CONVECTIVE LOOP HEAT LOSSES IN BUILDINGS

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ABSTRACT

Convective loop heat losses occur where heat is conducted from the building interior into an enclosed space within the thermal envelope and is then transferred convectively through the thermal envelope. In 1977 in a series of townhouses, a convective loop heat loss path was detected in the masonry block party wall separating the townhouses. This convective loop accounted for 15% of the total heat loss in the houses. Since then many other types of convective loop heat loss paths have been detected in a wide variety of buildings. Diagnostic techniques involving infrared thermography have been developed for detecting convective loop heat loss paths. However, a method for calculating the heat loss through specific convective loops has yet to be developed and these heat loss paths are largely ignored in theoretical modeling of building heat loss.

Some convective loops such as the townhouse party walls, are completely enclosed; house or attic air does not mix with the air in the block cavities. More often they are partially open admitting outside or interior air into the space. Sometimes they are open to both outside and interior air, in which case the convective loop is also an air infiltration site. This paper describes the types of convective loops found in buildings, illustrating them with thermograms and line drawings. A methodology for determining the magnitude of convective loop heat losses is presented with data from a few specific cases.

Examples of convective loops include hollow masonry block construction; spaces above ceiling soffits, ducting extending into unheated spaces; air paths associated with I-beams and channel sections; short-circuiting of insulation; and cases where deep air penetrations through the thermal envelope have reached several floors into the structure, cooling interior walls (occupant discomfort), removing heat (energy penalty) and confusing energy management control systems (sensors provide inaccurate "air temperature" readings).

INTRODUCTION

The energy balance within our buildings is viewed as the conductive loss and air infiltration (and ventilation) loss balanced by the heat input, whether by the heating system or free heat from the sun, appliances, or occupants. The discussions in this paper emphasize what at first might appear to be detail in the way energy is lost from the living space through the building envelope. The mechanism is the convective loop phenomena. The convective loop can (1) make the insulation ineffective, (2) cause significant portions of the interior room surfaces to be at temperatures that directly affect comfort, (3) directly interact with plumbing and energy distribution systems causing energy loss and possible pipe freezing, (4) cause thermostats to give false readings of interior conditions thereby resulting in energy waste and or discomfort, etc. The effects from convective loops can hardly be treated as unimportant since they may result in 10, 20 or even 50% increases in energy loss.

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With all these negative characteristics, why haven't we heard more about convective loops? Because convective loops are present in many forms they have not been fully appreciated in terms of energy loss and other building problems that can result from their presence. Furthermore, techniques such as infrared scanning must be employed to map building envelope areas of convective loop influence; thus, the full impact may not be realized. Often, only when measurements have been taken before and after remedial action to eliminate these problems can accurate assessments of the level of energy involvement be made.

Temperature differences, often dependent on insulation levels, proximity to the exterior or heating systems, etc., are produced on a variety of surfaces in our buildings. Contact with these surfaces causes a change in the air temperature and density and thus causes the air to either rise or fall resulting in air movement. This, of course, is the definition of natural convective flow. Convective loops involve natural convective flow that allows air to pass through the building thermal envelope, thereby exchanging heat and increasing building conditioning energy use.

The **closed convective loop** is observed where the air mass remains basically unchanged but temperature differences exist at the boundaries of the air mass to cause airflow to move in the loop motion. A simple example, and one that can result in major heat loss, is shown in Figure 1. Here insulation has been placed in the wall cavity so that it is not attached tightly to the inner wall or outer wall of the construction. Under these conditions, with air paths across the insulation, a convective loop is generated when temperature differences are present at the inner and outer surfaces of the wall construction. The convective loop thus formed is illustrated by the arrows in Figure 1. Insulation effectiveness can vary from near design levels (no air penetration) to near zero levels (easy air penetration), depending upon the ease of movement of the air through the insulation. Obviously, great care should be taken to avoid the establishment of this convective loop. However, field observations indicate that such loops are very common due to lack of attention in the installation of insulation.

The **open convective loop** merely allows the air mass to be replenished by other air. See the cross section of the wall, in Figure 2, modified to allow outside air to enter the gap between the interior wall construction and the insulation. This modification can result in the complete elimination of the effectiveness of the insulation when the air movement is sufficient. In fact, the insulating effect of the outer portion of the wall construction will also be eliminated in this case.

Please note that typical of convective loop phenomena, the airflows are not necessarily connected with air infiltration into the occupied space.

OTHER EXAMPLES OF CONVECTIVE LOOPS

The two examples cited to illustrate open and closed convective loops are by no means the only important convective loop phenomena that may be present in our buildings. Table 1 illustrates a number of other examples, but these too are not all inclusive. The varied and changing nature of our building constructions encourages new examples.

