Condensation in Glazed Flat Plate Solar Collectors

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Abstract

Glazed flat plate solar collectors offer a simple and cost effective approach to heating water. However, on clear nights solar collectors can transfer a significant amount of heat to the atmosphere by radiation. In areas with a cool climate and high relative humidity the radiation heat loss can lead to the temperature of the glazing often reaching the dew-point of the surrounding air, this leads to condensation developing on the glazing. If water condenses on the inside of the glazing and repeatedly drips onto the solar absorber this could lead to damage of the solar collector surface thus shortening its operating life. Also, the build-up of condensation on the glazing can lead to the growth of mould, is visually displeasing to the owner, and means energy must be “wasted” to evaporate the moisture during the following day.

This study aims to develop the understanding of the role that condensation plays on collector performance, as well as addressing ways of minimising the impact it has. In doing so, it uses numerical modelling and experimental testing to determine the frequency of condensation in glazed flat plate solar water heaters under typical operating conditions. It shows that climatic factors including relative humidity, ambient temperature and wind speed determine the frequency of condensation for any given location. However, it also reveals that the frequency of condensation can be modified by altering the convection heat transfer coefficient inside the collector and by using low emissivity coatings on the glazing layer.

1. Introduction

Modern society relies deeply on the use of fossil fuels, and it is generally understood that they cause some negative impacts on the environment. Solar energy is a promising alternative to this, as it can substitute fossil fuels in a clean and renewable manner. The use of solar water heating is widespread, particularly in Germany, China and Australia due to the fact that it can be cost effective and last for over 20 years.

However, over time the performance of solar water heaters decreases due to the corrosion and degradation of the materials inside the collector. A study conducted under the auspices of the International Energy Agency’s Solar Heating and Cooling Program suggested that the main reason for corrosion could be due to condensation inside the collector [1].

Condensation is a natural phenomenon often associated with enclosed spaces such as refrigerators, buildings and vehicles, due to changes in temperature and humidity. However, solar thermal flat plate collectors can also suffer from condensation problems, particularly in cold areas with high relative humidity such as continental and northern Europe [2-3], southern areas of Australia and New Zealand.

The mechanism of condensation in a solar thermal flat plate is principally driven by the release of heat into the atmosphere by radiation, particularly at night. Typically collectors will be fitted with ventilation apertures that allow ventilation at a rate of approximately 50 air changes per day [4] and so can allow moist air into the collector. As such, if the temperatures in the collector fall below the dew point temperature of the surrounding air, condensation can form on the collector. The existence of water can cause damage to the collector surface and create unfavourable microclimatic conditions for the internal materials [5]. In addition to this, energy must be used to evaporate the moisture the next day. Even in a small flat plate solar thermal collector condensation can occur, and repeated condensation dripping onto the solar absorber can lead to a degrading of the collector over time. Despite previous studies focussing on European climates, corrosion due to condensation and its impacts on the performance of solar water heating systems is also a significant problem in southern hemisphere locations [6-8].

In light of problems posed by condensation in flat plate solar water heaters and the relative lack of attention paid to the problem, this study set out to explore ways of reducing the occurrence of condensation in flat plate solar collectors.

2. Experimental Method

To develop an understanding of the microclimate inside a collector, an experiment to measure the absorber temperature, cover temperature and relative humidity in the air gap was constructed. A single glazed flat plate solar collector, with a matte black painted absorber, 1 meter long and 1.8 meters wide was positioned to face due north at an angle of 37° to the horizontal (Figure 1) on the Auckland University of Technology's (AUT) School of Engineering building.

The collector was fitted with nine T-type thermocouples (±0.3°C), four of which were attached to the surface of absorber, another four were attached to the inside surface of the cover [9] and the last used to measure the ambient temperature. The sensors for absorber and cover were uniformly distributed over the surfaces to determine the mean surface temperatures.

In addition, two relative humidity sensors (Honeywell, HIH-4000) were used to measure relative humidity inside the collector air gap and in the ambient air. A pyranometer (Apogee, SP110) was used to measure the global radiation incident on the collector, while atmospheric pressure and local wind speed were recorded by the AUT weather station. Additional meteorological data such as dew point temperature was taken from a nearby automated weather station recorded to the National Institute of Water and Atmosphere's (NIWA) Cliflo database [10].

