

## INTRODUCTION{ TC "INTRODUCTION" \1 1 }

Renewable energy technologies must do more than be environmentally friendly to be successful; they must also be economically feasible. A failure to meet this second requirement is the reason that many renewable energy applications have not gained more widespread acceptance. In the past few years, unglazed transpired collectors (UTCs) have emerged as a new solar air heating technology. UTC systems have achieved higher efficiencies at lower initial costs than previous solar air heaters. Furthermore, they have been found to be cost effective in a number of specific applications. The objective of this thesis is to determine what the potential economic impact of UTC systems is on a statewide basis.

### **1.1 Unglazed Transpired Collectors{ TC "1.1 Unglazed Transpired Collectors" \1 2 }**

Unglazed transpired collectors consist of a perforated, solar-absorbing plate mounted on a large south-facing wall [Kutscher, 1992]. Air is drawn into the plenum through the holes in the plate, up the plenum, and finally into the building, as shown in Figure 1.1.1. A canopy can be placed at the top of the collector to act as a header for improved flow uniformity along the collector length. This canopy is simply the collector plate with a deeper plenum near the top. The canopy typically has a lower porosity than the rest of the collector plate. When the ambient air temperature exceeds the summer bypass set temperature, the bypass damper opens, letting air directly into the building at ambient temperature and sealing off the entire collector to prevent hot air from entering the building. The outlet air from the collector is mixed with recirculated air from

the building before it is supplied to the building.

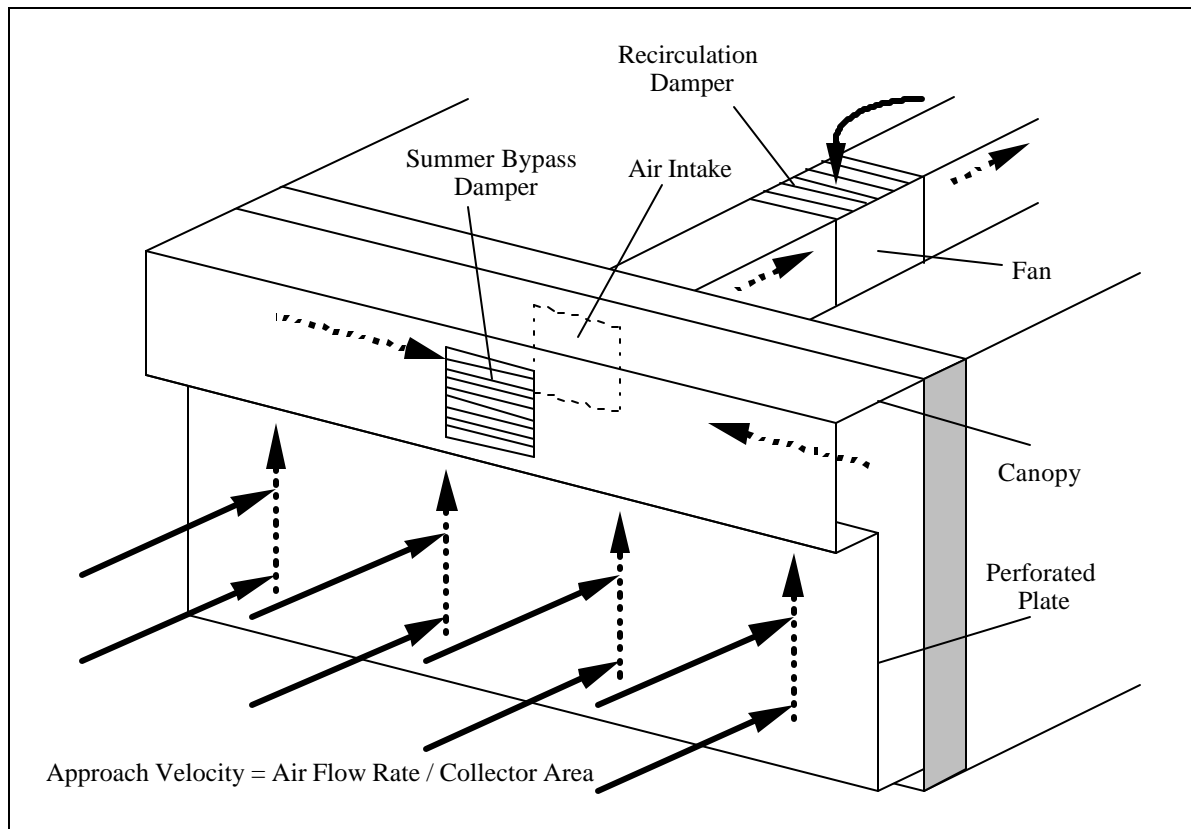


Figure 1.1.1. Perspective view of an unglazed transpired collector system. { TC "Figure 1.1.1. Perspective view of an unglazed transpired collector system." \l 5 }