A few of the examples cited in Table 1 should be further described. Whenever hollow masonry systems are used in construction, the possibility for the existence of convective loops is encouraged. When hollow blocks are used in basement wall construction, as shown in Figure 3, a closed convective loop pumps cold air cooled by contact with those surfaces facing the prevailing winter temperatures (Harrje et al. 1979; Shipp 1983). The cold air moves to the bottom of the basement wall and is heated as it continues its loop path upward behind the inside wall surfaces of the block. This means that insulation applied to inside surfaces must extend to the basement floor level, rather than extending to just below ground surface. Filling the block with insulation that impedes or eliminates the convective air loop is another solution; however, web conductivity through the block limits the improvements in the reduction of conduction losses. Adding external insulation above the ground level and preferably extending it below the ground surface would be the recommended approach, wherever feasible. Normally this is most easily accomplished in the construction phase.

The same masonry wall used as a fire wall or party wall in townhouse (row house) construction introduces problems similar to those in the basement wall (Dutt and Beyea 1979; Harrje et al. 1979). Here, rather than the closed loop illustrated in Figure 3, an open loop often exists in the case of the party wall as shown in Figure 4. Air can enter the wall through the open upper surface of the wall. Cold outside air moves downward through the wall picking up heat from the adjacent townhouses. Once heated, the air moves upward and out only to be replaced with additional cold outside air. Although these discussions have been limited to activity within the block the space between the block and the interior wall construction material can act in a similar way if a gap exists at the upper floor ceiling (shown in Figure 4) (Harrje 1976).

The extent of heat transfer losses from convective loops in townhouse party walls were estimated to be approximately 15% of the total house energy loss for typical heating season conditions (Dutt and Beyea 1979). If this condition is not remedied, the benefits from moving to high insulation levels on the remaining building envelope surfaces can be largely negated.

The solution to the party wall convective loop problem is best handled in the construction phase. The air passages in the wall must be either blocked off at the level of the upper ceiling insulation or the blocks must be filled with material to eliminate convective loops. Experiments to eliminate this problem once the building has been constructed resulted in partial success. The method involved pumping insulation into the masonry block construction by drilling into each block cavity. Blocks in the eaves locations were not accessible, thus limiting the improvement (Dutt and Beyea 1979; Harrje et al. 1979).

Other items in Table 1, such as duct or pipe involvement, can cause local heat loss and/or condensation problems as cold outside air chills interior surfaces. Use of infrared scanning techniques immediately points out such problem areas. This same statement is true for convective loop losses associated with ceiling soffits (see Figure 5) and sloping surfaces above stairwells. Infrared scanning immediately identifies that a problem exists (Harrje et al. 1980).

BUILDING EXAMPLE

The extent to which convective loop phenomena can directly influence the entire operation of a building is evident in the following example. The building in question is located in Trenton, NJ, and is a multifamily senior citizen's residence. The final building configuration was the result of retrofitting an attractive factory site of brick/masonry construction. A central energy management system was installed during the reconstruction process in the early 1980s. Individual apartment temperature sensors were located on the interior wall surfaces.

Some of the problems experienced in the building included uncomfortable room temperatures, variations in building operation in different wings, and inability of the energy management system to achieve goals of maintaining temperature and energy savings. The method used to attack these problems involved site visits to evaluate the local temperatures in the individual apartments and halls, external infrared scanning to evaluate the insulation levels and uniformity on exterior surfaces, fan pressurization of individual apartments to gain perspective on air tightness of the building, and visits to problem apartments where comfort complaints were most common, making use of an array of diagnostic procedures (Harrje and Gadsby 1984).

SCANNING PROCEDURE

Interior infrared scanning with sensitive equipment is needed to accurately map interior surface temperatures which give evidence of many of the convective loop problems outlined in Table 1 (Harrje et al. 1980; Pettersson and Axen 1980). Because interior evaluation also seeks information on the effectiveness of exterior wall insulation and the question of air leakage paths, fan pressurization (blower door) equipment is an important additional diagnostic tool. The diagnostic equipment is shown in Figure 6. To evaluate the losses associated with cold walls (or heated walls in the cooling season) one would desire the integration of the temperatures and surface areas involved. Such computer-infrared scanning arrangements are now available and should prove important in future convective loop effect documentation.

As noted previously, scanning is not limited to exterior surfaces. Figure 7 illustrates the surface temperature variations associated with an interior wall of the building under discussion. Though this apartment is not on the upper floor, the air penetration behind this wall originated 10 feet higher in the structure, moved downward within the interior walls picking up heat, and then moved out to be replaced by new cold air. Figure 8 indicates that another large portion of the inside wall surface has been influenced by convective loop activity, and that the temperature sensor location is within the area of influence. Wall surface temperatures have been shown to be depressed more than 10F below room temperature. From a comfort standpoint, this is similar to having large surfaces at temperatures similar to double glazed windows. Meanwhile the temperature control system struggles with erroneous information.

