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USE OF PHASE CHANGE MATERIAL (PCM) FOR FROST PREVENTION IN A MODEL GREENHOUSE

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ABSTRACT

In this study, the possibility of using phase change materials to prevent occurrance of frost in greenhouses during winter was investigated. The melting and freezing temperatures of the PCM were about 8 ^oC and 4 ^oC, respectively. The air temperature difference between the PCM and the control greenhouses was about 2 ^oC on average during the day and night time, PCM greenhouse having the higher temperature at night and lower temperature during the day. Frost was prevented on 7 out of 9 occasions, though the temperature difference between the greenhouses was small for some of these days. Solar fraction stored by the PCM store was about 30 %.

Key Words: Phase change material, Greenhouse, Frost prevention

BİR FAZ DEĞİŞİM MADDESİNİN MODEL BİR SERADA DONDAN KORUMA AMACI İLE KULLANILMASI

ÖZET

Bu çalışmada, bir faz değişim maddesini kullanarak küçük bir seranın dondan korunması imkanları araştırılmıştır. Bu seranın performansı, aynı taban alanına sahip fakat faz değişim maddesi içermeyen bir kontrol serası ile karşılaştırılmıştır. Araştırmada, erime ve donma sıcaklıkları sırasıyle 8 ve 4 ^oC olan bir faz değişim maddesi kullanılmıştır. Araştırma sonuçları, her iki sera arasında ortalama olarak 2 ^oC civarında bir sıcaklık farkı olduğunu göstermiştir. Burada, faz değişim maddesini içeren seranın sıcaklığı, kontrol serasına kıyasla, gündüz daha düşük gece ise daha yüksek olmuştur. Araştırma boyunca, dış ortamda donun oluştuğu 9 günden, 7 gün boyunca sera içerisinde don oluşumu önlenmiştir. Sistem ile ortalama % 30'luk bir güneş enerjisi toplama verimi elde edilmiştir.

Anahtar Kelimeler: Faz değişim maddesi, Sera, Dondan koruma

1. INTRODUCTION

Up to date, the solar energy storage studies for greenhouse energy conservation have mainly focused on sensible energy storage using rocks, water and earth. However, there have also been quite considerable numbers of studies on the use of PCMs for energy storage. The melting temperatures of the PCMs employed in those studies for greenhouse energy conservation were in general above 20 ^oC. For example, Jaffrin and Cadier (1982) used calcium chloride hexahydrate with a melting temperature of 25 ^oC as PCM in a multi-span, single glazed greenhouse of 500 m^2 ground area in France. The glass cover was doubled on the inside with an insulating PE air cap film. This film reduced the heat loss coefficient to half that of glass. Energy saving was 50 % in a full heating season. However, the overall cost of the greenhouse was twice that of a control greenhouse. In another study by Nishina and Takakura (1984), two kinds of PCMs melting at about 15 and 20 ^oC were used in a greenhouse of 352 m^2

ground area in Japan. The greenhouse was furnished with a two layers of thermal screens during the night: PVC and nonwoven fabric. They found that auxiliary heating was still needed during the experimental period, from December to March. Boulard et al. (1990) in France used the same PCM but with a melting temperature of 21 °C in a greenhouse of 176 m^2 ground area and obtained an energy saving of 41 %. In some of the Mediterranean countries, heating is carried out mainly for frost protection or to get air temperatures only few degrees above freezing, especially on the coastal areas. A PCM store might be used with some simple controllers to do this work as indicated by Kürklü (1994). This study therefore deals with the prospect of the use of a low melting temperature PCM for frost protection control in a greenhouse.

