ENERGY SAVINGS IN BUILDINGS THROUGH OPTIMIZED SURFACE HEAT RADIATION PROPERTIES

Ali Joudi[1], Harald Svedung[2]

[1]Solar Energy Research Center (SERC)
SE-781 88 Borlänge, Sweden
[2]SSAB Strip Products
SE-781 84 Borlänge, Sweden
Tel.: +46-243 / 72376, Fax: DW –71670
E-Mail: harald.svedung@ssab.com

1 Introduction

A large part of the unwanted heat flux through the envelope of buildings goes through external and internal sheets of coil coated steel. Our aim has been to investigate how the total solar reflectance and the thermal emittance of coil coated steel effects the surface temperatures and temperature gradients across roof- and wall segments while keeping a comfortable thermal indoor environment. Measurements of surface, air and radiation temperatures as well as of the amount of energy used for heating and cooling were done in four small test buildings during one year in the middle of Sweden.
Theoretical modelling of these and other buildings were done with and without the use of internal fluid dynamics. Measured results indicate increased vertical air temperature gradients and more stable air stratification with lower interior surface thermal emittance. If used wisely, solar reflective exterior material and thermally reflective interior material can save valuable energy. Arguably more so in larger buildings.

2 Experimental

The test cabins, specified in Table 1, were built with coil-coated steel claddings with different optical properties given in Table 2.

U-value	Wall	0.247 $W/m^2{}^\circ C$
	Roof	0.207 $W/m^2{}^\circ C$
	Floor	0.158 $W/m^2{}^\circ C$
Inside floor area	13 m^2	
Internal volume	37 m^3	
Total area enclosing volume	65 m^2	
Glazing	Double, 0.6 m^2 facing south	
Roof pitch	35°	
Location	Borlänge, Sweden Lat: N 60°	
Cooling system	Air conditioner split type EER:4.08	
Heating system	Floor heating – electrical coil	
Ventilation system	70 m^3/h nominal capacity	
Infiltration	fairly airtight/ negligible	
Internal load	negligible	

Table. 1 – Building specification and HVAC system.

The roof and walls of the cabins are intermediately well insulated. The floor construction was relatively well insulated and with some thermal mass. The HVAC system includes electrical floor heating with 1 kW peak power, an air to air heat pump with EER = 4.08 for cooling. Forced ventilation includes an air inlet at feet level and an exhaust fan at top level.

Cabin	Exterior TSR	Exterior Thermal Emittance	Interior Thermal Emittance
A	0.10	0.91	0.24
B	0.39	0.92	0.24
C	0.10	0.92	0.91
D	0.43	0.90	0.52

Table. 2 – Surface radiation properties of the cabins exterior and interior claddings.

The total solar reflectance, TSR, and the thermal emittance are obtained as mean values of the measured reflectivity spectra using as weight factors the terrestrial solar intensity and the 20˚C thermal infrared black body distribution, also shown in the figures, respectively.

Surface temperatures were measured with thermocouples attached both on the interior and exterior surfaces, approximately at the middle of each wall or roof.

The infrared radiation emitted from a surface depends on both its surface temperature and its emissive properties. Radiation temperatures in different directions were measured with directed radiation pyrometers. These infrared thermometers detect the temperature of the IR-radiation reflected or emitted by the target surfaces.

The electricity consumption was measured for heating, cooling and auxiliary power by three separate electricity meters in each house. The exterior air temperature, the global solar irradiation and the air speed close to the roof were measured with a free hanging naked thermocouple, a pyranometer, and a rotating wind transmitter, respectively.

3 Results

3.1 Cooling

The measured climate data during a one week cooling experiment is given in Figure 1.