The temperature variations on interior surfaces can be further enhanced by using gray step thermography. Figure 9 points out penetration of outside air in and around the box beam construction in a ceiling due to the presence of convective loops.

This combination of convective loop problems originated at the upper floor ceiling where gaps in the air barrier were found to be associated with the main beam supports. Rather than add a true barrier to the air flow, a 6- to 12-inch thickness of unbacked fiberglass batts bridged the 6-inch gap under the beams. This arrangement failed to prevent the deep pentrations of cold attic air into the building. Again infrared scanning documented the prime areas for retrofit. The combination of increased heat loss, comfort problems and energy sensor problems due to the convective loop sites in this building accounted for an estimated 50% overuse of heating energy. Under severe winter temperature conditions (several days below 0F) convective loops and air infiltration caused piping to burst deep within the building.

CURING THE CONVECTIVE LOOP PROBLEM

Curing the convective loop problem could be stated simply as avoiding air movement through the building thermal envelope. House doctor teams have observed convective loop problems in thousands of dwellings. Reviewing Table 1, the items listed as attic to ceiling soffits, attic to interior walls, and attic to stairwell ceiling represent a design problem at the upper portion of the building where air movement has not been controlled by vapor/air retarders or by wind protective systems. As shown in Figure 5, attic air moves past or through the insulation into the space above the ceiling soffits, where it is heated and moves past or through the insulation to the attic and out the attic vents. The requirement for a continuous vapor/air retarder has not been met. That envelope element must be placed immediately under the insulation to be effective. An effective seal at the gypsum board ceiling will influence air infiltration but will not modify the convective loop heat loss as illustrated. If there is concern for attic air movement into the porous insulation then there must be a wind barrier material at the upper insulation surface. As pointed out in a recent study (Jacobson et al. 1984) the insulation material choice can limit air movement through the insulation. In very cold climates convective loops within the insulation itself can compromise insulation performance. Movement to denser insulation has eliminated such convective loops.

Not every building has sloping ceilings or soffit arrangements in kitchens, bathrooms, etc., but all buildings have interior partitions. How well does the vapor/air retarder work in these partitions? Not very well. The retarding materials tend to stop at the wall surfaces. Material shrinkage over time, especially with wood construction, and the electrical and plumbing involvement within interior walls means that convective loops can extend into the walls extracting heat and causing problems such as condensation and staining at the upper edges of the walls. Such cold upper corner surfaces were shown in Figure 7. Viewed from the attic with infrared scanning equipment, the entire interior wall plan can usually be observed. Progressive builders have solved the air leakage problem by adding interior walls only after a continuous vapor/air retarder has been put in place. Other builders continue to argue whether or not any retarder is needed in ceilings and that argument is extending to wall construction. If convective loop phenomena are to be eliminated and air infiltration rates controlled, the ceiling surface on the upper floor must be treated in a consistent manor to eliminate undesirable air movement (Elmroth and Levin 1983). Once constructed, many of our buildings became very difficult to retrofit to alleviate these problems, e.g., flat roof construction in multifamily buildings often provides no access to the space above upper floor ceilings and such access may only be possible when the roof is being entirely replaced.

Retrofit procedures working from the attic include adding a polyethylene vapor/air retarder to the underside of the insulation working within the space above the stairwell ceiling and soffits and caulking and/or foaming along the cracks and openings associated with the interior walls. In one set of townhouses openings at the basement end of the cavity were sealed (Socolow 1978). Again it should be emphasized, the secret is to prevent the convective loop from being established by appropriate design of the masonry block construction, i.e., eliminating airflow in the block past the insulation level that constitutes the thermal envelope.

Exterior wall insulation must be installed to preclude short circuiting. In existing structures blowing additional wall insulation into wall gaps can eliminate short circuiting and, at the same time, can markedly reduce air infiltration in some wall constructions (Jacobson et al. 1984).

Ducting and piping extending from living spaces to unheated areas has often not been properly designed and installed. Ducting into attic areas should be insulated to at least attic levels; otherwise, as the air cools down between furnace operation cycles the cold air moves immediately back through the building envelope cooling down interior spaces. Since the supply air temperature for operating warm air systems exceeds room temperatures by 10F or more for heat pumps and as much as 70F for combustion-based systems, the need for very high insulation levels on ducts is apparent.

Piping extending through the building envelope can also carry heat away. One case study of a New Jersey school pointed out roof drains passing through classroom space. Not only was the convective loop wasting heat as the warmed air within the pipes moved upward and out of the roof drains, but the cold replacement air caused condensation on the pipe exterior surface and annoyance to the students below.