Unlike most solar air heaters, UTCs are not covered by a glazing, which significantly reduces the first cost. Since they are not glazed, they cannot be used to heat recirculated building air, only fresh air. The lack of a glazing eliminates the reflection losses associated with glazings, but could potentially increase the convection losses. However, natural convection losses are negligible as long as the approach velocity (volumetric flow rate per unit collector area) is above a minimum (only 0.02 m/s) [Kutscher, 1992]. And for large collector areas, the forced convection losses due to wind off the edges of the collector are also negligible [Kutscher, 1992]. Therefore, a UTC system that has a sufficiently large approach velocity and collector area must heat a large

amount of fresh air. For this reason UTC systems are well-suited for buildings that require a large amount of outside air. A UTC system that is designed and operated properly can be inexpensive and efficient relative to glazed solar air heaters.

UTC systems save energy in three ways. Most of the energy savings result directly from solar energy absorbed by the collector and convected to the air as it flows through the collector. As the air travels up the plenum behind the collector, it is also heated by energy convected from the outside wall surface. This recaptured wall loss can be seen in Figure 1.1.2. Additional energy savings results when the temperature difference across the outside wall is reduced with the UTC system. This lower temperature difference reduces the conduction through the wall, saving energy.

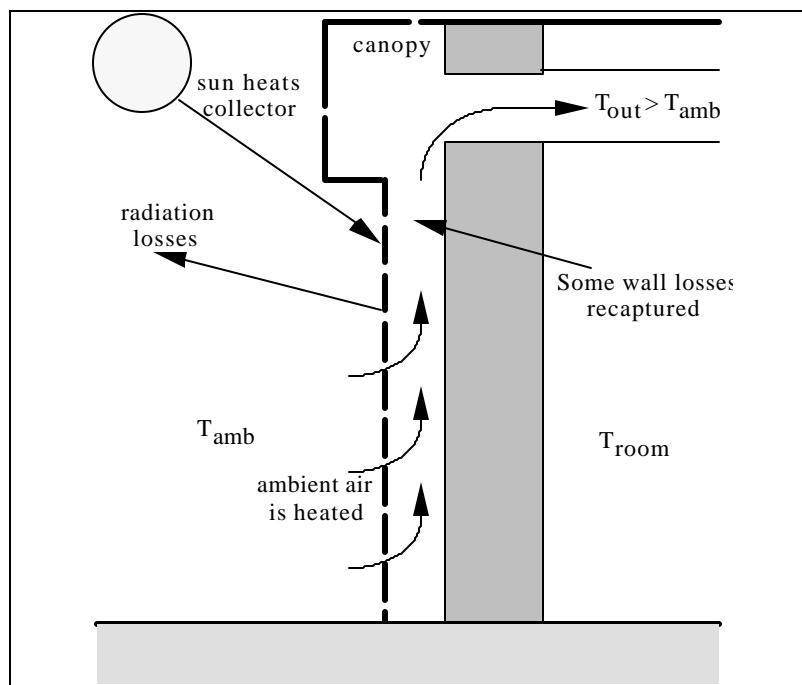


Figure 1.1.2. Cross-sectional view of an unglazed transpired collector system. { TC "Figure 1.1.2. Cross-sectional view of an unglazed transpired collector system." \ 5 }

The collector plate is usually corrugated for rigidity. Typical hole diameters are on the order of 0.5 to 4.0 mm, and hole pitches can vary from approximately 10 to 30 mm [Kutscher,

1992]. These values yield low porosities of 0.5 - 2%. The space between the collector and wall, called the plenum, has a depth on the order of 10 cm.

## 1.2 Introduction to TRNSYS and EES{ TC "1.2 Introduction to TRNSYS and EES" \1 2 }

TRNSYS is a transient system simulation program, developed by the Solar Energy Laboratory at the University of Wisconsin - Madison, which has been designed to model the performance of thermal energy systems [Klein, *et al.*, 1994a]. Each component in a system is modelled by a separate FORTRAN subroutine. The subroutines are linked and controlled by the main TRNSYS program. The FORTRAN code is modular and can be modified by the user. This feature allows components to be added or removed from the system, and new components can be written to add to the TRNSYS component library.

