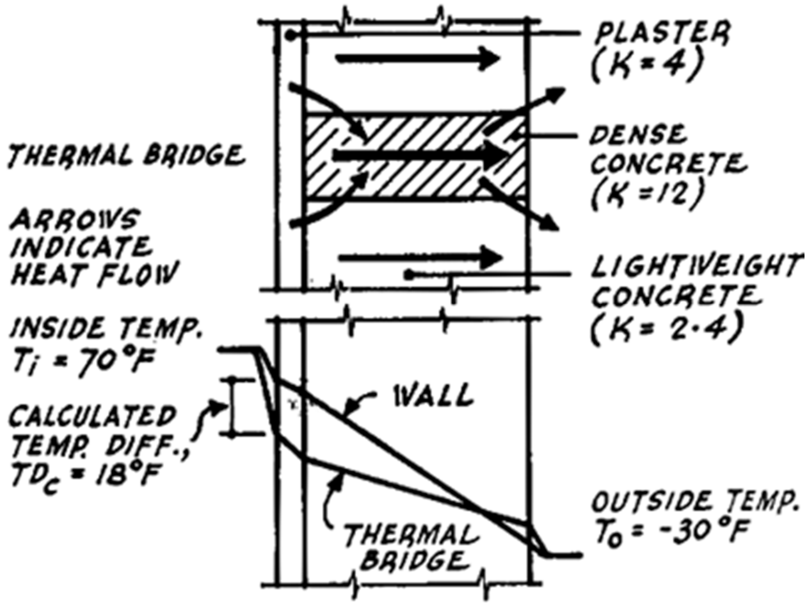

Figure 1. Calculated temperature gradients.

In Figure 2 the measured inside surface temperature pattern for the construction in Figure 1 is given for two widths of the structural member. Also given in each case is the difference between the inside surface temperature over the wall, measured remote from the bridge (equal to, the calculated value), and the minimum inside surface temperature measured over the bridge. This difference is designated as TD_m. Values are again based on an over-all temperature difference of 100°F. Values of TD_m or TD_c for any other over-all temperature difference will be in direct proportion.

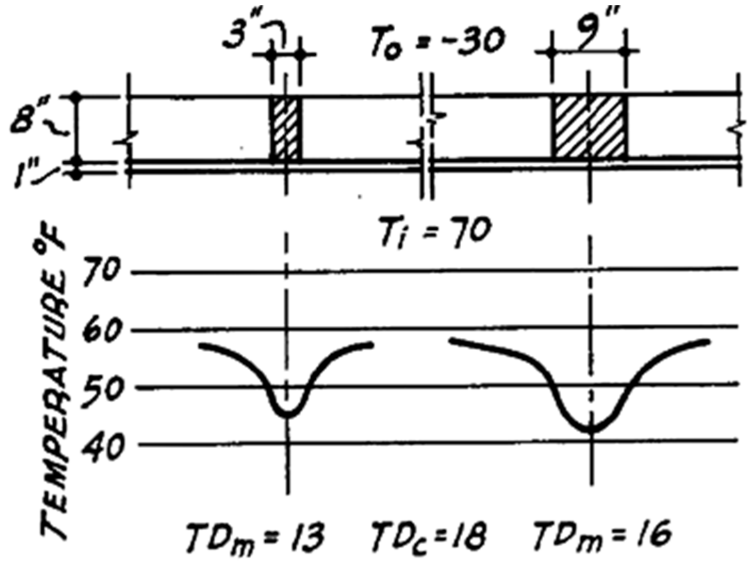

Figure 2. Measured surface temperatures.

It may be noted that TD_m is less than TD_c for both widths of member, and that TD_m approaches TD_c as the width increases. This is a result of the lateral heat flow taking place between the structural member and the surrounding wall; toward the inner side (of the wall) this warms the structural member and cools the adjacent wall. If the member is narrow the lateral heat flow may be enough to maintain the surface temperature considerably above the temperature predicted by simple theory. If the member is wide, however, the lateral heat flow does not extend to its centre and the actual minimum surface temperature approaches the value predicted by one-dimensional heat flow theory. With this type of bridge actual surface temperatures are warmer than those predicted by simple theory.

Insulation is sometimes placed over thermal bridges to increase inside surface temperatures, but its effectiveness will depend on how it is applied. Figure 3a shows thermal bridges similar to those of Figure 2, with insulation just covering the inner surface of the members to a thickness that will ensure the same calculated U-value at the member as that of the rest of the wall. In such a case TD_c = 0, but measurements show that TD_m = 8 for the narrow bridge and TD_m = 13 for the wide bridge. With insulation placed in a similar way on the outer surface of the members (Figure 3b) TD_m = 14 for both. Insulation thus placed is not very effective in raising the minimum surface temperatures, although the (surface) temperature patterns are altered.