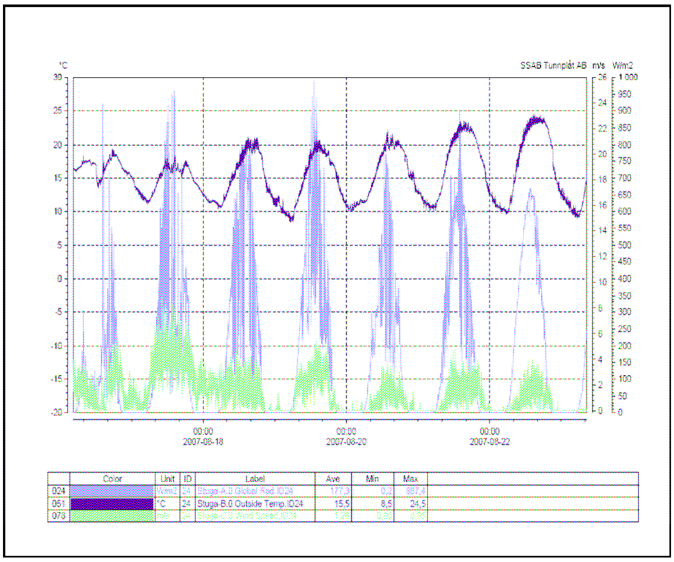

Figure. 1 – The global solar radiation, the outside air temperature and the wind speed close to the roof top are given as functions of time for a 7 days period in late August 2007.

The interior roof radiation temperature as given in in Figure 2, is quite similar during daytime in cabins A and C having low and high interior surface emittance respectively. Comparing the interior roof surface temperatures highlighted in figures 3 and 4 it is evident that the low emittance interior surface in cabin A remains warmer than the high thermal emittance interior surface in cabin C during cooling by the AC-units.

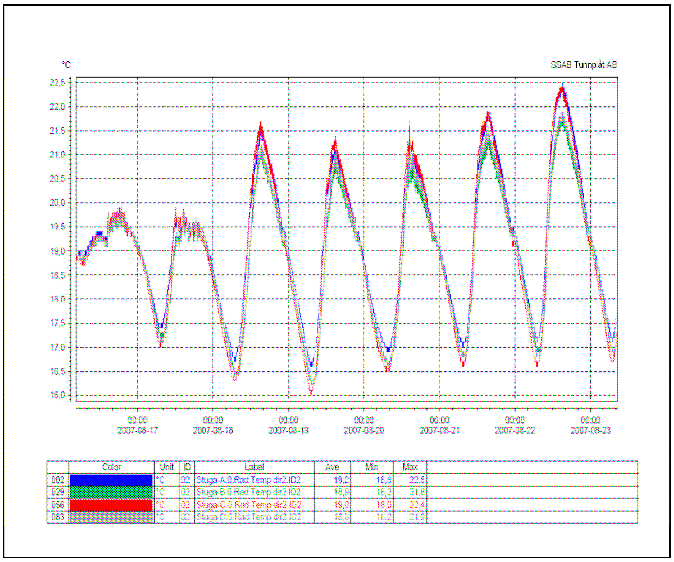

Figure. 2 – The radiation temperatures measured by pyrometers facing the upper part of the cabin interior in cabins A, B, C and D during late August 2007.

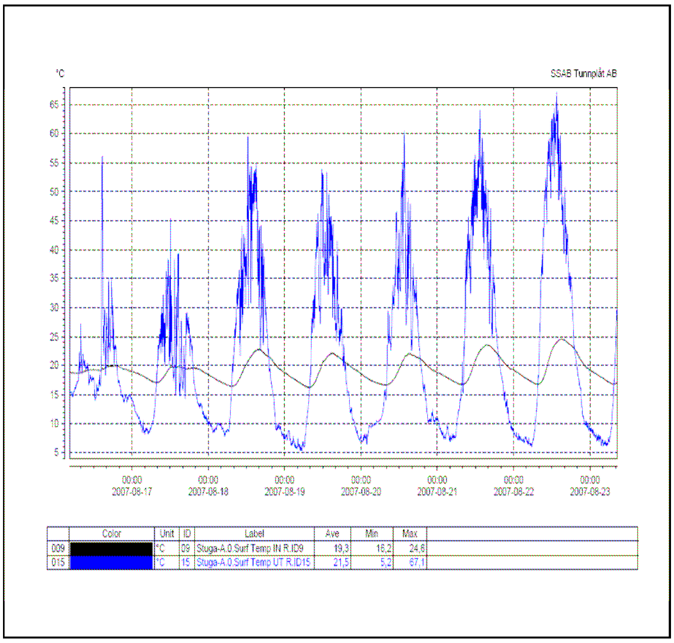

Figure. 3 – The temperatures on the interior and exterior surfaces of the south facing roof on cabin A are given for the late August 2007- test period.

