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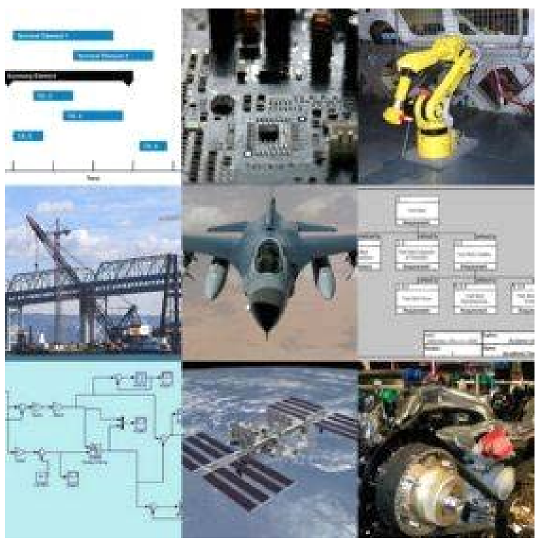

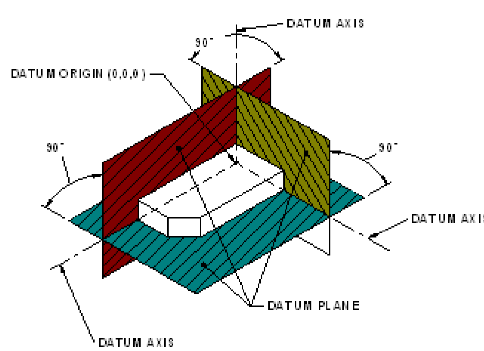

PDH Storm, by Engineers Edge, LLC

Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

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Transpired Collectors (Solar Preheaters for Outdoor Ventilation Air)

Simple, reliable technology can substantially reduce heating bills.

The President's Million Solar Roofs Initiative aims to install 1 million solar energy systems on residential, commercial, and public-sector buildings by 2010. Twenty thousand of those systems will be installed on Federal buildings. In support of the Initiative, and as part of a continual effort to ensure U.S. buildings are energy efficient and environmentally sustainable, the U.S. Department of Energy's Federal Energy Management Program (FEMP) will help install those solar systems targeted for the Federal sector.

FEMP is focusing on solar systems that include photovoltaics (PV), solar hot water for buildings and swimming pools, and solar space heating. Transpired solar collectors are a solar space-heating technology that is well proven, is readily available, and has considerable potential for application at Federal facilities. Transpired collectors use solar energy to preheat ventilation (outdoor) air as it is drawn into a building. The technology is ideally suited to building applications in which large volumes of space are heated or where high ventilation rates are required. By preheating ventilation air with solar energy, the technology removes a substantial load from a building's conventional heating system, saving energy and money. This *Federal Technology Alert* (FTA) is designed to give Federal facility managers the information they need to decide whether transpired collector technology is suitable for their facility.

Energy-Saving Mechanism

A transpired collector reduces the load on a building's heating system by heating intake air with solar energy. It preheats the ambient air by up to 40°F, reducing all or a portion of the load on a heating system during daylight hours. Although the transpired collector may not be able to achieve the required indoor air temperature on cloudy days or when the outside temperature plummets, it provides useful energy and reduces utility bills.

In addition to meeting a portion of a building's heating load with clean, free solar energy, the transpired collector helps

Keith Gawlik, NRE/PIX04118

save energy and money in other ways. It recaptures heat loss through a building's south-facing wall; heat that escapes through the south wall is captured in the air space between the structural wall and the transpired collector and returned to the interior. Also, by introducing make-up air through ceiling-mounted ducts, the system eliminates the wasteful air stratification that often plagues high-ceiling buildings.

Technology Selection

The FTA series targets technologies that appear to have significant untapped Federal-sector potential and for which some Federal installation experience exists. The new technologies presented in the series were identified through trade journals and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites, and other interested parties. Based on these responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data and experience exist.

Transpired collectors are one of many energy-saving technologies to emerge in the last 20 years. They were judged to be life-cycle cost effective (at one or more Federal sites) in terms of installation cost, net present value, and energy savings. Several other proven technologies have been slated for further study through the *Federal Technology Alert* series.

