GETTING TO NET-ZERO ENERGY WITH brick masonry

Coventry University's Lanchester Library was designed by U.K. firm Alan Short & Associates and completed in 2000. It uses 51% less energy than a typical air-conditioned building through the use of passive energy-conservation techniques.

SHORT & ASSOCIATES / COURTESY BRICK INDUSTRY ASSN.

LEARNING OBJECTIVES

After reading this article, you should be able to:

+ DEFINE the term "net-zero energy (NZE) building" and list the basic properties of heat loss and heat gain and their application to the design and construction of NZE buildings.
+ EVALUATE the typical R-values of masonry walls, the thermal mass properties of brick walls, and their use in net-zero energy buildings.
+ DESCRIBE various passive solar and active solar techniques (for renewable energy) and their application to net-zero energy buildings.
+ DESCRIBE thermal bridges that occur in structures, how they degrade the thermal performance of the wall, and why their reduction or elimination is critical to achieving a net-zero energy building.

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Net-zero energy (NZE) buildings are no longer a dream. In the past few years, NZEs have been popping up all over the U. S. and abroad. The U.S. Defense Department has committed to a net-zero pilot program for the military branches. There are even some net-zero plus buildings—those that produce more energy than they consume.

The exact definition of a net-zero energy building is still a subject of debate. Such a definition may include *NZ site energy* (energy consumed and generated at the building site), *NZ source energy* (which includes energy used to extract and deliver power to the site), or *NZ emissions* (the energy that produces emissions, and uses offsets to account for those emissions).

At its most basic, however, a net-zero energy building is one that generates at least as much energy as it consumes—although some NZE buildings may use renewable energy credits (RECs) to reach that goal. (For an excellent primer on NZE definitions, see "Defining Net-zero Energy Buildings," by Paul Torcellini, PhD, PE, and Shanti Pless, LEED AP, at: www.BDCnetwork.com/2011WhitePaper.)

While many factors must be taken into account to achieve net-zero energy use—correct building orientation, optimal daylighting and lighting efficiency, proper shading and sun control, the use of high-performance glazing, natural ventilation and air flow systems, even plug loads—this course will focus primarily on the building envelope.

Specifically, we'll discuss the use of brick and masonry in the design and construction of wall systems for NZE buildings. Although other materials can be used to create the walls for NZE buildings, brick has a unique and cherished aesthetic that makes it a strong candidate for use in net-zero energy buildings, just as it is used in so many other commercial and institutional buildings.

The course will review several underlying principles related to heat loss and heat gain, the insulating capabilities of masonry walls, the thermal mass properties of brick walls, the use of passive solar vs. active solar techniques, and the need to eliminate, or at the very least drastically reduce, thermal bridging in wall assemblies.

First, however, let's establish a few important precepts related to the design and construction of NZE buildings:

1. *Tackle energy demand first, then worry about energy supply.* This is the most important point to keep in mind when seeking to design an NZE building. Before considering any renewable energy strategies (active photovoltaics, wind turbines, etc.), Building Teams must reduce designed energy use as much as possible—preferably by at least 50% compared to a conventional building, although 65-70% has been proven achievable—within the project's budget constraints.

2. *Don't count too much on renewable energy sources to get you to net-zero energy.* It is virtually impossible to install enough solar panels, wind turbines, or other renewable energy sources on a building to make it net-zero without reducing its energy use drastically, as stated in the first point.

3. Keep in mind that *the more energy efficient the building envelope, the less you'll have to rely on renewable energy sources* to reach net-zero energy use.

4. You can replace PVs and other renewables in the future, but *it's virtually impossible to replace the wall systems*, so you have to get them right from the very start.

5. *If you can't go all the way to net-zero energy, you can still make your building "net-zero ready"* by making the building as energy efficient as possible, but without the use of PVs or other renewables. These can be added later at the owner's discretion—when the cost of renewables comes down or technology has made them more efficient and cost-effective.