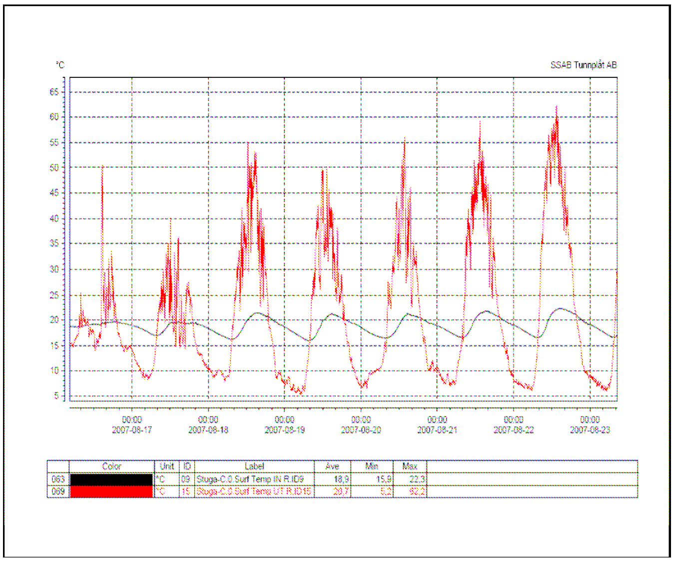

Figure. 4 – The temperatures on the interior and exterior surfaces of the south facing roof on cabin C are given for the late August 2007- test period.

Allowing for an increased interior surface temperature during cooling-hours while maintaining a similar interior climate contributes to decrease in temperature gradient across the building envelope. Another contribution would be the 7 Kelvin decrease in exterior surface temperature obtained by the use of high-TSR material as in cabin B.

The accumulated energy used by the AC-units in the cabins is given as functions of time in figure 5. The differences in energy use is consistent with those of the surface temperatures that we measured.

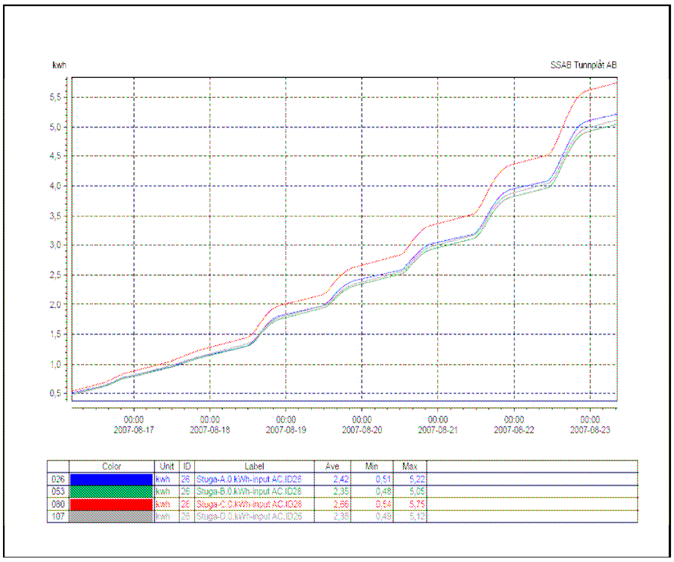

Figure. 5 – The accumulative energy used by the air-conditioning units in cabins A, B, C and D during late August 2007.

3.2 Heating

Electrical floor heating with highly emissive floor surfaces in all cabins was done during a week in late October. The climate measurements are shown in Figure 6. The radiation temperature as given in figure 7 for cabins A and C was kept similar during heating hours.

By comparing the interior roof surface temperatures shown in figures 8 and 9 for cabins A and C, respectively – it is evident that the low emittance, i.e., high thermal reflectance interior surface in cabin A remains cooler during heating hours compared to the high emittance (high absorbance) interior surface in cabin C.

A difference in accumulated energy used by the floor heating is shown in figure 10. The amount of energy saved by the low emittance interior surface is again consistent with the difference in temperature gradient across the building envelope.