Application

Any heated building in a cool, sunny climate that has at least moderate ventilation requirements and southern exposure could benefit from a transpired collector. Buildings that require large volumes of heated make-up air such as machine shops, vehicle maintenance buildings, and chemical storage facilities, are good candidates for a transpired collector. A long-term storage warehouse that does not require ventilation, would not be a suitable candidate. Also, buildings that have 100% recirculation/filtration systems would be unsuitable.

Heat recovery systems, which are common in many modern office buildings (but less common in industrial buildings), also preheat ventilation air. As such—because of redundancy of function—buildings with existing heat recovery systems may not be suitable for transpired collector applications.

Field Experience

As of 1997, approximately 40 transpired collector systems have been installed in the private sector and on two Federal sites—two systems at Fort Carson, Colorado, and one at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. Three of the 40 installations—the General Motors (GM) of Canada Oshawa Battery Plant, the Ford Plant in Oakville, Canada, and NREL—have been monitored extensively.

The installation at NREL is an ideal application of transpired collector technology. The facility is a 1300-square-foot (ft^2) chemical waste storage building that requires a ventilation rate of 3000 cfm to maintain safe indoor conditions. Also, because of the danger of combustion, open flames are prohibited in the building, so outside air is heated with electricity instead of gas. The 300-ft^2 transpired collector saves about 14,310 kWh annually (25.7% of the energy required to heat the facility's ventilation air). With a local electric rate of $0.025/kWh, the annual savings equates to about $360. The installation has a simple payback of 4.7 years.

Case Study

The GM Battery Plant in Oshawa, Canada, is a 100,000-ft^2 facility in which automotive batteries are manufactured. The plant was built in the 1970s and consists of an open shop floor and a 28-foot-high ceiling. GM operates two full-time production shifts within the plant and conducts maintenance activities at night and on weekends, so the building is continuously occupied. In 1991, plant management opted to install a transpired collector to correct the ventilation problems.

The monitoring program showed that the transpired collector saved GM 208,000 Btu per year for every square foot of installed solar collector. The majority of this savings—or 150,000 Btu/ft^2/year—resulted from the thermal energy gained directly by the outside air as it passed through the collector. The balance of the savings—or 58,000 Btu /ft^2/ year—came from recaptured heat loss through the wall clad with the transpired collector. The value of these savings depends on the heating source assumed to be displaced.

At the GM plant, steam was the existing primary heating source, but the system was incapable of providing the necessary quantities of heated outdoor air for ventilation. To redress the airflow problems with a steam option would have required the installation of a packaged rooftop steam-operated system with roof curb, steam piping, and outlet ducting. These systems are installed for about $2.16/cfm. To supply the same volume of air that the transpired collector supplies, the steam system would have to deliver 25,200 cfm and would cost $55,000. Also, the fan on the steam system would require an additional 3.6 kW to operate (compared to the transpired collector system), which would increase electricity costs by $1,430 annually.

Implementation Barriers

The biggest hurdle transpired collectors must overcome is user acceptance. Many solar technologies have been stigmatized by the rapid expansion of solar markets in the 1970s, when many poorly designed and poorly performing systems were deployed. Many potential users are reluctant to commit to a solar technology if a proven conventional option is available. Transpired collector technology has been proven to be a valid, reliable technology for reducing energy use and saving money, and the body of scientific data proving its effectiveness continues to grow.

Federal Technology Alert

Transpired Collectors (Solar Preheater for Outdoor Ventilation Air)

Simple, reliable technology can substantially reduce heating bills.

Abstract

Transpired collectors are a renewable energy technology that is well proven, is readily available, and has considerable potential for application at Federal facilities. Transpired collectors use solar energy to preheat ventilation (outdoor) air as it is drawn into a building. The technology is ideally suited for buildings with at least moderate ventilation requirements in sunny locations with long heating seasons.