Again, the best solution for these problems is an understanding of the building physics that underlie generating convective loops and eliminating the problems through correct design procedures.

CONCLUSION

A variety of convective loop problems exist within our buildings. The convective loop occurs because of a design or construction error. These problems are not confined to existing buildings but continue to be part of our latest construction. The detection method most suitable for evaluating the presence and the extent of convective loops in our buildings is infrared scanning. In the principal example cited, not only can the presence of convective loops waste energy, but comfort and building control effectiveness are also compromised. Ways to avoid the problems have been outlined together with retrofit strategies. House doctor experiences in thousands of homes point out the importance of controlling these phenomena which have negative effects on the building thermal envelope.

BIBLIOGRAPHY

Dutt, G.S. 1981. "House Doctor Visits -- Optimizing Energy Conservation Without Side Effects." New Energy Conservation Technologies and their Commercialization. Berlin: Springer-Verlog.

Dutt, G.S. and Beyea, J. 1979. "Hidden Heat Losses in Attics -- Their Detection and Reduction." Princeton University Center for Energy and Environmental Studies Report No. 77.

Dutt, G.S. and Harrje, D.T. 1981. "Improved Thermal Designs for Light Frame Structures." Forest Products Laboratory Conference, Madison, WI.

Elmroth, A. and Levin, P. 1983. "Air Infiltration Control in Housing: A Guide to International Practice." Document D2:1983. Stockholm: Swedish Council for Building Research,

Harrje D.T. 1976. "Retrofitting: Plan, Action and Early Results Using Townhouses at Twin Rivers." Princeton University Center for Energy and Environmental Studies Report No. 29.

Harrje, D.T.; Dutt, G.S.; and Beyea, J. 1979. "Locating and Eliminating Obscure but Major Energy Losses in Residential Housing." ASHRAE Transactions, Vol. 85, Pt. 2, pp. 521-534.

Harrje, D.T.; Dutt, G.S.; and Gadsby, K.J. 1980. "Isolating the Building Thermal Envelope." Thermal Infrared Sensing Applied in Energy Conservation in Building Envelopes (Thermosense III). R.P. Madding, Editor, pp. 50-57. Bellingham: Society of Photo-Optical Instrumentation Engineers.

Harrje, D.T. and Gadsby, K.J. 1984. "Diagnostics of Energy-Related Building Problems Using Today's Technologies." *Energy Technology*. R.F.Hill, Ed. Vol. XI, pp. 364-374. Rockville: Government Institutes.

Jacobson, D.; Harrje, D.T.; and Dutt, G.S. 1984. "Measurement of Air Leakage Properties of Common Residential Insulating Materials." ASTM Conference on Thermal Insulation Materials and Systems, Dallas, TX.

Latta, J.K. 1984. "The Principles and Dilemmas of Designing Durable House Envelopes for the North." Building Practice Note #52. National Research Council of Canada.

Nisson, J.D., Feb. 1985, June 1985. Energy Design Update. Canaan: Energy Design Assoc. Inc.

Nisson, J.D. and Dutt, G.S. 1985. *The Superinsulated Home Book*. New York: John Wiley & Sons.

Pettersson, B. and Axen, B. 1980. "Thermography - Testing of the Thermal Insulation and Airtightness of Buildings." Document D5. Stockholm: Swedish Council for Building Research.

Shipp, P.H. 1983. "Natural Convection Within Masonry Walls." *ASHRAE Transactions*, Vol. 89, Pt. 1, pp. 401-416.

Socolow, R. H., Ed. *Saving Energy in the Home -- Princeton's Experiments at Twin Rivers",* 1978. Cambridge: Ballinger.

TABLE 1

Typical Convective Loops

Open Loop	*Closed Loop*
o Attic to ceiling soffits	o Short circuit wall insulation
o Attic to interior walls	o Party wall system
o Pipes/ducts to outside	o Basement wall system
o Flow through vertical shafts	o Ducting into unheated areas
o Attic to stairwell ceiling	o Within loose insulation
o Flow behind wall/ceiling insulation	o Rock bed systems
o Party wall systems	
o Flow through finger spaces in masonry veneer walls	
o Fireplace chimneys	

