NIST/GSA Design Guidelines for Thermal Envelope Integrity

A.K. Persily
Member ASHRAE

ABSTRACT

Office building envelopes are generally successful in meeting a range of structural, aesthetic, and thermal requirements. However, poor thermal envelope performance does occur due to the existence of defects in the envelope insulation, air barrier, and vapor retarder systems. These defects may result from designs that do not adequately account for heat, air, and moisture transmission, with many being associated with inappropriate or inadequate detailing of the connections of envelope components. Despite the existence of these thermal envelope performance problems, information is available to design and construct envelopes that do perform well. In order to bridge the gap between available knowledge and current practice, the National Institute of Standards and Technology has developed thermal envelope design guidelines for federal office buildings for the General Services Administration. The goal of this project is to transfer the knowledge on thermal envelope design and performance from the building research, design, and construction communities into a form that will be used by building design professionals. These guidelines are organized by envelope construction system and contain practical information on the avoidance of thermal performance problems, such as thermal bridging, insulation system defects, moisture migration, and envelope air leakage. This paper describes the guidelines prepared by NIST for GSA.

INTRODUCTION

The exterior envelopes of office buildings perform a variety of roles including keeping the weather outdoors, facilitating the maintenance of comfortable interior conditions by limiting heat, moisture, and air transmission, providing a visual and daylight connection to the outdoors, limiting noise transmission, supporting some structural loads, and providing an aesthetically pleasing appearance. Although building envelopes are generally successful in meeting these varied requirements, there are cases in which they do not provide performance in one or more of these areas. Shortcomings in building envelope thermal performance are manifested by excessive heat, air, or moisture transmission that may lead to increased energy consumption, poor thermal comfort within the occupied space, and deterioration of envelope materials. While some cases of poor performance occur due to the specification of insufficient levels of thermal insulation or inappropriate glazing systems, many other cases occur because of discontinuities in the envelope insulation and air barrier systems, such as thermal bridges, compressed insulation, and air leakage. Some of these discontinuities result from designs that do not adequately account for heat, air, and moisture transmission, are difficult to construct, do not have sufficient durability to perform for a reasonable length of time, or cannot withstand wind pressures or differential movements of adjoining elements. Other thermal envelope defects are due to poor construction technique.

Despite the existence of these thermal envelope performance problems, information is available to design and construct envelopes with good thermal envelope performance. In order to bridge this gap between available knowledge and current practice, the Public Buildings Service of the General Services Administration (GSA) entered into an agreement with the Building and Fire Research Laboratory of the National Institute of Standards and Technology (NIST) to develop thermal envelope design guidelines for federal buildings (Persily 1992). The basic goal of this project is to take the knowledge on the avoidance of such thermal defects from the building research, design, and construction communities and to organize it into a form for use by building design professionals. These guidelines are not intended to direct the designer to choose a particular thermal envelope design or a specific envelope subsystem but rather to provide information on achieving good thermal envelope performance for the design already chosen. The guidelines will provide the designer who has already made decisions on insulation levels, construction materials, and glazing areas with specific information to make the building envelope perform as intended through an emphasis on design details that avoid thermal defects. Much of the material in these guidelines is in the form of common design details for specific building envelope systems and discussion of aspects of these details that lead to thermal defects. Alternative details that have been shown to correct these thermal defects are presented and discussed.

BACKGROUND AND DESCRIPTION

Background

The development of these guidelines was originally motivated by GSA's experience with office buildings exhibiting poor thermal envelope performance (Grot et al. 1985). Diagnostic evaluations of these buildings revealed the existence of high levels of air leakage and numerous

Andrew K. Persily is a group leader at the National Institute for Standards, and Technology (NIST), Gaithersburg, MD.

thermal insulation system defects. GSA realized that improvements in building envelope design and construction were necessary to avoid similar situations in future projects and entered into an agreement with the Building and Fire Research Laboratory at NIST to develop these design guidelines. The development of the design guidelines has involved several sources of information, including a review of published literature, voluntary contributions acquired by a BTECC/NIBS (Building Thermal Envelope Coordinating Council of the National Institute of Building Sciences) project committee, and comments from the project committee itself and a group of technical consultants to NIST.