Figure 1: Experimental solar collector

3. Experimental Results

Though the experimental data was collected over a relatively long time-frame, for clarity and brevities sake, experimental data is presented for a single day. Figure 2 shows the hourly measured meteorological conditions for a typical test.

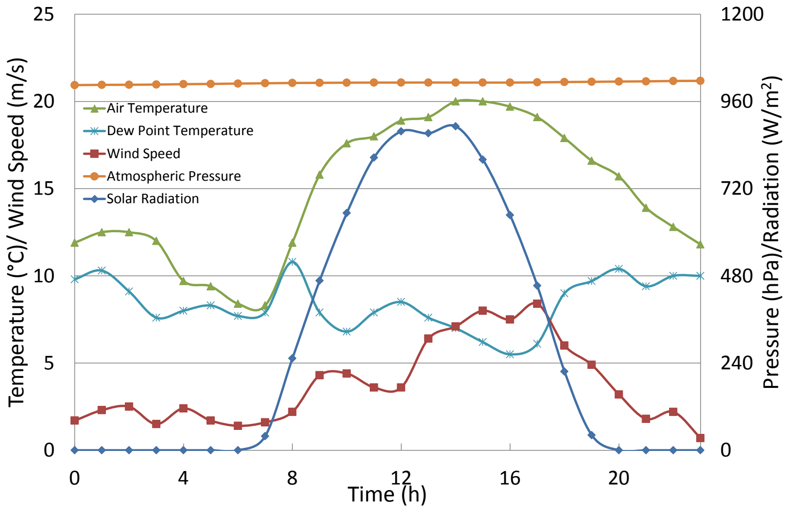

Figure 2: Meteorological conditions for a typical test

For the test day shown, the average absorber and cover temperatures were recorded a ten minute intervals with no cooling flow passing through the collector. In Figure 3 it can be seen that under these conditions, the absorber temperature varies by over 100°C over the course of the day. Perhaps more interestingly, in the early morning both the absorber and cover temperature are close to the ambient and dew point temperatures.

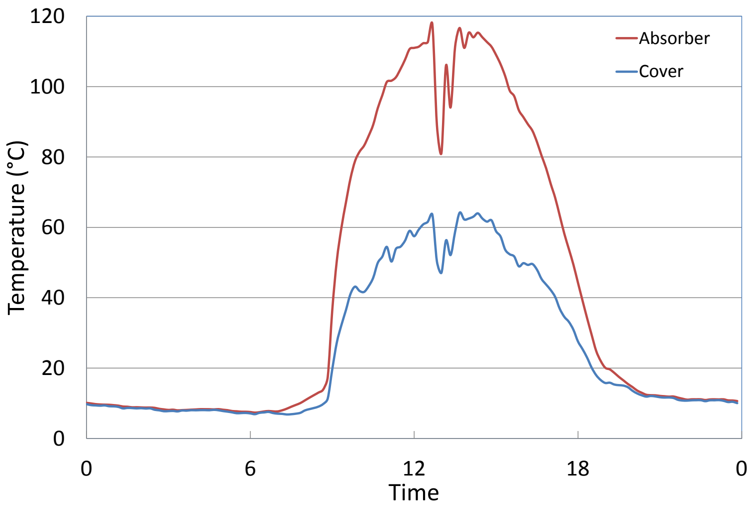

Figure 3: Absorber and cover temperatures for a typical test

Exploring this phenomena further, if we consider the relative humidity both outside and inside the collector, as shown in Figure 4, we can see that there are times when there is a significant variation between these two values. During the day the measured relative humidity decreases inside the collector, as the air gap between the absorber and cover increases in temperature. However at night, as the cover and absorber cool the relative humidity in the gap increases again. On inspection it is apparent that this leads to the situation where the relative humidity in the collector is greater than that of the surrounding air. Under such conditions it is possible that condensation could occur.

