THERMAL SIMULATION AND ECONOMIC ASSESSMENT OF UNGLAZED TRANSPIRED COLLECTOR SYSTEMS

by

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ABSTRACT

Unglazed transpired collectors (UTCs) have recently emerged as a new solar air heating technology. These collectors consist of a perforated, solar-absorbing plate mounted on a large south-facing wall. Air is drawn through the holes in the plate, into the plenum, and finally into the building. Unlike most solar air heaters, they are not covered by a glazing, which eliminates the reflection losses associated with glazings. Complete systems are relatively inexpensive, efficient, and particularly suited to applications in which a high outdoor air requirement must be met.

A TRNSYS model has been created for UTC systems. The basic energy balances of the system are solved each time step. The UTC system model predicts the energy savings, which is comprised of the active solar gain, the recaptured wall loss, and the reduced wall loss. The model is used to perform parametric studies of UTC system operation.

Annual simulations are performed on several buildings, and the results are then extrapolated to find the potential statewide impact of UTC systems in different economic sectors in Wisconsin. The statewide economic potential of UTC systems is assessed for the commercial, residential, agricultural, and industrial sectors. The economic analysis is based on the P_1, P_2 method of life cycle savings. UTC systems on existing buildings are competitive with electric heating systems, but not with gas or oil heating. Electric heating is not widely-used in most buildings which are well-suited for UTC systems, with the exception of large apartment buildings. Therefore, there is no substantial statewide economic potential for UTC systems on existing buildings except in the residential sector. However, UTC systems should be considered for new buildings because a low first cost allows them to compete with gas and oil heating.

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NOMENCLATURE

Roman

A	total collector area (m^2)
A_c	cross-sectional area of plenum in direction of air flow (m^2)
A_s	collector surface area (m^2) = $(1-\sigma)$ A
C_A	UTC system cost per unit collector area ($/$m^2$)
C_E	UTC system fixed cost ($)
C_F	fuel cost ($/GJ)
c_p	specific heat (J/kg-C)
D	hole diameter (m)
D_h	hydraulic diameter (m)
f	friction factor
$\mathcal{F}$	solar fraction
FS	fuel cost savings
g	acceleration of gravity (m/s^2)
Gains	internal building gain (W)
h	heat rate coefficient (W/m^2-C)
ht	collector height (m)
I_T	incident solar radiation on the collector surface (W/m^2)
LCS	life cycle savings ($)
$\dot{m}$	mass flow rate (kg/s)
Nu_x	Nusselt number where x is the characteristic length
P	hole pitch (m)
P_1	ratio of life cycle fuel savings to first-year fuel savings
P_2	ratio of life cycle capital expenditures to initial investment
P_c	cross-sectional perimeter of plenum in direction of air flow (m^2)
Pr	Prandtl number
Q	annual energy (J/yr)
$\dot{Q}$	heat rate (W)
Re_x	Reynolds number where x is the characteristic length
T	temperature (C) or (K)
U	heat rate coefficient (W/m^2-C)
UA	total UA for walls and roof (W/C)
V	approach velocity (m/s)
V_{plen}	plenum velocity (m/s)

Greek

α	absorptivity
β	fraction of conventional system supply air that is outdoor air
ΔP	pressure drop (Pa)
$\Delta\rho$	density difference between ambient and plenum air (kg/m^3)
ε	emissivity
ε_{HX}	heat exchanger effectiveness of collector
η_{sol}	solar efficiency
γ	fraction of UTC system supply air that is outdoor air
ρ	density (kg/m^3)
σ	porosity of the collector plate
σ_{sb}	Stefan-Boltzmann constant (W/m^2-K^4)
ζ	non-dimensional pressure drop across collector

Subscripts

1	air supply from UTC system
2	air supply from conventional system
abs	absorbed solar
acc	acceleration
amb	ambient air
aux	auxiliary
avg	average
bal	balance
bldg	building loss
buoy	buoyancy in the plenum
col	collector plate
cond,wall	conduction through the wall
conv,col-air	convection from the collector to the air
conv,wall-air	convection from the outside wall surface to the air
D	hole diameter (m)
film	average film coefficient for air against the original wall
fric	friction in the plenum
gnd	radiative ground
ht	collector height (m)
load	total load
max	maximum
min	minimum
mix	mix of outlet and recirculated air

out	collector outlet air
pot	potential conduction through the wall
plen	plenum air
rad,col-sur	radiation from the collector to the surroundings
rad,wall-col	radiation from the outside wall surface to the back of the collector
red,wall	reduced wall loss
room	room air
save	saved
seg	market segment of an economic sector
skin	skin loss from building
sky	radiative sky
solair	sol-air
sup	supply air
sur	radiative surroundings
trad	traditional heating system
u	useful energy
wall	outside wall surface

Matrices and Vectors

[A]	coefficient matrix for energy balances and rate equations
[b]	constant vector for energy balances and rate equations
[x]	unknown vector