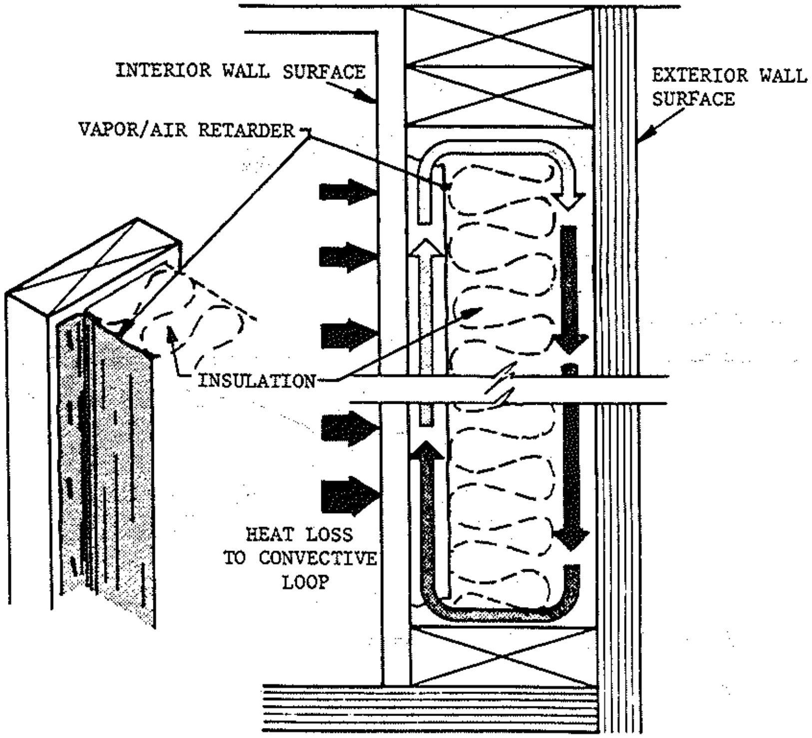

Figure 1. Closed convective loop, example of improperly insulated exterior wall

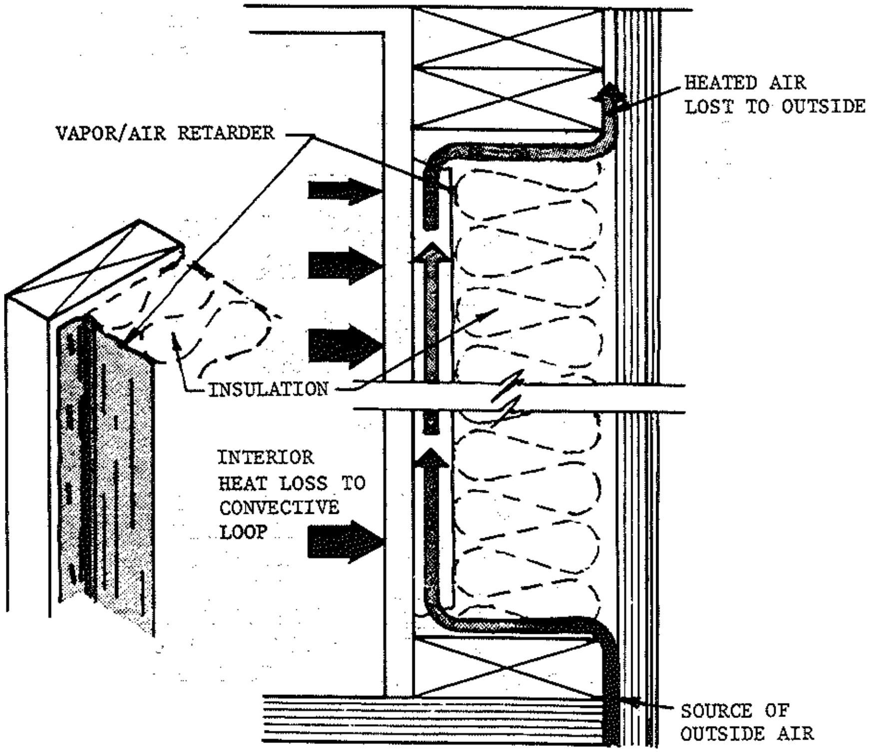

Figure 2. Open convective loop, example of exterior wall that allows airflow

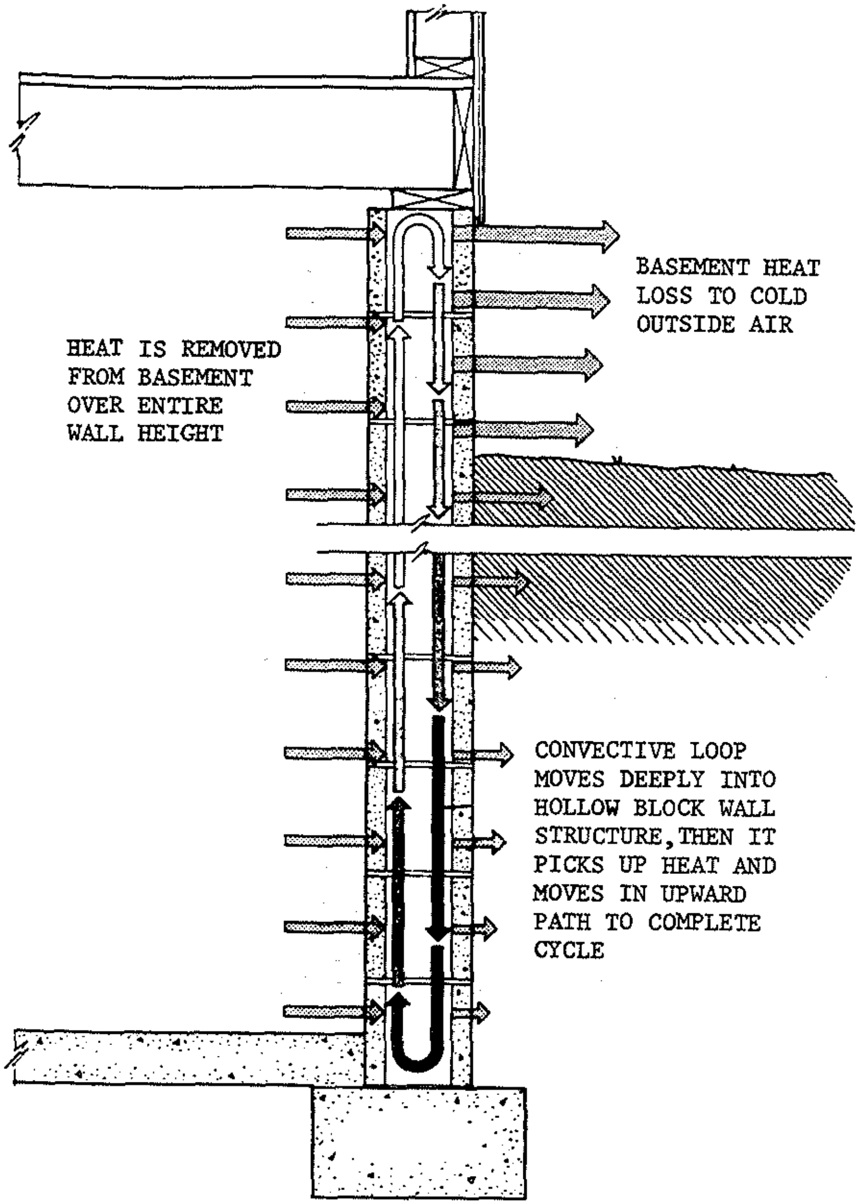

Figure 3. Basement masonry wall using hollow block construction which encourages convective loops