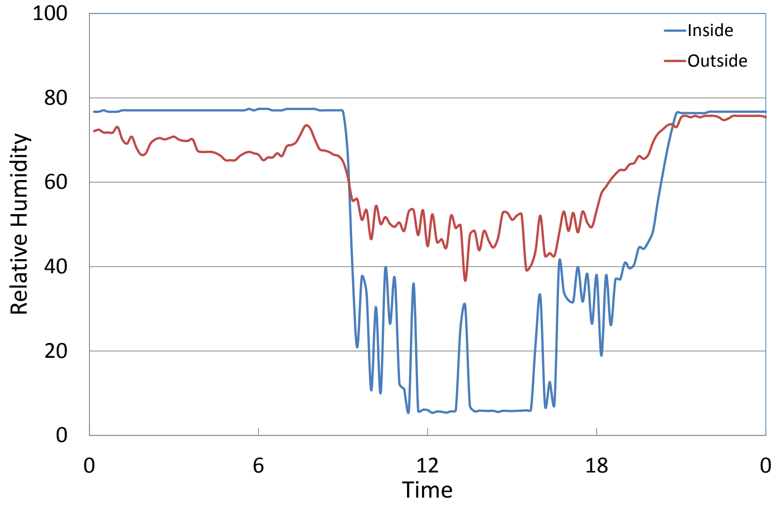

Figure 4: Relative humidity in solar collector

In light of the previous observations and considering the high relative humidity in the air gap and the potential for condensation it was decided to look more closely at the temperature of the absorber and the cover. In Figure 5, the temperature of these elements during the early morning period is examined. Here it can be seen, that at two points in time, both the cover and absorber temperature fall below the dew point of the surroundings. Because the collector had ventilation holes and so would have the same internal pressure as the atmosphere, this would suggest that condensation may have been present on both these surfaces.

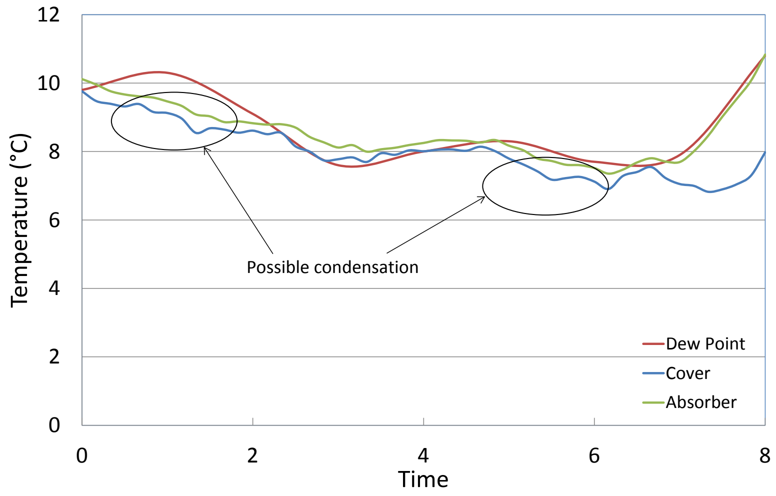

Figure 5: Cover and absorber temperature vs Dew point temperature

Now, although condensation was not physically observed during the experimental period shortly after the experimental testing of temperatures and humidity's had been completed, the collector experienced an evening of very clear skies and high humidity such that condensation was found on the collector as shown in Figure 6. Though the majority of the condensation visible in this image is on the covers external surface, it serves to illustrate the potential problem should the collector components fall below the dew point.