Transpired collector technology is remarkably simple. A dark, perforated metal wall is installed on the south-facing side of a building, creating approximately a 6-inch (15-cm) gap between it and the building's structural wall. The dark-colored wall acts as a large solar collector that converts solar radiation to heat. Fans mounted at the top of the wall pull outside air through the transpired collector's perforations, and the thermal energy collected by the wall is transferred to the air passing through the holes. The fans then distribute the heated air into the building through ducts mounted near the ceiling. By preheating ventilation air with solar energy, the technology removes a substantial load from a building's conventional heating system, saving energy and money.

This *Federal Technology Alert* (FTA) of the New Technology Demonstration Program is designed to give Federal facility managers the information they need to decide whether they should pursue transpired collector technology for their facility.

This FTA describes the transpired collector, its energy-saving mechanisms, and the factors that influence its performance. Worksheets are included that let the reader perform the preliminary calculations to determine if a given facility is suitable for a transpired collector system and to determine the amount of energy such a system would save annually. The FTA contains a case study documenting the performance of the transpired collector installed at General Motors' battery plant in Oshawa, Canada. The document concludes with contacts for additional information and a list of articles, conference papers, and academic theses pertaining to the technology.

Warren Gretz, NREL/PIX04257

Figure 1. A transpired collector heating system being installed on a Federal Express facility in Littleton, Colorado.

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About the Technology

Transpired collectors use solar energy to preheat ventilation (outdoor) air as it is drawn into a building. The technology is ideally suited for buildings with at least moderate ventilation requirements in sunny locations with long heating seasons.

Transpired collector technology is remarkably simple. A dark, perforated metal wall is installed on the south-facing side of a building, creating approximately a 6-inch (15-cm) gap between it and the building's structural wall (see Figure 2). The dark-colored wall acts as a large solar collector that converts solar radiation to heat. Fans associated with the building's ventilation system mounted at the top of the wall draw outside air through the transpired collector's perforations, and the thermal energy collected by the wall is transferred to the air passing through the holes. The fans then distribute the heated air into the building through ducts mounted from the ceiling. By preheating outdoor air with solar energy, the technology removes a substantial load from a building's conventional heating system, saving energy and money.

A transpired collector is installed on all or part of a building's south-facing wall, where it will receive the maximum exposure to direct sunlight during the fall, winter, and spring. The size of the wall varies depending on heating and airflow requirements and climate, but in many applications, the transpired collector will cover the maximum south-facing area available. The amount of energy and money saved by a transpired collector depends on the type of conventional fuel being displaced, occupant use patterns, building design, length of heating season, and the availability of sunlight during the heating season. In general, each square foot of transpired collector will raise the temperature of 4 cubic feet per minute (cfm) by as much as 40°F, delivering as much as 240,000 Btu annually per square foot of installed collector.

In addition to the metal sheeting that captures solar energy, the transpired collector heating system includes air-handling and control components that supply the solar-heated air (see Figure 2). The ventilation system, which operates independently of a building's existing heating system, includes a constant-speed fan to draw air through the transpired collector and into the distribution duct. Engineers typically use a 3-horsepower, 32-inch blade fan with about 10,000-cfm capacity.

As shown in Figures 3 and 4, the transpired collector system also contains a bypass damper located directly in front of the fan inlet duct. During the summer months when ventilation air does not need to be heated, this damper opens, circumventing the air-heating system. The bypass damper automatically opens when the air outside reaches a predetermined temperature, usually about 64°F.

Conserval Systems, Inc., of Toronto, Ontario, and Buffalo, New York, is currently the only supplier of the technology. Conserval has been manufacturing and installing a range of heat recovery and solar products since 1977. They received the first patent for transpired collector technology in 1989.