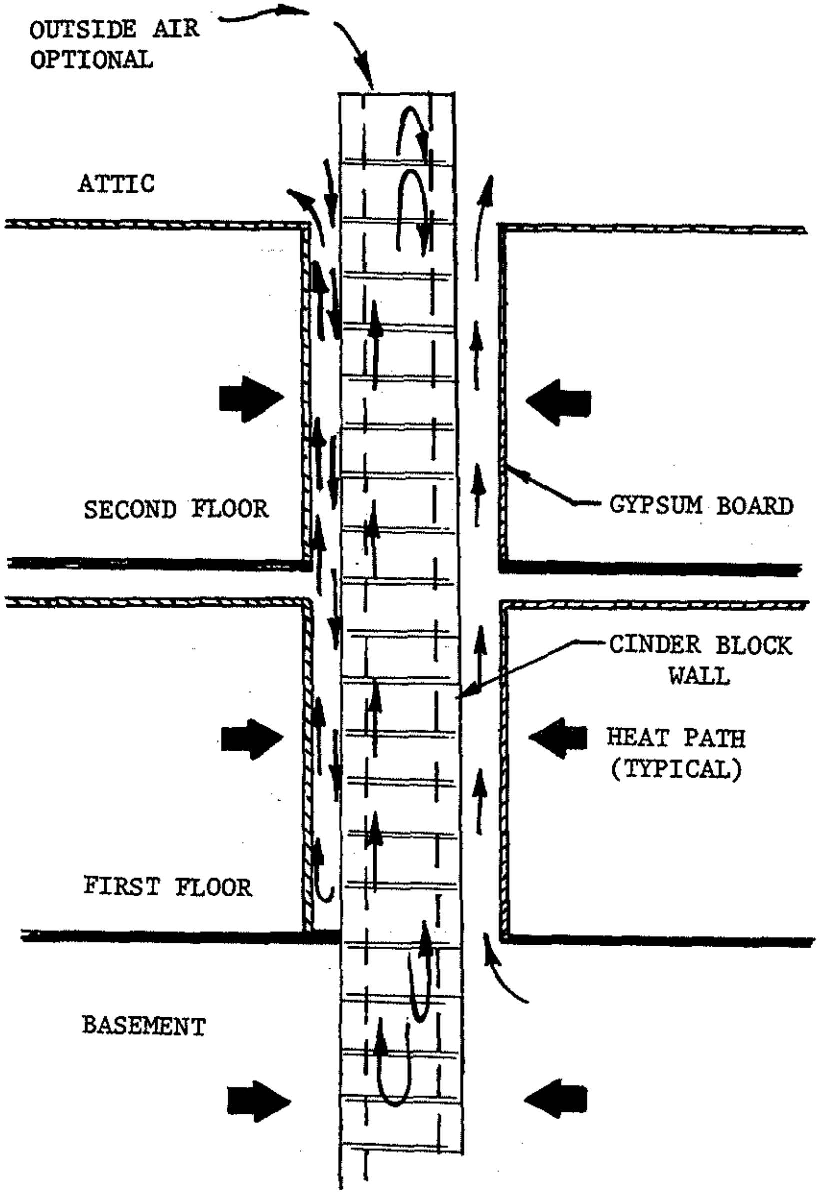

Figure 4. The party wall; convective loop flow in wall and between wall on interior construction