The development of the NIST/GSA envelope design guidelines began with a review of research results and technical information on thermal envelope performance and design (Persily 1990). The review included the examination of research on thermal envelope performance, case studies of thermal envelope performance defects, thermal envelope designs specifically intended to avoid such defects, and general design principles for ensuring good thermal envelope performance. The information obtained from the review includes the classification of thermal envelope defects, such as thermal bridges, insulation defects, and air leakage, along with several specific examples of each. Research in the area of calculation and modeling has enabled the quantification of the effects of thermal defects on envelope heat transfer rates and the effects of air leakage on building infiltration rates. However, these results are of limited usefulness in relating specific envelope designs to specific levels of performance. The review did identify several principles for the design and construction of building envelopes that avoid the occurrence of thermal defects. Many design details were identified that provide effective alternatives to the details that result in these defects. The main conclusions of the literature review are that thermal defects exist and have significant detrimental effects on energy consumption, thermal comfort, and material performance. Publications that identify these defects and present alternative designs have been limited to specific buildings and to a small number of envelope components and component connections associated with specific building constructions. There are no thorough presentations of thermal envelope defects, poor design details, or alternative designs for the great variety of building envelope systems. The thermal envelope guidelines are intended to be just such a presentation, and the review has shown that the published literature is an incomplete source of this information. However, the practical experience of building envelope design and construction professionals is a good source, and their knowledge is a major source of input to the guidelines. A recent book by Brand (1990) is an exception to the general lack of published information. His book provides details and discussion of thermal envelope design for good airtightness and insulation performance for a limited number of wall systems.

The literature review also examined existing standards and construction guidance documents for information on thermal envelope integrity. Most of these documents contain general information on design principles and construction techniques or guidance on the selection of U-values and glazing systems. While some of these documents recognize the importance of thermal envelope defects, they do not emphasize the importance of these problems or contain the information or design details necessary to construct building envelopes that avoid these defects. Construction handbooks cover many important areas of envelope design but generally do not address thermal defects and air leakage. Construction guides that were developed specifically to promote energy-conserving designs address insulation levels, thermal mass, fenestration, and materials but not thermal defects. In some cases they mention the importance of controlling infiltration by sealing the envelope and the need to avoid thermal bridges, but they do not indicate how to design and construct an envelope that actually achieves these goals. A design guide of particular interest was developed by a manufacturer (OCG 1981) and contains many design details for walls, roofs, and envelope intersections. The guide is very good on insulation system continuity but does not deal with air leakage and air barrier systems. The sections on the thermal envelope within the energy standards developed by GSA, ASHRAE (1989), and DOE (1989) concentrate on insulation levels and fenestration systems. At best they mention the importance of thermal bridges and air leakage, but they do not contain sufficient criteria for their control.

In order to obtain additional information for potential inclusion in the guidelines and to obtain an independent review of their development, a contract was issued by NIST to the National Institute of Building Sciences (NIBS) to obtain the expertise of the Building Thermal Envelope Coordinating Committee at NIBS. A BTECC/NIBS project committee was established, in part to solicit and review voluntary contributions of materials for consideration in preparing the guidelines. The project committee sent out requests for information to hundreds of individuals and organizations and received about 50 responses. Many items of interest were obtained, primarily from industry associations. The BTECC/NIBS project committee then reviewed this material for its relevance to the guidelines. As NIST developed the guidelines, the committee reviewed them and contracted with selected consultants for more detailed reviews.

Based on the results of the literature review, it was determined that much of the information needed for the guidelines is not in published form but is available from design professionals and building envelope consultants. In order to benefit from this source of information, NIST contracted with selected experts in the field of building envelope design to prepare material for the guidelines in their specific areas of expertise.

Description

The purpose of the guidelines is to provide practical design information directed toward achieving good thermal envelope performance by avoiding thermal defects. The guidelines intentionally do not cover many other issues important to the thermal performance of office building envelopes, such as the selection of particular envelope systems, determination of appropriate levels of thermal insulation, daylighting and other glazing system issues, thermal mass effects, design methodology, thermal load calculations, and interactions between the envelope and HVAC equipment. The guidelines, as stated, do provide information on how to achieve good thermal performance and avoid thermal defects for a variety of envelope systems and subsystems. It is assumed that the designer has already chosen the envelope system and will use the guidelines as a source of information on design issues key to thermal envelope performance for that system.