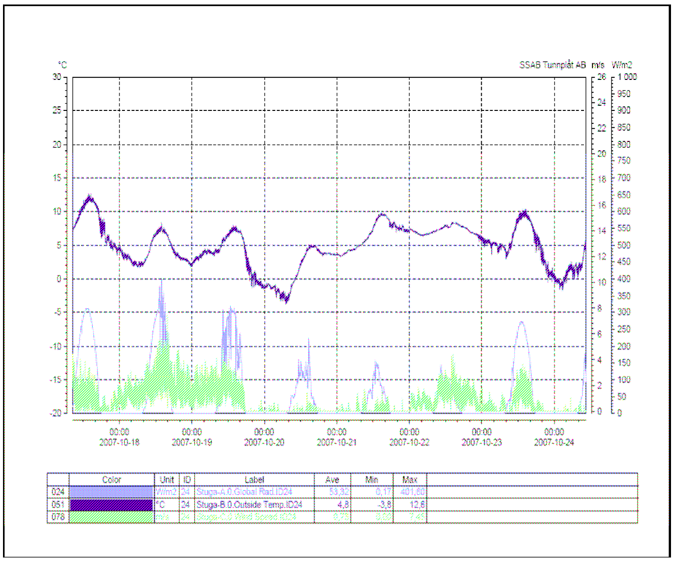

Figure. 6 – The global solar radiation, the outside air temperature and the wind speed close to the roof top are given as functions of time for a 7 days period in late October 2007.

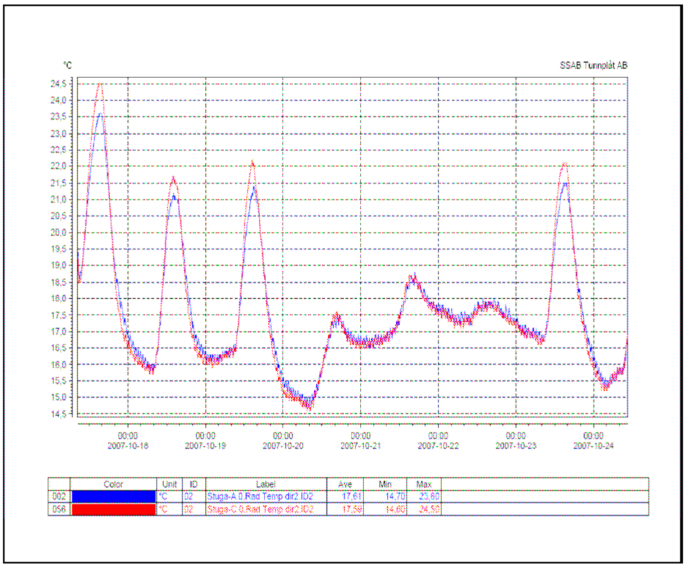

Figure. 7 – The radiation temperatures measured by pyrometers facing the upper part of the cabin interior in cabins A and C during late October 2007.

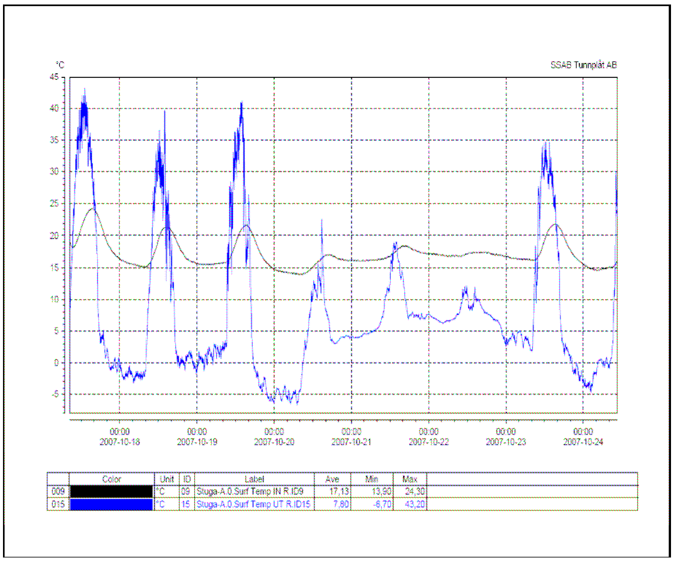

Figure. 8 – The temperatures on the interior and exterior surfaces of the south facing roof on cabin A are given for the late October 2007- test period.