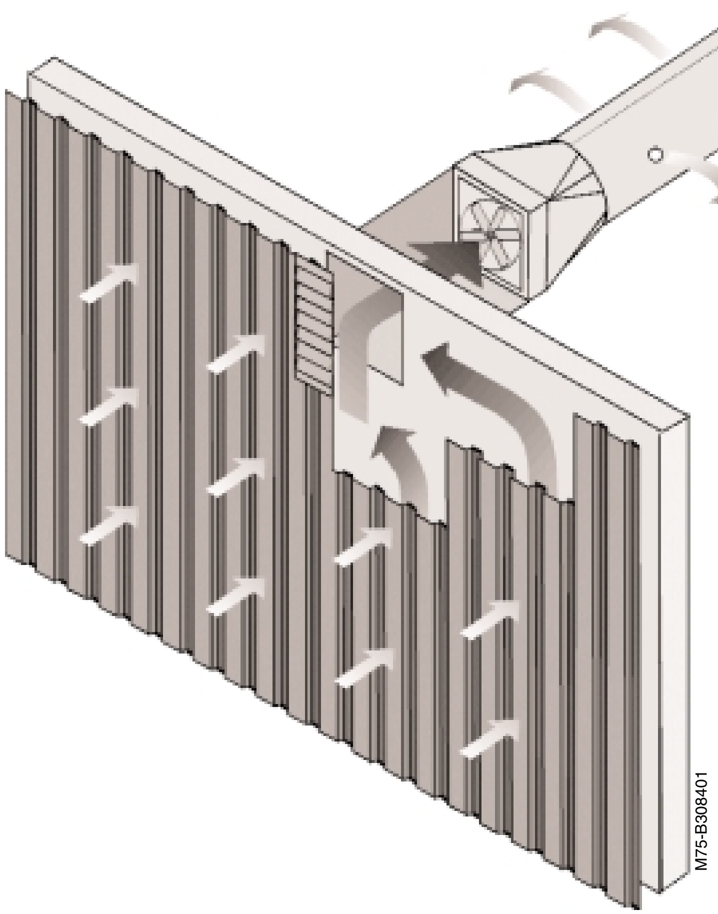


Figure 2. Transpired collector components.

Application Domain

As of 1997, about 40 transpired collector air-heating systems had been installed in locations around the world on apartment buildings, warehouses, airplane hangars, factories, and in many other applications. Three transpired collector systems are in

A Wall by any Other Name...

The solar ventilation air-heating technology described in this *Federal Technology Alert* has been referred to by a variety of different names since it was first marketed in 1989. Conserval Engineering Inc., the company that holds the patent rights, refers to it as a "Solarwall®" heater. The research community, which has studied the technology in depth, refers to it as an "unglazed transpired solar collector" or "solar air-heating systems using perforated absorbers." In other literature it has been called "solar ventilation preheat system" or simply "transpired collectors."

In this document, we use the term "transpired collector" to refer to the technology described. The reader seeking additional information (see the "Literature" section on page 15) should not be confused by the different names by which the technology is presented in the scientific and popular literature.

use in the Federal sector—two at Fort Carson, Colorado, and another at the Waste Handling Facility at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. High-profile industrial users include Ford Motor Company, General Motors Corporation (GM), McDonnell Douglas, and Federal Express.

The Federal-sector potential for this technology is considerable. Any heated building in a cool, sunny climate that has at least moderate ventilation requirements could benefit from a transpired collector. Buildings that require large volumes of heated make-up air, such as machine shops, vehicle maintenance buildings, and chemical storage facilities are good candidates. There are thousands of such facilities in the Federal sector.

Energy-Saving Mechanism

A transpired collector reduces the load on a building's heating system by heating intake air with solar energy. It preheats the ambient air by up to 40°F, reducing all or a portion of the load on a heating system during daylight hours. Although the transpired collector itself may not be able to achieve the required indoor air temperature on cloudy days or when the outside temperature plummets, it still provides useful energy and reduces utility bills.

The dark-colored transpired collector is a large solar collector, absorbing the solar energy striking it. The wall captures between 60% and 75% of the available solar energy, making it one of the most efficient solar collectors designed to date. In addition to capturing direct solar radiation, the transpired collector collects the indirect, scattered, and reflected sunlight known as diffuse solar radiation. Typically, diffuse solar radiation, which includes a portion of the radiation on clear days and all the radiation on overcast days, makes up about 25% of the total annual radiation at the Earth's surface.

The dark, corrugated metal sheets that make up the wall are 0.8-millimeter (mm)-thick and are typically manufactured from aluminum or galvinized steel. The perforations through which the air flows are 1.6 mm in diameter and are placed at regular intervals. The total percentage of the collector made up of these holes is referred to as the collector porosity.