The guidelines are concerned primarily with heat conduction, air leakage, and airborne moisture transfer through the building envelope. The discussion concentrates on these issues, the mechanisms associated with each, and how they are best controlled. However, it is obvious that the control of heat, air, and moisture transfer is only one of many performance requirements of thermal envelopes. Envelope design must address all the varied requirements and the potential interactions between the envelope elements intended to meet them. Some of these other envelope design issues, which are not explicitly covered by the guidelines, include structural performance, aesthetics, fire safety, lighting, and rain penetration. While these issues are outside the scope of the guidelines, they are addressed as necessary in reference to their interactions with those design features intended to control heat, air, and moisture transfer. The prevention of rain penetration is particularly relevant because the elements intended to control rain penetration often relate to those controlling heat, air, and airborne moisture transfer. A separate section on rain penetration is included in the guidelines.

The guidelines present many design details that lead to thermal defects, along with improved alternatives. The alternative details included in the guidelines include only those based on generally accepted practice and with time-tested performance as determined by those involved in the development and review of the guidelines. Suggested fixes that have not been tested in the field are omitted, though they may possibly provide acceptable performance.

The guidelines are organized as shown in Table 1. Each section consists of a series of stand-alone fact sheets addressing a specific issue or system. The introduction discusses the background to the development of the guidelines and describes their content and format. Much of this introduction is included in this paper. The first section, on "Principles," provides background information on thermal envelope performance, including a discussion of thermal defects and their potential consequences. The fact sheets in this section are not necessary for the user but do provide useful background information and describe the motivation and bases for the guidelines. The second section, on "Design," contains fact sheets on basic design principles for achieving good thermal performance and avoiding thermal envelope defects. The material in this section describes air barriers, vapor retarders, and thermal insulation systems, specifically addressing the design features of each that are essential to thermal envelope integrity. This section also contains a discussion of rain penetration and a fact sheet on how the processes of design and construction relate to thermal envelope performance. The section on "Systems" constitutes the substance of the guidelines, containing discussions of several different envelope systems. These fact sheets on particular envelope systems and subsystems describe those design features that are crucial to achieving good thermal performance and also contain examples of poor designs to be avoided, which may lead to thermal defects. The appendices contain a glossary, bibliography, and a list of organizations with activities related to thermal envelope design.

Thermal envelope design is impacted by climatic factors, in particular temperature and ambient relative humidity levels. The need for a vapor retarder and its location within the thermal envelope and the position of the thermal insulation within the envelope are issues that are

TABLE 1
Outline of the Design Guidelines

INTRODUCTION
Description of Guidelines
Background

PRINCIPLES
Building Envelope Performance
Thermal Envelope Performance
Thermal Envelope Defects
Design and Construction Process

DESIGN
Air Barriers
Vapor Retarders
Thermal Insulation
Rain Penetration Control
Sealants

SYSTEMS
Glass and Metal Curtain Walls
Masonry
Stud Walls
Precast Concrete Panels
Stone Panel Systems
Metal Building Systems
Exterior Insulation Finish Systems
Roofing Systems

APPENDICES
Bibliography
Glossary
Organizations
Thermal Envelope Diagnostic Techniques
NIBS Project Committee

influenced by these climatic factors. The literature review conducted prior to the development of the guidelines noted a definite lack of design guidance and research results relevant to warmer climates and to climates with both significant heating and cooling seasons. Much of the previous work on thermal envelope performance has been done in Canada, which accounts for some of this climatic imbalance. Recent efforts have attempted to address the lack of information on warm-climate thermal performance issues, but the warm-climate gap is still prevalent. When design guidance is provided that is only appropriate to a particular climate, it is clearly noted.

THE PROBLEM

There are many examples of thermal and air leakage defects in the envelopes of office buildings, both in case studies from specific building envelope designs and in discussions of generic building construction types. As part of the literature review, these defects were classified into ten general categories. Table 2 is an outline of these thermal defects. The first two categories are fairly general, thermal bridges and insulation defects, and the remaining eight categories are based on particular envelope systems, i.e., roofing, wall assemblies, curtain wall and panel systems, concrete masonry wall systems, metal building systems, air barriers and sealants, component interfaces, and other assemblies. All thermal defects are basically discontinuities in the envelope insulation layer or the plane of airtightness within the building envelope. Some are designed into the thermal envelope. Others are the result of poor construction or occur over time due to the effects of wind pressure, aging, and differential movements of building components.