TABLE 1.
TYPICAL R-VALUES OF BUILDING MATERIALS

BUILDING MATERIAL	R-VALUE
Polyisocyanurate insulation	6.8
Spray polyurethane foam	6.7
Extruded polystyrene	5.0
Lightweight CMU	2.0
Normal weight CMU	1.11
Air space	0.96
Air film (1)	0.68
Brick	0.44
Air film (2)	0.17

SOURCE: ASHRAE HANDBOOK—FUNDAMENTALS

TABLE 2.
TYPICAL R-VALUES OF BRICK WALLS

WALL ASSEMBLY	R-VALUE
14-inch brick + lightweight CMU cavity wall with 4-inch air space and 2-inch XPS insulation	14.5
16-inch brick + lightweight CMU with 4-inch air space and 2-inch polyiso insulation	19.3
14-inch brick + lightweight CMU with 4-inch air 3-inch XPS insulation	19.5
16-inch brick + lightweight CMU with 4-inch air space and space and 3-inch polyiso insulation	26.3

SOURCE: BRICK INDUSTRY ASSOCIATION TECHNICAL NOTES ON BRICK CONSTRUCTION

IN WALL ASSEMBLIES, THERE'S MORE TO ENERGY EFFICIENCY THAN R-VALUE

There are three ways that heat (energy) is "transferred" in a building: by *conduction*—heat flow through materials; by *convection*—heat flow through air currents; and by *radiation*—heat flow from materials.

Heat transfer in the building envelope is affected by many factors, notably the amount of insulation, the size of the glazing area, the mass and thickness of the walls, and the thermal resistance of wall materials. Heat transmission can be controlled through such strategies as solar controls (e.g., sunshades) to reduce heat gain (due to radiation), insulation to reduce heat gain from conduction, and air barriers to reduce air infiltration. You should consider all three in combination and not rely on just one strategy.

The commonly used metric for *thermal resistance*—the ability of a material to prevent heat transfer—is *R-value*, measured in units of (hr °F sf)/Btu. The term R-value is used all the time to provide a simple way to evaluate thermal performance of a material, but it is a static measurement that looks at a single moment in time or one part of a day. To understand how heat transfer in a building really works, we need a way to look at it over a longer time frame.

To get a more complete perspective on the energy efficiency of a wall system, we have to look at the rate of heat flow through all the materials in that wall, per unit of temperature difference between the outside and inside air. This overall coefficient of heat transmission is the *U-value*, expressed in Btu/(hr °F sf). U-value is calculated by determining the thermal resistance (R-value) of each component of the wall assembly, adding them up, and taking their reciprocal:

$$U = 1/(R1 + R2 + R3 \ldots)$$

To achieve energy efficiency in a wall assembly, the R-values should be as high as possible and the U-values as low as possible. But R-value of a material is not always a predictor of total energy efficiency.

In Figure 1, the various forms of insulation have relatively high R-values, ranging from 5.0 to 6.8, as you'd expect. Brick is near the bottom, at 0.44, while a typical concrete masonry unit (CMU) comes in at 1.11 and a lightweight CMU at 2.0. The logical assumption would be that a wall constructed of brick and masonry would not be very energy efficient. But that does not take into account how a typical brick and masonry wall actually performs.

Figure 2 shows what can be achieved with brick and masonry separated by an air space containing insulation. Properly detailed, such wall assemblies can achieve R-values ranging from a low of 14.5 to as high as 26.3. (By the way, it's possible, although not necessarily recommended, to achieve R-40 by using four-inch brick veneer and 2x6 wood stud wall incorporating advanced framing techniques with batt insulation, half-inch OSB at the corners, and two layers of two-inch-thick polyiso insulation. Welcome back, super-insulated structures of the 1970s!)

In sum, **you have to consider the effectiveness of the entire wall system, not just the R-value of its individual parts.** Seen in this light, brick and masonry can become important components of a highly efficient and durable wall assembly.

Caution: The International Building Code—and, by reference, the TMS 402 "Building Code Requirements for Masonry Structures"—requires that, if the space between the brick veneer and its backing is greater than 4½ inches, you have to make sure the wall ties can withstand greater forces due to the greater distance. Some wall ties can span a distance of five or six inches before you would need to use thicker wire ties or increase their spacing, but anything over 4½ inches has to be analyzed by an engineer. Also note that the Brick Industry Association recommends a one- to two-inch air space between the insulation and the brick veneer, to allow for proper air flow and moisture drainage, which therefore limits the thickness of the insulation you can use.