In addition to meeting a portion of a building's heating load with clean, free solar energy, the transpired collector helps save energy and money in other ways. The collector recaptures heat loss through a building's south-facing wall; heat that escapes through the south wall is captured in the air space between the structural wall and the transpired collector and returned to the interior. Also, by introducing make-up air through ceiling-mounted ducts, the system eliminates the wasteful air stratification that often plagues high-ceiling buildings.

Other Benefits

The solar energy collected by a transpired collector displaces fossil fuel that would otherwise be burned to produce heated ventilation air. Greenhouse gas (CO_2) and acid rain emissions (SO_x and NO_x) are reduced proportionally. Electricity is consumed, though, by the distribution fans and dampers.

The transpired collector can also improve a building's appearance, giving the south-facing side a neat, clean, uniform look. Although initially many black transpired collectors were installed, other colors work well too, which gives the user some aesthetic options. The product is now available in a variety of shades, including brown, blue, gray, and red.

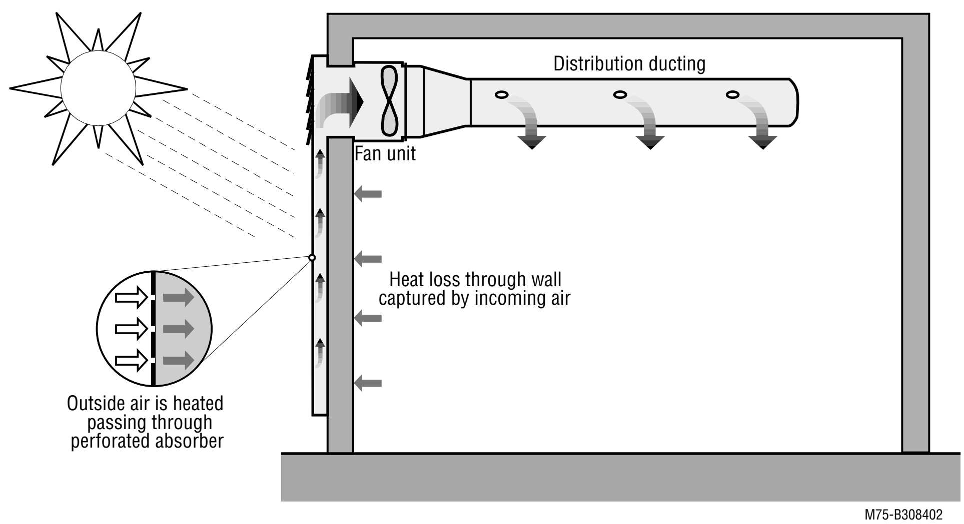


Figure 3. Transpired collector operation during the winter months.

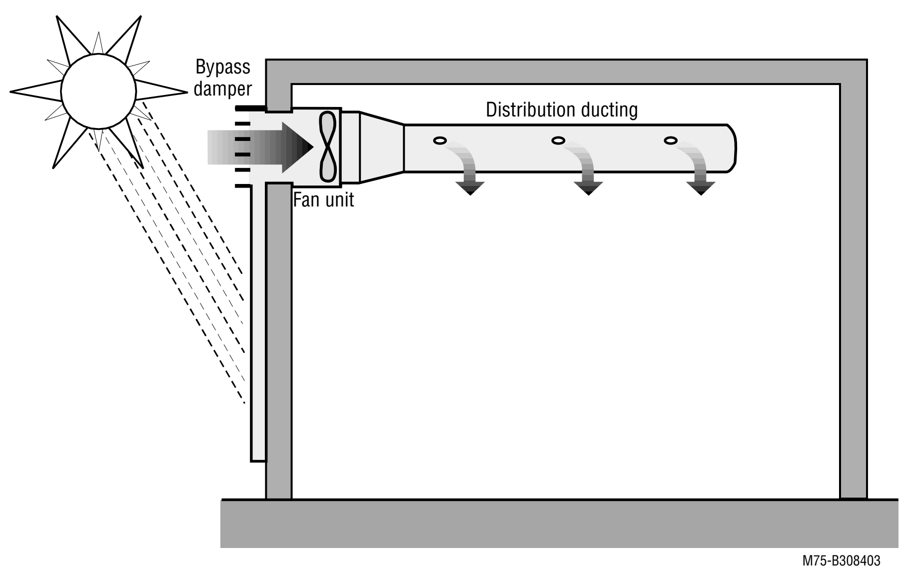


Figure 4. Transpired collector operation during the summer months.