The guidelines contain about 20 examples of thermal defects caused by poor design decisions, details that cannot be constructed in the field, and poor construction technique. Figure 1 shows an example of the inadequate support of envelope elements at a parapet in a concrete masonry wall (Quirouette 1989). The rigid parapet insulation was spot adhered to the polyethylene air barrier/vapor retarder, which was attached at the top of the stud wall and at the top of the parapet plate. Because the polyethylene was not adequately supported, it moved back and forth with the wind pressure and eventually tore. The movement of the polyethylene pulled the rigid insulation away from its original location, which, in turn, pulled the polyethylene further out of place. The parapet air seal was rendered totally ineffective, as was the rigid insulation.

Many of the thermal envelope defects occur at the intersections of envelope systems, such as wall/roof and wall/floor intersections. Figure 2 is an example of a wall/roof intersection in a concrete masonry wall that shows several problems (Turenne 1980). First, there is an insulation discontinuity where the wall and roof meet. Also, the wall air barrier is not carried up and sealed to the roof membrane, resulting in air leakage at this intersection. Even if the wall air barrier is sealed to the roof membrane, it is difficult to seal the bottom of the beam to the top of the backup wall due to the differential movement of these two elements. The air seal at this location must be designed to

TABLE 2
Summary of Thermal Envelope Defects

Thermal Bridges
Structural elements
Component connections
Envelope penetrations
Corner effects
Insulation Defects
Discontinuity in insulation system design
Voids and gaps
Unsupported insulation
Compression by fasteners and other elements
Fibrous insulation exposed to air spaces
Poor fitting batt insulation
Roofing
Insulation defects: gaps
Thermal bridges: penetrations, structural elements
Air leakage: penetrations, structural elements, flutes in corrugated steel decking, incomplete attachment of loose-laid membranes
Wall Assemblies
Airflow passages within the envelope
Poor material selection or attachment
Curtain Wall/Panel Systems
Thermal bridges in factory-made panels
Panel seams
Panel supports penetrating insulation and/or air barrier
Concrete Masonry
Air leakage through blocks and mortar joints
Air seal to spandrel beams and columns
Upward air movement through concrete blocks
Metal Buildings
Purlins: thermal bridges, insulation compression
Air channels due to corrugated claddings
Air Barriers and Sealants
Discontinuity of air barriers
Use of insulation or insulation adhesives as air barriers
Punctured or displaced air barriers
Polyethylene: inadequate support, lack of continuity
Inappropriate selection of sealant materials
Sealant failure due to differential movement
Lack of interior finishing
Component Interfaces
Floor/wall
Window/wall
Wall/roof
Column/wall
Wall/wall
Wall/ceiling
Other Assemblies
Overhangs
Soffits
Stairwells
Interior partitions

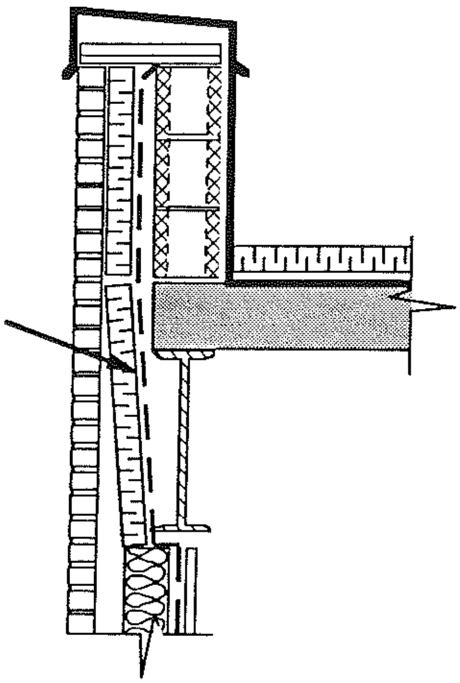

Figure 1 *Example of inadequate material attachment (Quirouette 1989).*

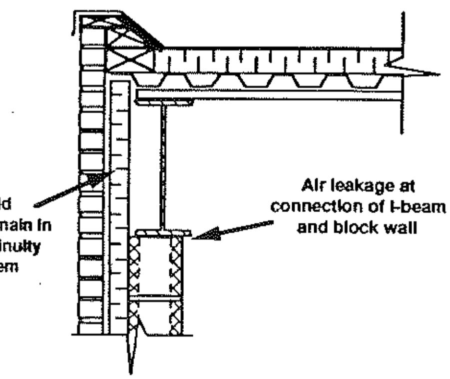

Figure 2 *Deficient masonry wall/roof intersection (Turenne 1980).*

accommodate this movement. In this figure, no space is provided at this point, and therefore deflection of the beam will put loads on the wall for which it is not designed, leading to cracking or worse. Although the rigid insulation is carried up outside the beam, it is not supported and is unlikely to remain in place due to its exposure to wind pressures.