VALUE ADDED FROM THERMAL MASS

Thermal mass is another crucial factor in the design and construction of an energy-efficient wall assembly. Thermal mass is often ignored when the discussion revolves around R-value only. Thermal mass affects the total heat loss or gain through a material, but doesn't fit neatly into an R-value equation.

Materials like masonry and brick with high thermal mass (i.e., high heat capacity) exhibit *"thermal lag"*—they take longer to transmit heat and cold through the wall than other materials, such as metal or glass. Thermal lag has a small dampening effect on indoor temperature, but it is the process of the heat slowly working its way through the wall and shifting the peak temperature that is the real benefit. Thermal lag helps to even out indoor temperature swings due to the slow release of heat.

That's why an ancient building with three-foot-thick masonry walls feels so cool on the interior on a hot summer day: the mass of the masonry absorbs heat, stores it, and slowly releases it into the interior. Similarly, today's masonry wall systems slow the rate of heat transmission during the day and radiate stored heat to the interior at night.

For these reasons, using steady-state calculations (such as those used to determine R-value) to measure the heat flow through masonry walls may overstate the case by as much as 60%, depending on the climate in which the project is located and where the insulation is located in relation to the mass.

A couple of points to keep in mind: First, *climate matters.* Using thermal mass to optimize the energy efficiency of your building envelope works best in climates that experience frequent and high diurnal (day/night) temperature swings. Over time, the heat transmission rate changes with variations in temperature, but thermal mass moderates

these temperature changes, especially when there are wider temperature swings over a 24-hour period.

That's why the pueblos, with their massively thick adobe walls, were so effective in moderating the intense heat of the desert day and the chilling cold of the desert night.

Second, *thermal mass must be properly detailed.* In the case of a brick cavity wall, the mass—predominantly the CMU—must be closer to the building occupants; in other words, it must be toward the interior. The recommended assembly, exterior to interior, would therefore be: brick veneer, air space, insulation, CMU. Therefore, insulation on the inside face of the wall would defeat the purpose of thermal mass.

How do you know you have an effective mass wall? The industry standard is a wall with a heat capacity greater than 7 Btu/sf °F, or if the density is less than 120 lb/cubic foot, then the heat capacity must be greater than 5 Btu/sf °F, —in other words, lightweight concrete.

Table 3 shows the heat capacity values for various types of brick walls. At 12.1 Btu/sf °F, brick veneer with CMU has the highest heat capacity by far. There can be as much as a 40% difference in the U-value requirement between a mass wall and a non-mass wall. Just using R-value won't tell you that, because R-value does not take into account the benefit of thermal mass, nor does it factor in the negative effect of thermal bridging. Building codes take thermal mass into account by actually requiring less insulation in a mass wall system to meet the insulation requirements. Besides the potential cost savings, the temperature through the wall is moderated over time, thereby making it easier to obtain thermal comfort for the building's occupants.

TABLE 3.
HEAT CAPACITY VALUES FOR BRICK WALLS

WALL ASSEMBLY	BTU/SF °F
3 5/8-inch brick	5.9
5 5/8-inch hollow brick	7.3
Brick veneer/WS wall	7.4
Brick veneer/CMU wall	12.1

SOURCE: ASHRAE HANDBOOK—FUNDAMENTALS

ADDING BRICK AND MASONRY TO YOUR PASSIVE SOLAR STRATEGIES TOOLKIT

Another consideration on the road to a net-zero energy building is the use of *passive solar strategies* to achieve energy efficiency. Passive solar uses all heat transfer mechanisms—radiation, conduction, and convection—within the building structure as a way to naturally heat and cool a building.

Such strategies usually call for an east-west elongated floor plan, a highly efficient glazed south wall, overhangs or exterior shelves to block out summer heat, and thermal storage media (such as brick and masonry) exposed to the radiation penetrating the south-facing wall.