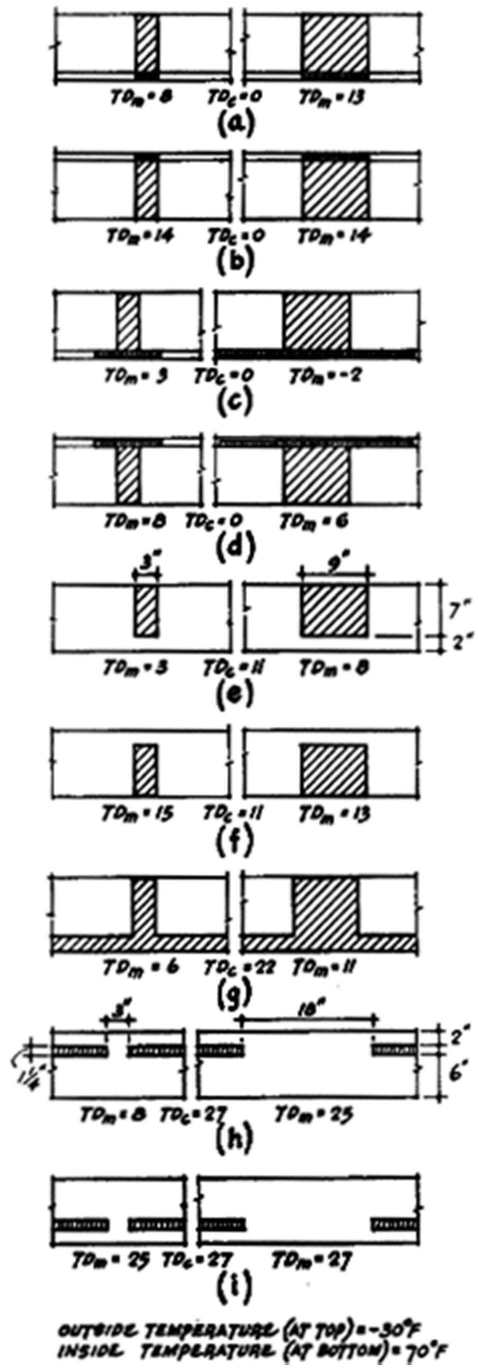

Figure 3. Surface temperature characteristics of thermal bridges.

If insulation is placed on the inside, the structural members are colder than those in the uninsulated case, and toward the inside there is greater lateral heat flow into the member from the adjacent wall. Minimum surface temperatures thus occur on the wall adjacent to, the member, and the temperature over the member is increased. With insulation on the outside, lateral beat flow out of the member into the adjacent wall (in the outer part of the wall) largely nullifies the effect of the insulation.

With insulation extended on both sides of the members by the width of the member (Figures 3c and 3d) the surface temperatures are improved appreciably, particularly for interior insulation. The negative value of TD_m indicates that the surface over the bridge is warmer than the surface of the wall. To reduce TD_m to zero, using exterior insulation, would require that the insulation overlap the members by a considerable amount. It will be noted that with the insulated members the actual inside surface temperatures can be lower than those given by one-dimensional heat flow calculations (TD_m is greater than TD_c), in contrast with the results for the thermal bridges in Figure 2.

With partial thermal bridges in masonry, where the structural members do not extend through the wall completely, the wall material between the member and the wall surface acts in part as insulation. With the member placed toward the outside (Figure 3e) lateral heat flow in the wall material on the warm side raises the surface temperature over the bridge and TD_m is less than TD_c . In contrast, with structural member placed toward the inside (Figure 3f) the surface of the bridge is colder and TD_m larger than TD_c , as it is with exterior insulation.

It now becomes clear that one means of improving surface temperatures over a thermal bridge is to induce lateral heat flow on the warm side of the wall into the region of the bridge. The thermal bridges of Figure 3g are similar to those of Figure 2, except that the plaster coating has been replaced by 2 inches of dense concrete; TD_m is less, even though TD_c is greater.

A further example of the effect of lateral heat flow on surface temperature distribution is given in Figures 3h and 3i. These illustrate a panel consisting of two concrete slabs (k = 12) with foamed polystyrene insulation between (k = 0.24); examples of two widths of joint are given. The TD_c value for the panel is high because the U-value of the section at the joint is much higher than that at the insulation. With a narrow joint, however, actual surface temperature variations are greatly reduced by lateral heat flow from the heavy slab on the warm side of the insulation into the joint (Figure 3h). This lateral heat flow does not extend far enough into the wider joint to alter significantly the temperatures at the centre. If the slabs are reversed so that the narrow slab is on the inside (Figure 3i), lateral heat flow in the inner slab is greatly reduced and that in the outer slab correspondingly increased. This has the effect of lowering the surface temperatures over the joints.