THE SOLUTION

The solution to thermal envelope defects is the use of good design and construction practice based on sound building science, careful detailing, and good field technique. The construction of building envelopes with good thermal performance can be achieved based on existing information and materials. Success requires a commitment to thermal envelope integrity from the very beginning, the design of all envelope details based on the achievement of complete continuity of the thermal insulation and air barrier systems, effective communication between the designers, contractors, and field personnel regarding the design intentions and the importance of construction technique to thermal envelope performance, and the careful inspection of construction. The following "rules" (based in part on Brand [1990]) for thermal envelope design serve as a good foundation and need to be followed for all envelope details:

- Enclose the building in a continuous air barrier.
- Provide continuous support for the air barrier against wind loads.
- Ensure that the air barrier is flexible at joints where movement may occur.
- Provide continuous insulation to keep the vapor retarder warm and to conserve energy in the building.
- Keep the insulation tight to the air barrier.
- Design copings, parapets, sills, and other projections with drips to shed water clear of the facade.
- Provide the means for any water that does penetrate the facade to drain back to the outside.

The design guidelines contain dozens of design details, both unacceptable and acceptable, in the section on systems. The unacceptable details show common designs that result in air leakage, thermal bridging, and other thermal defects. The acceptable details show alternative designs with improved performance. The acceptable details are based on published case studies and material provided by several technical experts on contract to NIST. Only those details that have a history of acceptable performance are included in the guidelines, as opposed to proposed details that have not withstood the test of time and the elements. Therefore, the details presented only cover those elements that have been covered elsewhere and mostly those applicable to heating situations. There is a need for the development and presentation of additional design details for a wide variety of envelope elements in all climates.

A selected number of details from the guidelines are presented below. Figure 3 shows both an unacceptable and an acceptable detail of the connection between a curtain wall and grade (Quirouette 1983). This connection is particularly sensitive to rain penetration and air infiltration. In the first detail, the requirements for both air barrier and insulation system continuity are violated. The insulation under the mullion is out of line with the mullion thermal break, and the air seal under the mullion is out of line with the mullion air seals. In addition, cold air infiltration past the flashing and into the insulation creates the potential for condensation on the interior of the mullion. Rainwater accumulation in the cavity between the wall section and the

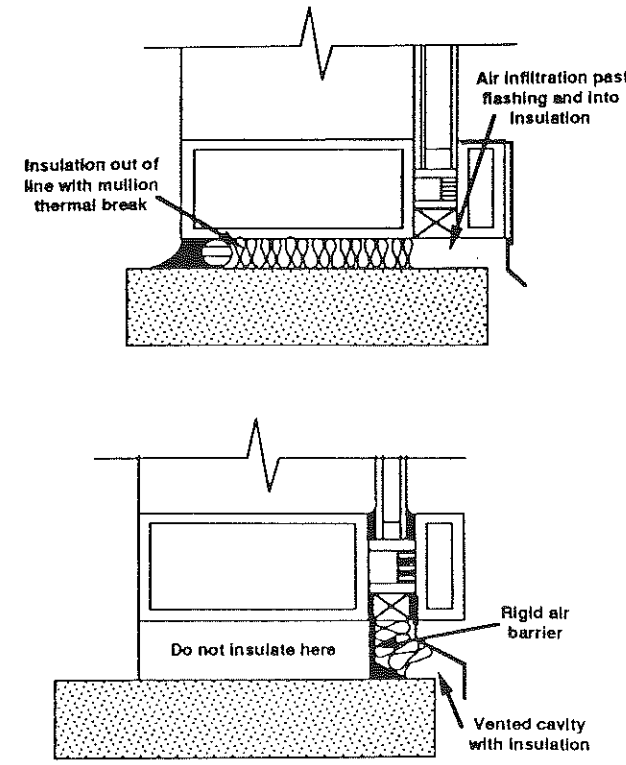

Figure 3 *Curtain wall/grade connection (Quirouette 1983).*

floor deteriorates the floor-to-mullion seal. The acceptable detail maintains the continuity of both the insulation and air barrier systems. The insulation is located on the exterior of the air barrier to control condensation. A sealant is used at the base of the air barrier to create a sloped edge or water dam to control rain penetration. Flashing is installed under the mullion cap to ensure that water draining from above is directed to the outside of the cavity.