2. MATERIALS AND METHODS

In this experiment a model and a control greenhouse each having 13.5 m^2 ground area and 28 m^2 surface area covered with a single layer of clear PE were used. Greenhouses were oriented East-West in the research area of the School of Plant Sciences of the University of Reading. The distance between the greenhouses was 1 m. The tapered PCM store in the PCM greenhouse included 120 PCM tubes (see Figure 1). The PCM used was a mixture of some salts (ie. NaCl, KCl) together with some additives to prevent supercooling and had a melting temperature of about 8 °C and a freezing temperature of 4 °C. Its thermal conductivity and latent heat of fusion were about 0.5 W/m^2 °C and 216 kJ/kg, respectively.

The PCM store contained a 24 V actuator and a 350 mm axial fan of 23 m^3/min (1380 m^3/h) capacity. The control unit common to both greenhouses included an automatic fan speed controller to adjust the air flow
rate in the PCM store to an acceptable level; 2 thermostats (FARMSTAT) for minimum and maximum set temperatures for the flaps on the PCM store to open or close and 2 thermostats for the ventilation fans. Outside and inside solar radiation were measured by tube solarimeters. These solarimeters were calibrated against a standard Kipp Radiometer on a clear day. The air (outside, inside and store outlet) and soil temperatures were measured by using platinum resistance thermometer probes (PRT). All of the PRTs were calibrated in a controlled temperature bath starting with ice. The data were recorded using a BBC microcomputer and a combined data logger (Murdoch, 1991).

2. 1. Sensors

PRTs for air temperature measurements were placed at 1.5 m above ground level and were protected from direct sunlight. To do this, a small unit was constructed connecting pot plates to form a vertical cover over the sensors and extra care was taken to ensure that there was enough air movement over the sensors. Solarimeters in the greenhouses were placed approximately 60 cm above the ground level so that they were well away from the shading effect of the plants. Outside solar radiation measurements were carried out at the roof level of the greenhouses. The solarimeters were frequently cleaned to remove dust and other contaminants that formed on them.

2. 2. Control System

Air flow rate was measured by a hot wire anemometer according to principles given by Osborne and Turner (1969). The flow was adjusted to the required level by the variable speed control unit on the fan.