The size and configuration of such a passive solar system will depend on a number of factors: the climate zone, the latitude of the building, its orientation, the topography of the site (hills, trees, depressions that could block the sun), the type of building, and its intended use.

There are two basic types of passive solar strategies: direct gain systems and thermal storage wall systems.

Direct gain systems use south-facing windows to allow sunlight to penetrate through to the interior, where brick floors and walls store the sun's heat during the day and release it gradually.

Thermal storage wall systems allow heat from sunlight to absorb into interior brick walls acting as collection devices and slowly allow the penetrating heat to warm the interior. Thermal storage walls exhibit less temperature fluctuation than direct gain systems due to the slow transmission of heat through the thermal mass. Their performance can be enhanced by providing vents to induce convection, although the vents should be closed at night to prevent heat loss.

It is also possible to combine direct gain and thermal storage wall systems to achieve higher temperatures than either system alone can provide, while reducing the temperature fluctuations that can occur in direct gain systems. Properly detailed, a *combined system* can provide optimal occupant comfort and thermal performance, while saving energy.

Other passive techniques should also be considered to reduce the energy consumption within a building. *Passive cooling* is a technique that had been used for centuries, until the advent of mechanical air-conditioning systems in the early 20th century.

Two brick buildings in the U.K. that use passive cooling—Lanchester Library, Coventry University, and the Contact Theatre, both designed by Short & Associates—use thermal mass and passive cooling techniques to reduce the energy needed to run HVAC equipment.

According to researchers at the Institute of Energy and Sustainable Development at Leicester's De Montford University, the Coventry Library uses 51% less energy than the typical air-conditioned building, which shows that it is possible to get quite far along toward net-zero energy with the use of passive techniques.

Building Teams should consider the use of passive techniques like proper building orientation first, but insulation must also be brought into the mix in order to achieve net-zero energy use. In general terms, **it's usually advisable to use as much insulation as is physically and economically feasible.**

Choosing the right insulation for the specific project requires good judgment and careful attention to detail. Here are the usual suspects, ranked by R-value/inch of thickness. Each must be evaluated not just on R-value, but on numerous other factors as well, such as cost, ease of installation, moisture resistance, and fire performance:

R-VALUE PER INCH BY INSULATION TYPE

Polyisocyanurate	6.8	Expanded polystyrene	4.0
Spray foam	6.7	Icynene	3.6
Extruded polystyrene	5.0	Mineral wool	3.3

SOURCE: ASHRAE HANDBOOK—FUNDAMENTALS

AIR BARRIERS: ESSENTIAL COMPONENTS OF BRICK MASONRY WALLS

For NZE buildings, the use of an air barrier is a crucial piece of the brick/masonry wall puzzle. Properly specified, detailed, and installed, *air barriers provide numerous attributes to the wall system:* continuous coverage, bridging capability, security, and durability. They are impermeable, thereby preventing air (which often contains moisture) from flowing into or out of the building.

Most commercially available air barrier products can be used within

a masonry wall. Based on my experience in the field, liquid-applied or spray-applied materials work the best since they seal around the numerous wall ties used to tie the brick to the backing. Almost all the architects I come into contact with have been using air barriers and are getting good results.

You must, however, use an air barrier that prevents air leakage, and its installation should be verified after construction. Use a blower door test or other appropriate test to verify the air barrier's performance. The Air Barrier Association of America (www.airbarrier.org) recommends the following:

- The air barrier material should not exceed 0.004 cfm/cf for a pressure difference equivalent to a 25 mph wind.
- The air barrier assembly should not exceed 0.04 cfm/cf for a pressure difference equivalent to a 25 mph wind.
- Testing should be done in accordance with ASTM E2178 (for materials) or ASTM E2357 (for air barrier assemblies).