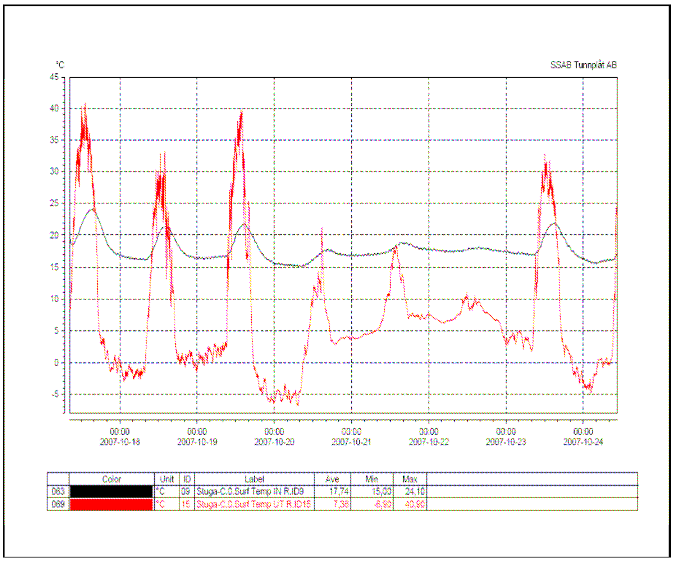

Figure. 9 – The temperatures on the interior and exterior surfaces of the south facing roof on cabin C are given for the late October 2007- test period.

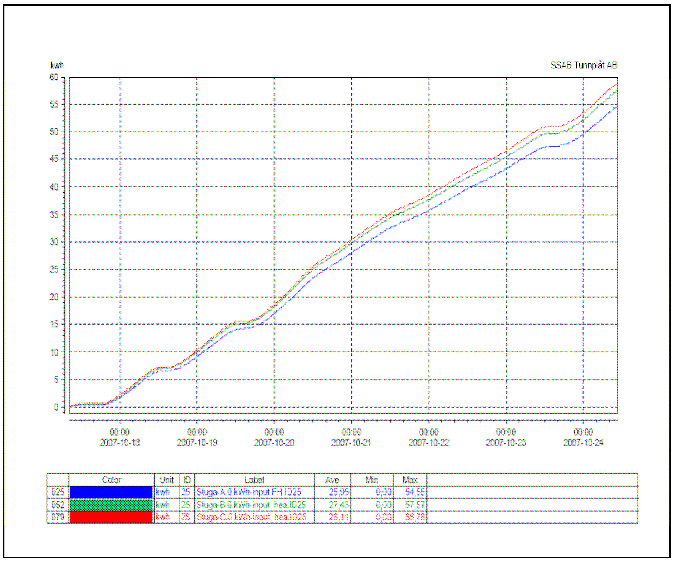

Figure. 10 – The accumulated energy used for heating in cabins A, B and C is given for the late October test period.

4 Preliminary modelling

Simple steady state calculations indicate that the explicit modeling of radiation heat-transfer between the highly emissive heated floor and the remaining surfaces with variable emissivity is essential in order to estimate the effect on heating consumption. Dynamic simulations of the test cabins over one year show the reduced heating consumption that we see in our measurements by the use of highly reflective interior surfaces, only in those cases where an explicit representation of the radiation heat flux between the interior roof and wall surfaces and the heated floor is included. It should be noted that this is not the case for some of the simulation tools used by architects today. Simulations without explicit radiation heat-transfer between surface nodes and without thermal air-stratification also fail to show the reduction in cooling demand by the use of highly reflective interior surfaces that can be seen in our measurements[1].

5 Literature

1. **Svedung H., Joudi A., Bales C., Rönnelid M., Wäckelgård E.,** Highly reflective coatings for interior and exterior steel cladding in energy efficient buildings. Submitted to Energy and Buildings.