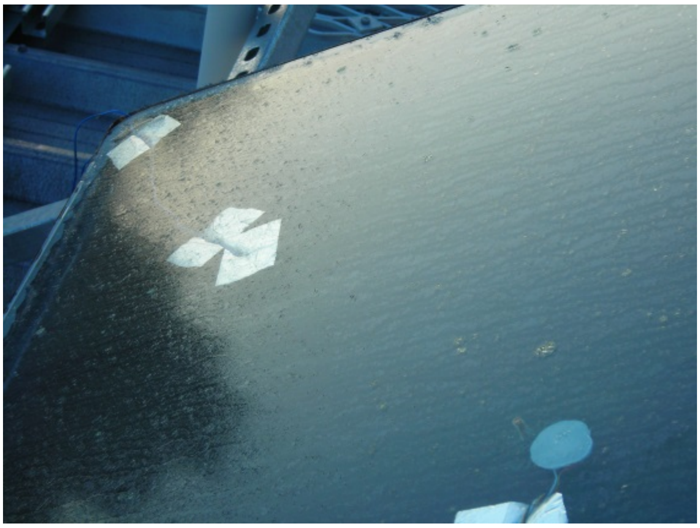

Figure 6: Condensation on collector

4. Numerical Analysis

Having demonstrated the potential for condensation occurring in collectors it was decided to undertake a modelling analysis to better understand the factors that influence the frequency of condensation in solar collectors. To do this it was decided to model the performance of a single glazed flat plate collector operating under typical meteorological year (TMY) conditions for locations across Australia and New Zealand using TRNSYS [11].

As the baseline for comparison, a simple pumped water loop collector utilising a theoretical single glazed flat plate collector (Type 942) with design parameters similar to that of the experimental collector, and listed in Table 1, was modelled.

Table 1: Collector Properties (TRNSYS, Type 942)

Collector length	1	m
Collector width	1	m
Collector Depth	0.1016	m
Number of tubes	10	-
Tube diameter	0.01	m
Bond width	0.01	m
Bond thickness	0.001	m
Bond thermal conductivity	385.00001	W/m.K
Plate-to-cover spacing	0.0254	m
Emissivity of cover	0.9	
Infrared transmittance of cover	0	
Index of refraction for cover	1.526	
Cover extinction	0.0184	
Emissivity of absorber plate	0.9	
Plate absorptance	0.96	
Plate thermal conductivity	385.00001	W/m.K
Thickness of the absorber plate	0.0005	m
Thermal conductivity of edge/back insulation	0.045	W/m.K
Thickness of edge/back insulation	0.0254	m

For the simulations it was assumed that the collector was coupled to a storage tank of 300L volume and subjected to a water draw profile as shown in Figure 7.

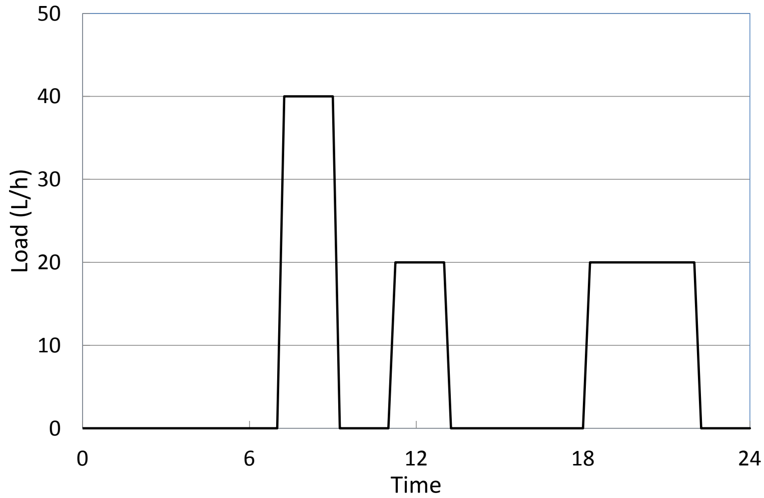

Figure 7: Hot water profile

By using the Type 942 model it was possible to monitor both the cover and absorber temperature across the entire simulation (a TMY). As such, it was assumed that if at any point during the simulation either of these temperatures dropped below the dew point temperature from the TMY data (Type 15 weather data processor) that condensation would occur on the surface. However, this neglects the possibility of the condensation draining away due to the inclination of the collector or by ventilation through venting apertures.

5. Numerical Results

5.1 Influence of location on condensation frequency

To determine the effect of location on the occurrence of condensation the model was tested for Auckland, Christchurch and Wellington in New Zealand and Canberra, Melbourne, Hobart and Perth in Australia. In Figure 8, the simulated amount of condensation time on the cover and absorber over the TMY for each city is shown.