Installation

The transpired collector attaches to a building's existing structure. The building frame is usually sufficient to support the collector sheeting, so racking requirements and construction costs are minimized. Although many transpired collectors have been installed as retrofits, the system economics improve if installation takes place during initial construction or building renovation. The system payback period can be reduced by up to half if the transpired collector installation can be incorporated with other construction work.

The transpired collector is attached to the structural wall with a support grid of vertical and horizontal Z-channels. These channels are perforated to accommodate airflow between the collector and the structural wall. The vertical channels are attached to the existing wall, the horizontal channels are attached to the vertical channels, and the perforated metal sheets are affixed to the horizontal channels.

The fan unit, which includes the fan, dampers, and thermostat controls, is mounted directly to the interior side of the south-facing wall. For each fan unit installed, a hole must be cut through the structural wall to allow air to flow into the building. A minimal amount of sheet-metal ducting is required to form a proper seal between the fan and the wall.

Installation time varies depending on a building's structural design and the total collector area being installed, but retrofit installations typically require 10 to 14 days.

Building codes and regulations pertaining to issues such as the location of outdoor air openings, weather protection for ducts on the building exterior, minimum duct thickness, and criteria for multistory applications should be addressed on an installation-by-installation basis. The applicability of codes may vary based on building height and area, construction type, and use group.

Federal-Sector Potential

The potential savings to be achieved by use of this new technology were estimated as part of the technology-screening process of the New Technology Demonstration Program.

Technology-Screening Process

The new technologies presented in the *Federal Technology Alert* series were identified through trade journals and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites, and other interested parties. Based on these responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data and experience exist. Transpired collectors were judged to be life-cycle cost effective (at one or more Federal sites) in terms of installation cost, net present value, and energy savings. Several other proven technologies have been slated for further study through *Federal Technology Alerts*.

Estimated Savings and Market Potential

Figure 5 shows the average payback periods for transpired collector systems in three different geographic locations based on three different prices for natural gas. The data were derived from analyses conducted by Science Applications International Corporation (SAIC), which, in conjunction with the International Energy Agency, has developed a spreadsheet model to estimate economics of transpired collectors in different climates. The model outputs simple payback periods, taking into account the cost of auxiliary heating fuel, the cost of electricity to operate the fan, the geographic location, and the building type.

SAIC has used this model to compare paybacks at three locations—with greatly differing climates—in the United States: Denver, Colorado; Washington, D.C.; and Syracuse, New York. The model produced payback comparisons for a range of energy costs, from $3/MBtu for natural gas to $24/MBtu for electricity ($0.08/kilowatt-hour [kWh]). These paybacks assume the collector was installed during building construction and assume a net installed cost of $5/ft^2 (see discussion of costs on page 7). Payback periods for retrofit installations—which would have a net cost of approximately $10/ft^2 —would be twice those for new installations.

Laboratory Perspective

Researchers at NREL in Golden, Colorado, have been studying transpired collector technology since 1989. In fact, researchers at NREL and engineers at Conserval simultaneously—and independently—developed the concept of using unglazed, perforated metal sheets as solar collectors for heating air. Since that time, researchers have improved the efficiency of the technology and gained a fundamental understanding of its heat transfer and airflow characteristics. The technology has been the subject of a number of dissertations conducted at universities in the United States and Canada. These investigations and other relevant publications are cited in the Literature section on page 15.

The research community has monitored and continues to monitor a number of the transpired collectors in use in both the Federal and private sectors. These monitoring programs have demonstrated that transpired collector technology is a reliable and effective way to save energy. They have also demonstrated that the current methods used to estimate the performance of the technology are valid.

Application

This section addresses technical aspects of applying transpired collector technology. The range of applications and climates in which transpired collector technology can best be applied are addressed. Design and integration considerations are discussed, including equipment and installation costs, installation details, maintenance, and codes and standards.