Figure 4 shows an acceptable connection between a masonry wall and a roof edge in a steel frame building (Brand 1990). This is an alternative detail to the defective example shown in Figure 2. In order to support the air barrier, the beam is bridged with sheet metal or some other rigid material. A gap is provided between the beam and the top of the block wall, and this gap is sealed with a flexible membrane to accommodate movement at this joint. Both the wall air barrier and the membrane base flashing are sealed to the roof membrane to maintain the continuity of the air barrier system. Insulation is placed in the gap between the wall insulation and the roof insulation to keep the air barrier warm at this location and to maintain the continuity of the insulation system.

Figure 5 shows unacceptable and acceptable details of the wall/floor connection in a steel stud wall (Winter 1989). This intersection is a common location for thermal bridging and air leakage when the floor slab extends to the exterior facade, as is the case in the unacceptable design. In the

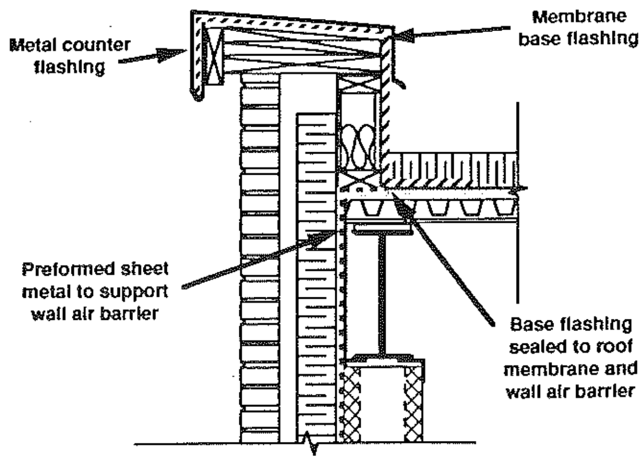

Figure 4 *Masonry wall/roof edge intersection (Brand 1990).*

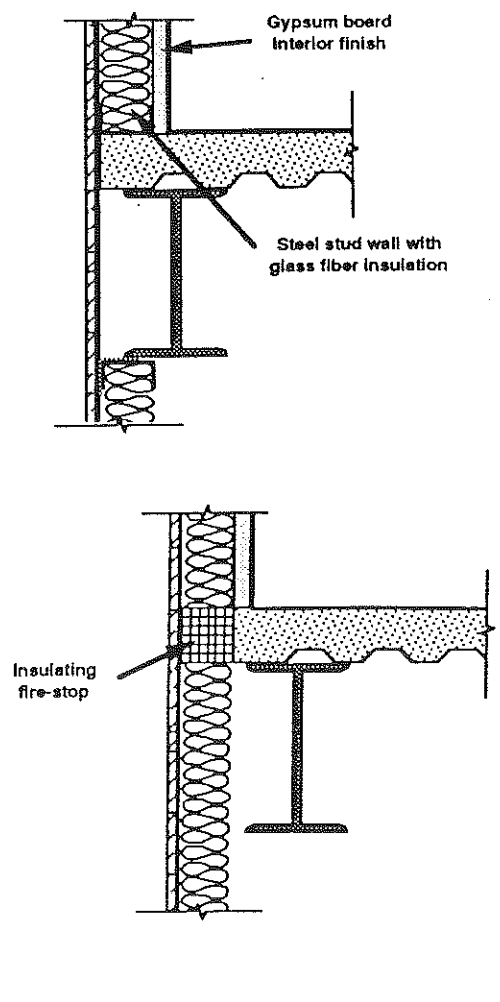

Figure 5 *Steel stud wall/floor intersection (Steven Winter Associates 1989).*

acceptable design, the floor slab and beam are moved back so that the insulation is continuous across the floor slab. A fire stop must be provided at the slab edge. This detail does not include the air barrier, but an air barrier is necessary and several options exist for its inclusion in this wall system.

ACKNOWLEDGMENTS

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