The webs in hollow and insulated concrete blocks and the ties in cavity brick walls or in metal curtain walls are thermal bridges similar to the joints in insulated concrete panels. In most cases the temperatures over such bridges are considerably warmer than those predicted by simple theory, because of lateral heat flow in the interior slab or skin.

Thermal weaknesses often occur at wall-floor or wall-partition intersections. Figure 4a represents a heavy concrete slab intersecting an exterior wall of lightweight masonry. Thermal properties of the materials are the same as those in Figure 2. This will be recognized as similar to the partial thermal bridge of Figure 3f, but with the bridge extended into the building. There is a drop in the wall surface temperature toward the corner, giving a TD_m value of 9 compared with 13 for the partial bridge. With the slab extended to the outside of the wall the TD_m value is 11.

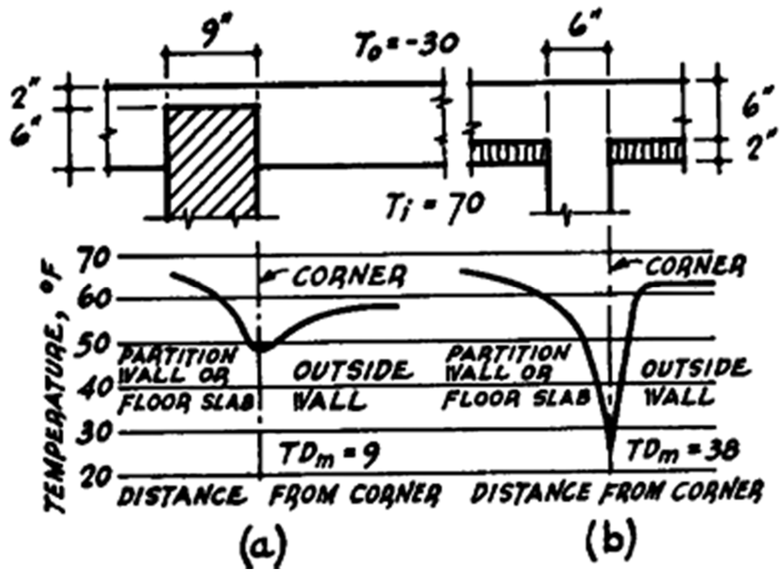

Figure 4. Surface temperatures at floors and partitions.

The wall temperature pattern at the intersection of exterior walls and partitions will be distorted even if the partition does not extend into the wall. This is due in part to the reduced air convection in the corner that lowers the surface temperature there. It is also due to the influence of the partition on heat flow into that part of the wall that it covers. If the partition is of low conductivity (lightweight masonry) it will reduce heat transfer into the wall and this, combined with the reduced air convection, may cause a significant lowering of the wall surface temperatures at the corner.

In Figure 4b a heavy concrete slab (k = 9) bridges insulation (k = 0.22) placed over the inner surface of the wall. The temperature at the corner is greatly reduced in relation to the rest of the exterior wall and TD_m is very large. This is a situation that makes it impossible for many modem insulated masonry buildings to carry the level of relative humidity of which they are otherwise capable. The problem is further aggravated if the floor slab or partition is allowed to project on the exterior, for example, to form a balcony slab. The fin formed by the projection increases heat loss from the wall and correspondingly lowers inside surface temperature. The problem might be overcome by insulating both interior surfaces of the slab for a sufficient distance from the wall, although this is not always practical or even possible.

Conclusion

Application of insulation over the entire exterior of a wall provides an ideal solution to the problems presented by thermal bridges. Although a light cladding is required to protect the wall, the number and size of the supporting ties that pass through the insulation are small. These ties will be attached to large high-conducting structural members located inside the insulation, and there should be no significant effect on the inside surface temperatures.

It should be stressed that many of the thermal bridges occurring in present-day construction can be avoided, or their effects minimized, if they are recognized in the early stages of design. Simple one-dimensional heat flow calculations will greatly assist in identifying potential problems from thermal bridges, but temperature values so obtained can be in considerable error. Judgement in applying calculated values can be improved by comparison with measured values where available. Those used in this Digest were obtained from French and Norwegian sources. Although more precise methods of calculation are available, it is usually impractical to apply them except in very simple configurations. Where accurate temperature data are essential for complicated sections, appropriate thermal tests should be undertaken.