Application Considerations

The following subsections briefly discuss the prerequisites for a successful transpired collector application and the factors that influence project cost-effectiveness.

Application Prerequisites

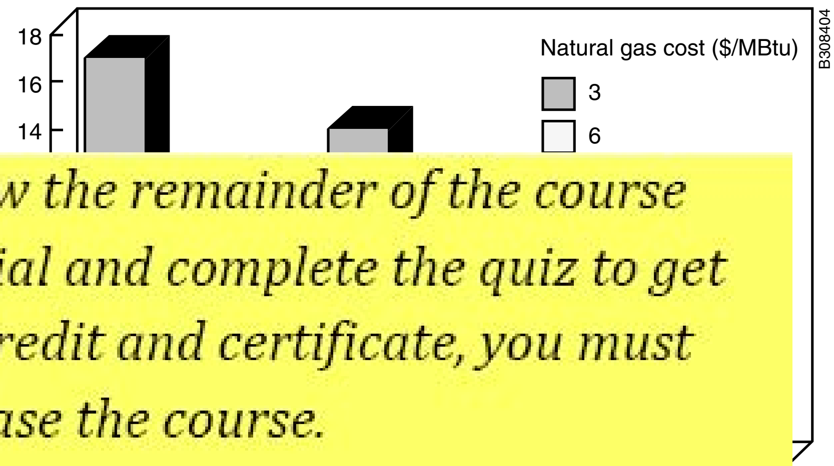
- **Suitable South-Facing Wall**—A sufficient area of suitable south-facing exterior wall is required for installing the transpired collector's metal cladding. A wall with a high percentage of window or door area will likely be unsuitable, as will a wall that is heavily shaded throughout the day. A facade does not have to face true south for a transpired collector to operate effectively. Any wall within 45 degrees of true south will work, but the best performance is realized when the wall is within 20 degrees of true south.

- **Ventilation Load—**A candidate building for a transpired collector must hav minimum ventilation requirement. long-term storage warehouse, for ple, would not be a suitable applic because such a structure would nc to be ventilated. Also, buildings th 100% recirculation/filtration syste would be unsuitable. The Project section, below, discusses the influ of ventilation loads on the cost-effectiveness of an application.
- **The Absence of a Heat Recovery System—**Heat recovery systems, are common in many modern offic buildings (but less common in ind buildings), also preheat ventilatior Because of redundancy of functio buildings with existing heat recov tems may not be suitable for trans collector applications.

Cost-Effectiveness Factors

The following paragraphs present major factors influencing the cost-effectiveness of transpired collector a cations. The worksheets presented in Sizing and Energy-Savings Calculatio section (pages 9–11) provide quantita estimates of energy savings.

- **The Cost of Conventional Energ** The cost of the conventional energ for space heating has a dramatic i on the overall cost-effectiveness o transpired collector application. W kind of energy is being displaced thermal energy supplied by the tra collector and how much does that ventional energy cost? The price c ventional energy (that is, electricity, fossil fuels, or steam) can vary greatly from season to season and from region to region. The higher the price of the conventional energy used for space heating, the more cost effective the transpired collector application becomes.
- **Climate—**Transpired collectors are most cost effective in sunny climates with long heating seasons.
- **Project Scale—**Although transpired collectors have been installed on many large industrial buildings, they can also be cost effectively applied to smaller structures. A key to a successful application is the building's ventilation rate. For example, a



- Manufacturing plants
- Vehicle maintenance facilities
- Hazardous waste storage buildings
- Gymnasiums
- Airplane hangars
- Schools
- Warehouses requiring ventilation

What to Avoid

The following is a list of general applications and conditions that preclude the cost-effective use of transpired collector technology:

- Outdoor air not required

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eliable. than the h would There are g, or overheating, and to date, no problems have been reported from users in the field regarding holes becoming plugged or degradation of the absorber surface. Even if the collector becomes dented, performance is not affected.

Equipment Warranties

The fan is covered by a 1-year manufacturer's warranty, and the color coatings used on the collector sheeting are warranteed for 20 years.