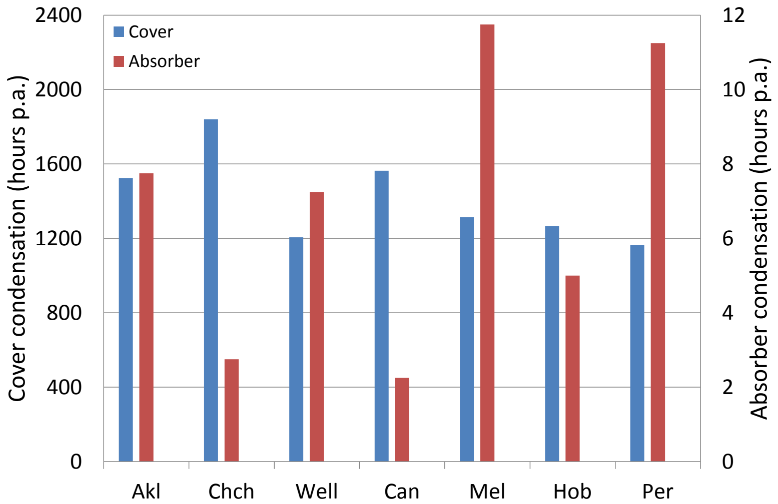

Figure 8: Modelled results of condensation occurrence

From this it can be seen that the predominance of condensation occurs on the cover of the collector. Now this may form on the exterior surface of the cover as illustrated in Figure 6, however, it can also be seen that in all locations the absorber may be subjected to condensation across the year. In extreme circumstances it is foreseeable that this could even result in freezing within the collector.

If we examine this further, using Perth as an example, in Figure 9 it can be seen that in winter, condensation occurs more than in summer. This phenomenon can be attributed to the cooler, more humid conditions typically encountered during this time of year. Now considering locations such as Christchurch and Canberra, where clear skies during winter often occur, it is interesting to note that both exhibit the highest frequency of condensation on the cover. This suggests that the radiant heat loss due to the emissivity of the glazing plays a significant role in the occurrence of condensation.

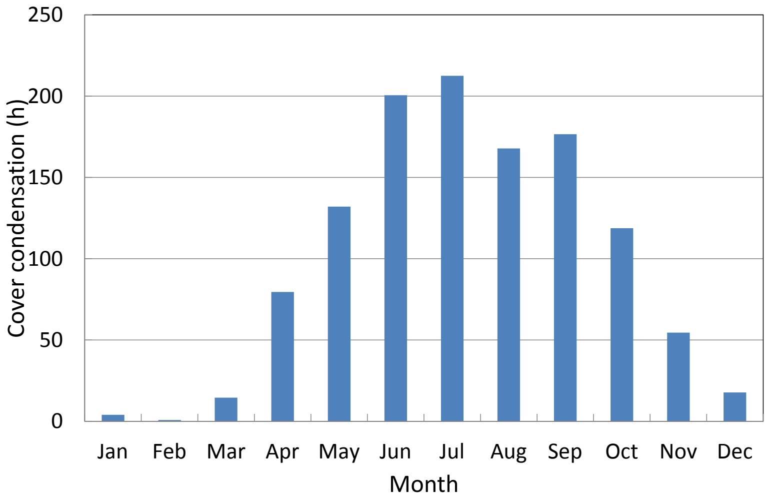

Figure 9*:* Monthly distribution of cover condensation occurrence in Perth

Similarly, if we consider Wellington it can be seen that this location has a relatively low frequency of condensation on the cover. The reason for this may be due to the relatively high average wind speed in this area, which would act to reduce the significance of radiant heat losses and so, the frequency of condensation.

In summary, it can be seen that condensation in flat plate collectors will occur relatively frequently in New Zealand and southern Australia, and is a function of the location and the collector design.

5.2 Influence of the slope of the collector on condensation

When considering changing the location of a collector, one would change the slope of the collector to maximise the solar radiation collected. In the modelling, changing the slope of the collector influences the heat transfer coefficient for natural convection in the air gap, and the heat transfer coefficient for thermal radiation from the cover to ambient air.