STOP THERMAL BRIDGING BEFORE IT STARTS

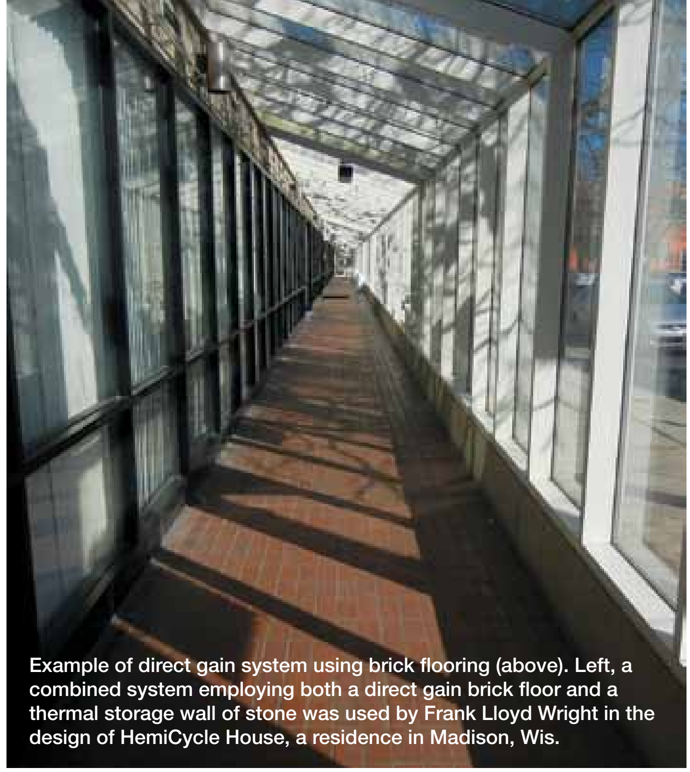
To have any chance of achieving net-zero energy use in your building, you have to eliminate *thermal bridging*—the transfer of heat (energy) across elements in a wall system—or at the very least reduce it as much as possible. These thermal breaks may seem minor, but they can add up and destroy or severely degrade the thermal performance of your wall system.

Thermal bridges often occur at transition points in a wall assembly, such as at windows or other openings, but they can be anywhere in the wall system.

Steel studs are often overlooked as a source of thermal bridging. Steel is a highly efficient conductor of energy, and the thermal bridges caused by the steel studs in a brick veneer steel stud wall can reduce the effective R-value of an R-19 batt to as little as R-7. Using continuous rigid insulation outside of the studs can eliminate this particular thermal bridge.

Steel shelf angles in masonry walls are another element that can act as a thermal bridge. To minimize this problem, clip angles can be used to anchor the shelf angle to the structure. Clip angles will reduce the contact area, thus minimizing the thermal bridge and allowing you to place insulation between the steel angle and the structural frame. This detail may allow you to use smaller, less costly shelf angles, thereby recovering some or all of the additional cost of the clip angles. Various steel fixing manufacturers now have these elements available.

Another potential source of thermal bridging is **slab edge construction,** which is popular in some parts of the country, notably New York City. A great deal of energy can be lost through this detail. This is also true of slab edges that are exposed behind a brick wall. In my professional opinion, slab edge details should not be used, especially in a wall system designed for use in a net-zero energy building.



Example of direct gain system using brick flooring (above). Left, a combined system employing both a direct gain brick floor and a thermal storage wall of stone was used by Frank Lloyd Wright in the design of HemiCycle House, a residence in Madison, Wis.

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Thermal bridging can also occur in areas that were intended to have insulation, but where the thermal barrier was broken during construction due to improper installation. Visual inspection during construction (or infrared thermography after the job is completed) can be used to reveal such breaks, which may be able to be reinsulated. Obviously, it is much better to avoid such problems in the first place.

How, then, do you get to net-zero energy buildings with brick masonry?

First, get to the highest level of energy efficiency you can, preferably in the 65-70% range, by following these guidelines:

- Start with passive techniques: building orientation, daylighting, thermal mass, etc.
- Insulate, insulate, insulate—with the understanding that there is a point of diminishing returns on how much insulation you can use, based on cost, physical barriers, etc.
- Use air barriers to control air/moisture infiltration.
- Eliminate—or at least minimize—thermal bridges.

Only then should you consider applying active photovoltaics, wind turbines, or other energy-producing sources to reach net-zero energy use in your project.+

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> EDITOR'S NOTE

This completes the reading for this course!
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