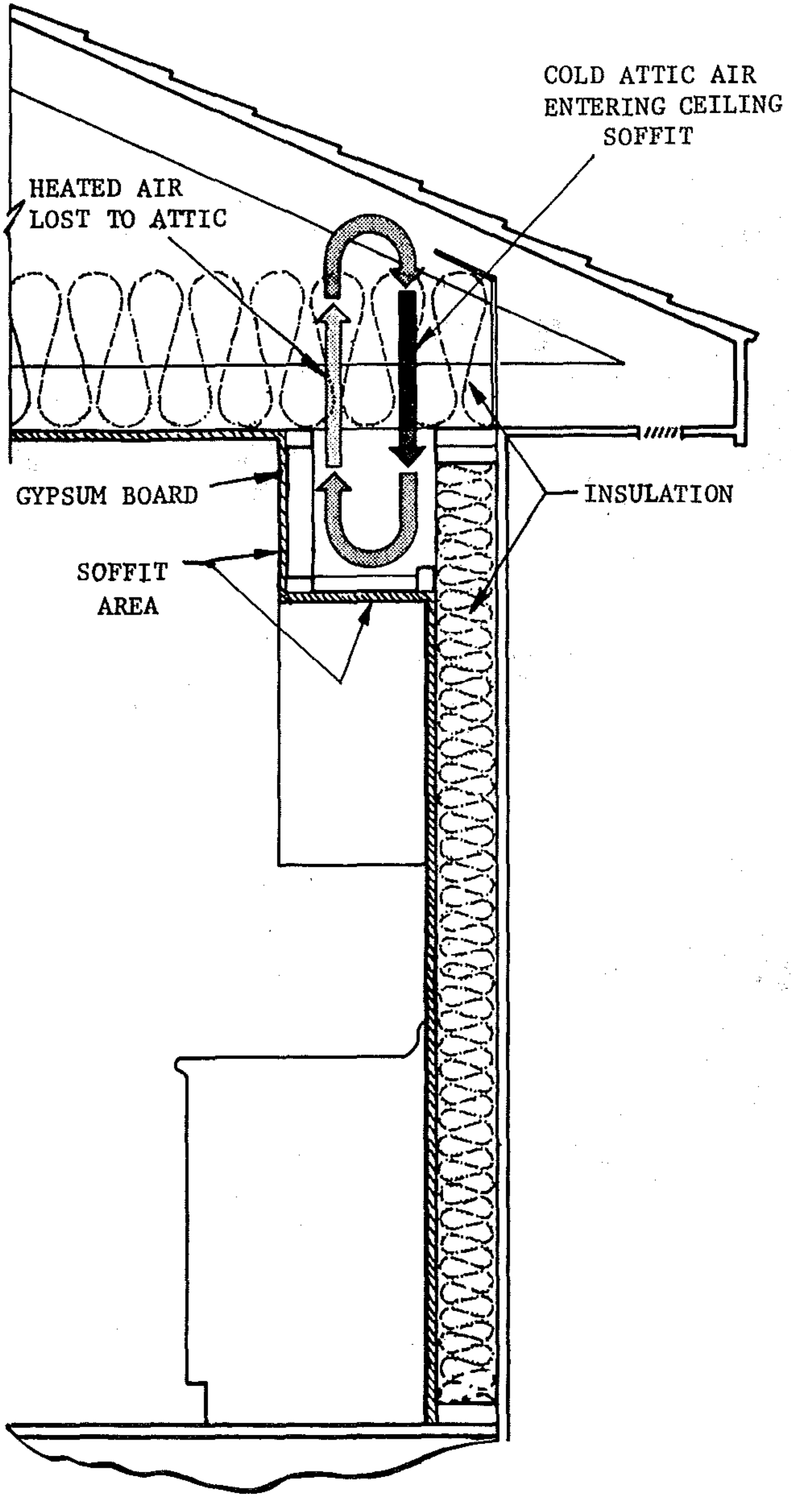

Figure 5. Convection loop associated with ceiling soffits above kitchen cabinets

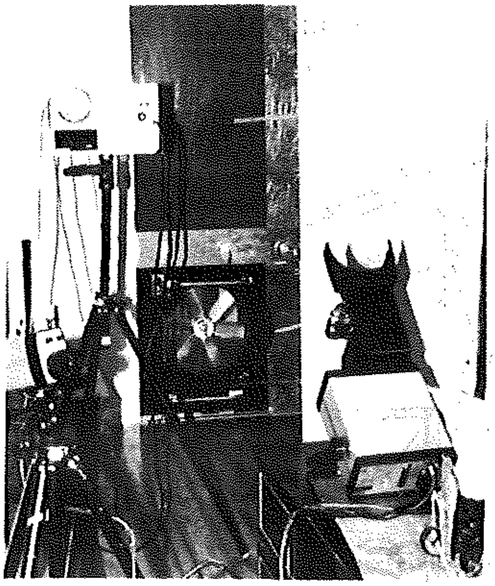

Figure 6. Blower door in place with control and measurement system; in foreground, IR scanner on left and thermographic display and camera on right

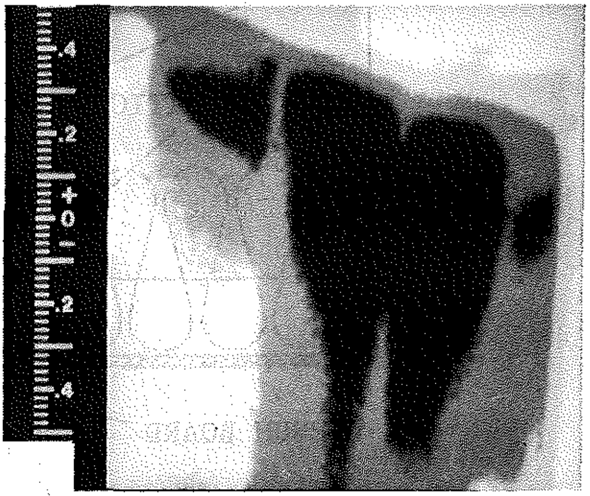