In exploring this further the slope of the collector (in Auckland) was also changed, the slope was set as 15°, 30°, 60°and 75°. Figure 10 shows the relationship between the number of expected condensation hours and slope of the collector. This indicates that increasing of the slope of the collector has a relatively minor impact on condensation on the cover of the collector.

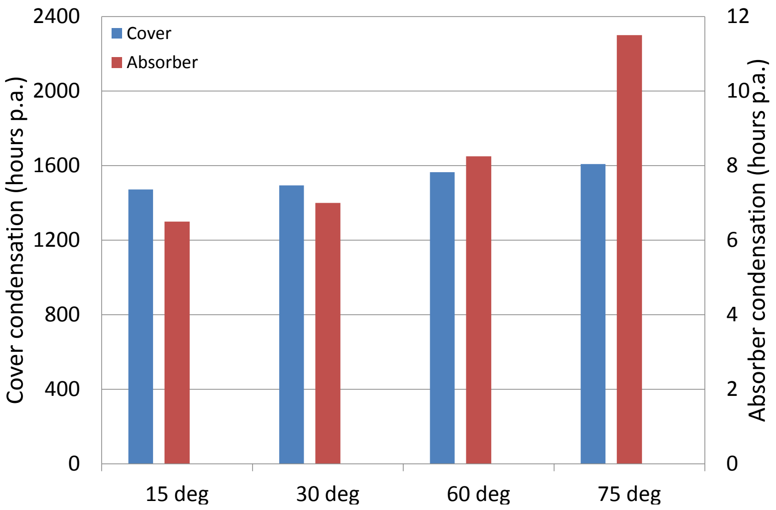

Figure 10: Effect of collector slope on condensation occurrence

5.3 Influence of the air gap on condensation

In considering the design of the collector, it is desirable to reduce the convective heat transfer between the cover and the absorber. Typically this air gap would be in the order of 2-3cm to achieve the optimum heat transfer coefficient. In Figure 11 (for Auckland) it can be seen that in doing this it also achieves a very slight reduction in the occurrence of condensation on the collector cover compared to a much larger gap. Additionally, the model suggests that a very narrow gap could reduce this further, though this would influence the day time heat loss too.

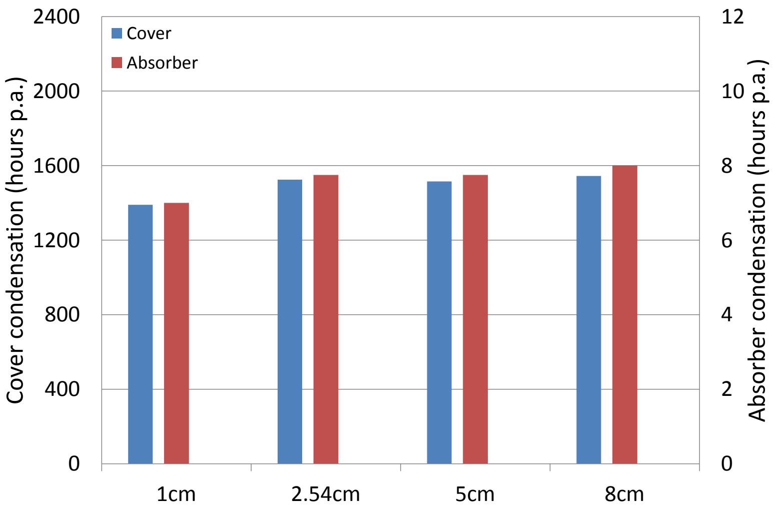

Figure 11: Influence of air gap thickness on condensation occurrence

5.4 Influence of absorber and cover emissivity on condensation

Previously it was noted that the clear skies in some locations could be responsible for an increased frequency of condensation, due to the radiant heat loss to the sky. In order to reduce the impact of this phenomenon it is possible to utilise selective surfaces that reduce the radiant heat loss from the absorber. In Figure 12 (for Auckland), it can be seen that reducing the emissivity of the absorber from 0.9 to 0.1 results in a significant decrease in the frequency of condensation on the cover of the collector. Perversely though, the model suggests that this modification would increase the condensation on the absorber.