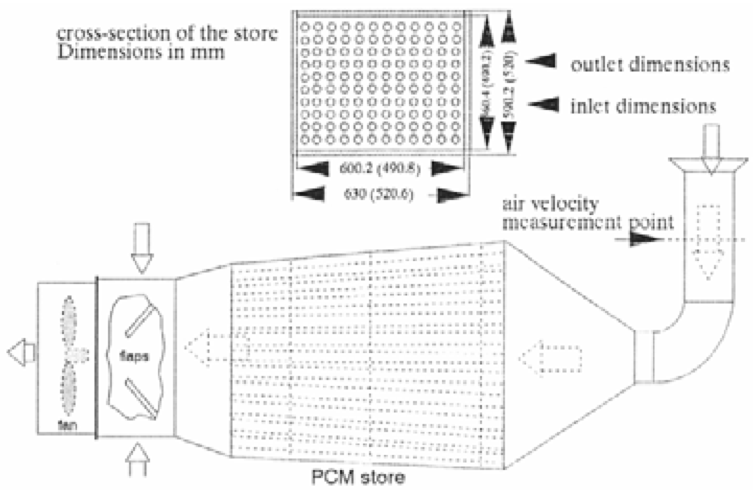

Figure 1. General view and dimensions of the PCM store

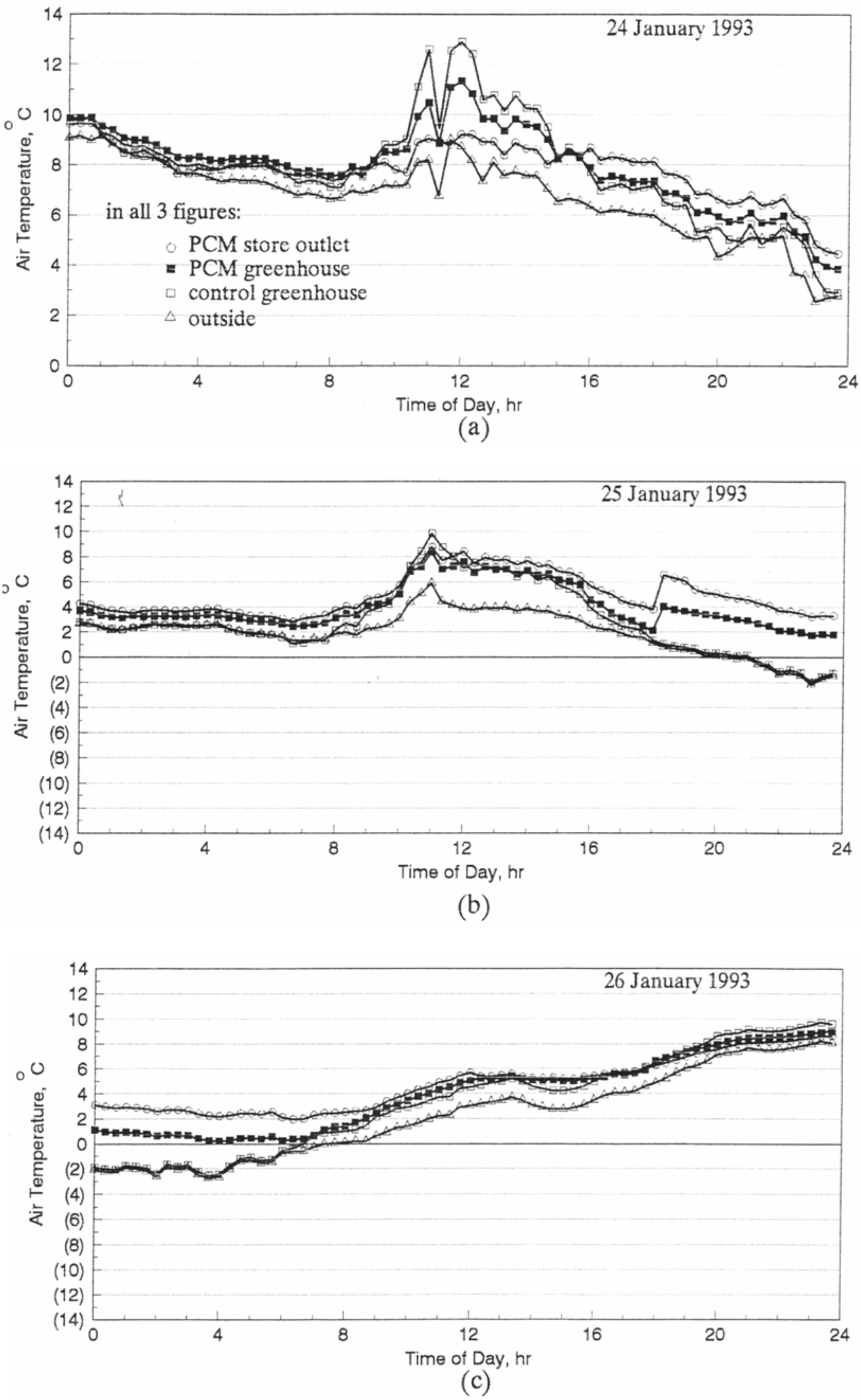

Figure 2. Variation of the air temperature with time of the day on 24, 25 and 26 January