A single unglazed transpired collector can be modelled with a TRNSYS subroutine, which calculates the energy saved and outlet temperatures for each hour in the simulation. To use the outlet air from the UTC as the inlet to, for example, a rotary heat exchanger, some outputs from the transpired collector subroutine can simply be used as the inputs for the rotary heat exchanger subroutine. The components in a system and the links between these components are specified in a file called a TRNSYS deck. The TRNSYS deck is where the parameters and inputs of each component are specified. The difference between parameters and inputs is that parameters are constant throughout the entire simulation and inputs may change each hour during the simulation.

Engineering Equation Solver (EES) is a program designed to solve a system of simultaneous, non-linear equations [Klein and Alvarado, 1994b]. This software does not require that the equations be entered in any particular order, and each equation does not need to be simplified or formatted. However, it would be difficult and time-consuming to perform an annual simulation with EES. It is used to solve the UTC system equations for one time step, as a check on the accuracy of the TRNSYS subroutine. EES is also used to generate the curve fits for air

properties used in the UTC model.

### **1.3 Background and Literature Review** { TC "1.3 Background and Literature Review" | 2 }

Unglazed transpired solar collectors are relatively new, but they bear similarities to several older types of solar air heaters. Previous work on porous beds [Hamid and Beckman, 1969], matrix air heaters [Hamid and Beckman, 1971; Neeper, 1979; Singh and Bansal, 1983], and glazed transpired air heaters [Bansal *et al.*, 1983; Rhee and Edwards, 1983] have provided the foundation for the development of unglazed transpired solar collectors. Currently, UTC systems are marketed by Conserval Engineering Inc. of Downsview, Ontario [Hollick, 1994].

Experimental studies of the solar efficiency and air temperature rise from UTCs were performed at the National Solar Test Facility (NSTF) near Toronto, Canada for Conserval [Hollick, 1994]. However, the most comprehensive study to date on unglazed transpired collectors was done by Kutscher [1992]. He performed theoretical, numerical, and experimental analyses of heat transfer for air flow through low porosity perforated plates. This work was continued at the National Renewable Energy Laboratory (NREL), and two articles have been published which provide good summaries of the important results [Kutscher *et al.*, 1993a; Kutscher, 1994a]. At the University of Waterloo, additional model development has been done by Cao [1993a; Cao *et al.*, 1993b] and Brunger and Hollands [1994], and similar work was carried out by Golneshan [1994] on slotted transpired plates. Investigations of the air flow distribution through transpired plates were done by Dymond [1994; Dymond and Kutscher, 1995] and Gunnewiek [1994]. Additional work from NREL can be found in two annual reports [Kutscher, 1993b; Kutscher, 1994b] which outline the progress on computer software being developed to predict the performance of different collectors in different conditions. The results of monitoring collector installations on two buildings at NREL, the Bulk Storage Facility and the Waste Handling Facility, are also reported. However, the installations at NREL have some

shortcomings, and the best data to date from an installed UTC system come from a General Motors battery production facility in Oshawa, Ontario. The collector was installed by Conserval Engineering in 1991 and has been monitored and analyzed by Enermodal Engineering [1994] and Brunger and Hollands [1994].

#### **1.4 Scope of Study{ TC "1.4 Scope of Study" \1 2 }**

A thorough analysis of the performance of UTC plates has previously been done [Kutscher, 1992]. This base of knowledge is used to build a TRNSYS model so that the complete system performance can be evaluated. The model is validated against data from laboratory experiments [Hollick, 1994] and monitored installations [Enermodal, 1994]. Buildings that are good candidates for this new technology are identified. The thermal performance and economic benefits of transpired collectors placed on these buildings are calculated, and these results are extrapolated to estimate their potential statewide impact for Wisconsin.

The UTC system theory and TRNSYS model that are developed for this project are described in Chapters 2 and 3, respectively. Chapter 4 describes the results from TRNSYS simulations. Chapter 5 details the economic theory of UTC systems, and Chapter 6 describes the statewide impact of UTC systems in Wisconsin. Finally, the conclusions and recommendations of this project are presented in Chapter 7.