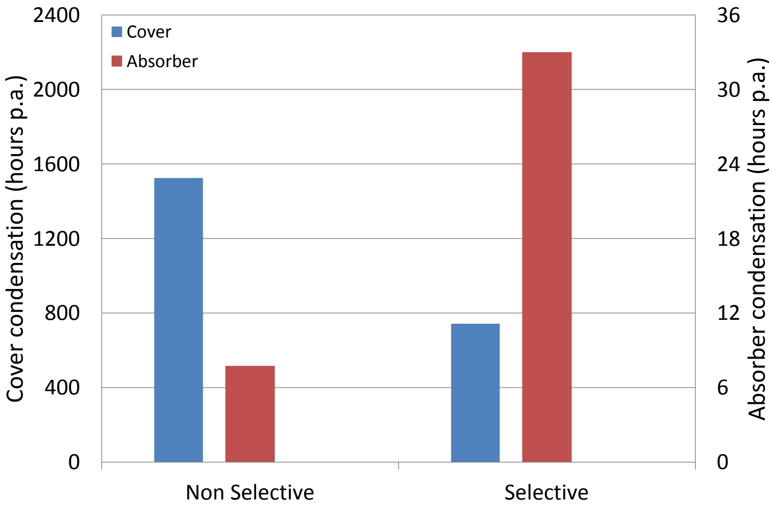

Figure 12: Effect of selective surfaces on condensation frequency

Examining the use of selective surfaces more closely, it is possible that the cover emissivity could also be modified to reduce its radiant heat loss. In Figure 13 (for Auckland) it can be seen that by reducing the emissivity of the glazing from the baseline value of 0.9 to an emissivity of 0.1, condensation on the cover is effectively eliminated (of course, in achieving this in reality the transmittance of solar radiation may be affected though this was not modelled). Ironically though, the increased frequency of condensation at the absorber remains relatively unchanged, though this could hypothetically be eliminated through ventilation or use of absorbing desiccants.

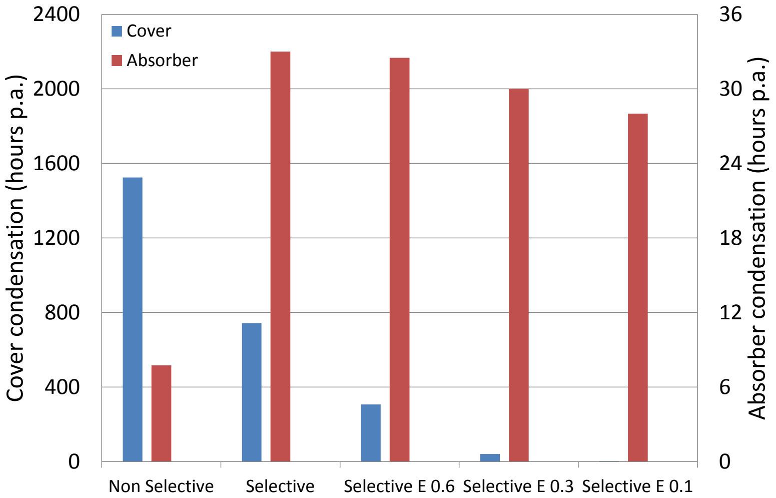

Figure 13: Effect of low emissivity glazing on condensation frequency

6. Conclusions

Avoiding condensation in solar collectors is a critical issue in terms of their durability and performance. During the night the temperature of the collector will often drop below the dew point temperature due to thermal radiation. In climates where the air at night becomes saturated with humidity, condensation will form both on the inside and outside of the collector glazing. If too much condensation occurs on the inside of the glazing, it will drip on to the absorber surface; furthermore, it may also result in condensation forming directly on the absorber which will consequently lead to long-term damage.

This study charted the undertaking of an experiment examining the microclimatic conditions in a flat plate solar water heater and examined how this could lead to condensation occurring in them. Subsequent modelling showed that climatic factors can determine the frequency of condensation for any given location. Finally it also revealed that the frequency of condensation can be modified by altering the design of the collector, the slope of the collector and most significantly by using low emissivity coating on the glazing layer.

Acknowledgements

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