Figure 7. Thermogram of convective loops in interior partition. Upper portion of wall may be subjected to condensation and staining

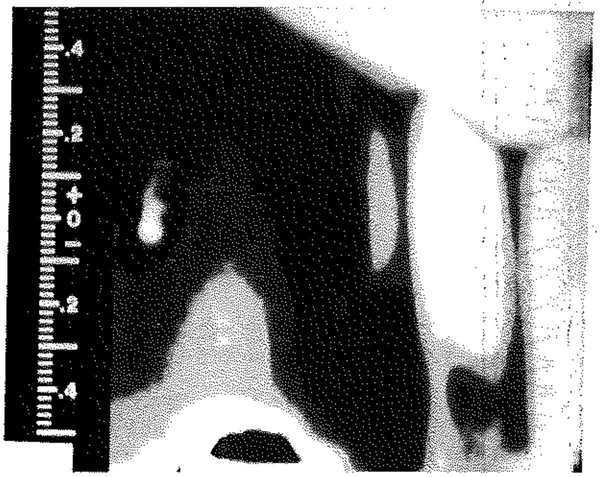

Figure 8. Thermogram of apartment partition wall showing wide range of surface temperatures and proximity to temperature sensor

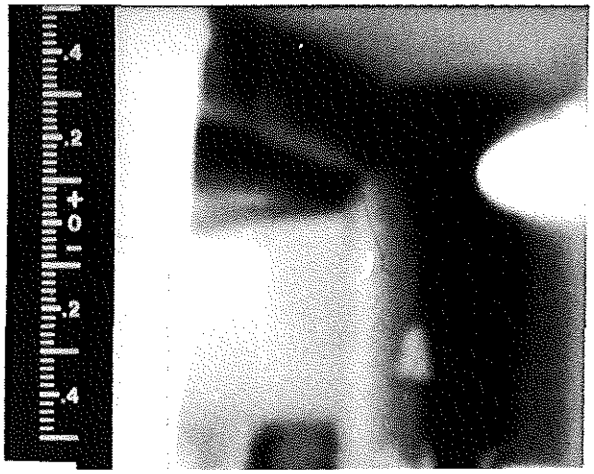

Figure 9. Box beam convective loops shown in wall-ceiling thermogram