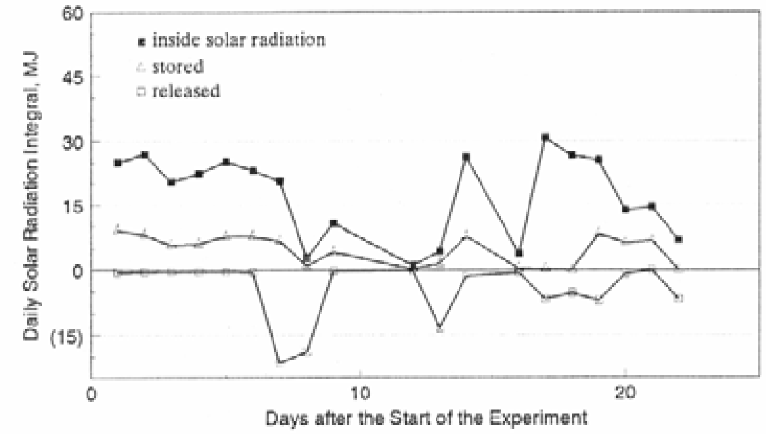

Figure 3. Magnitud'es of energy storage and release by the PCM store

The average of these measurements were taken for the calculations. The air flow rate of the axial circulation fan in the control greenhouse was reduced to the level of the one in the experimental greenhouse on the PCM store (via a net of wire before the fan). Each greenhouse was equipped with a polyethylene duct for uniform air circulation. The control strategy of the flaps on the PCM store was as follows (Ta being air temperature):

If Ta < 2 ^{o}C then flaps open.
If 2 ^{o}C < Ta < 5 ^{o}C then flaps closed.
If Ta > 5 ^{o}C then flaps open.

Although the experiment was started on 10 January, the data recording was commenced on 19 January. This was because the complete set up of the data logger took more time than anticipated.

3. RESULTS

3. 1. Comparison of Both Greenhouses in Terms of Air Temperature

The data presented here include measurements of three successive days in January 1993 only due to space limitation.

Figure 2 shows the variation in temperature of outside, experimental and control greenhouse air together with the store outlet air temperature. On January 24, all temperatures were over 5 ^{o}C until about 22.00 h (Figure 2a). Energy storage continued until about 16.00 h and thereafter a small amount of sensible energy was released until the maximum set temperature was reached in the experimental greenhouse, making its air temperature about 0.4 ^{o}C higher than that of control greenhouse and 1 ^{o}C higher than that of outside. The outside solar irradiance was about 200 W/m^2 at maximum intensity. As the day progressed to 25 January, the air temperature of the control greenhouse approached the outside air temperature (Figure 2b). Energy storage took place on this day from about 11.00 h to 12.00 h. As the temperature of the experimental greenhouse air dropped below 2 ^{o}C at around 18.00 h, the temperatures of the PCM store outlet and experimental greenhouse air went up due to the opening of the flaps on the store and releasing its mainly latent heat. Whilst air temperatures of both the control greenhouse and outside dropped below 0 ^{o}C, the temperature of the experimental greenhouse was kept about 2 ^{o}C until the end of the day. The temperature of the experimental greenhouse air dropped to about 1 ^{o}C on the first part of 26 January (Figure 2c). Later on, all the air temperatures inreased as the day progressed. The minimum air temperatures in the experimental greenhouse were always higher than those in the control one due to energy release from the PCM store. However, when there was no energy storage or release from the PCM store, the air temperatures were almost equal. Maximum air temperatures were higher in the control greenhouse and the diference between the greenhouses was about 2 to 3 ^{o}C. However, average air temperatures for both greenhouses were almost equal.

3. 2. Magnitudes of Energy Storage and Release

Figure 3 shows the extent to which energy was stored or released by the store in the PCM greenhouse for about 22 day experimental period with 20 minutes data recording intervals. On the first day in the figure (19 January), the total solar radiation integral was 25 MJ and whilst approximately 9 MJ of this energy was stored during the day time, only about 0.5 MJ was released at night. The amount of energy released was much less than stored since the air temperature in the greenhouse was above the minimum set temperature for energy release (ie. 2 ^oC). There were 9 days with air temperatures below 0 ^oC during the data recording period. Frost was prevented on 8 occasions. The frost occurred randomly throughout the experimental period. About 6 MJ was released at night on the day number 17, 18 and 19 which coincided with 4, 5 and 6 February respectively, although there was almost no energy stored during the day time on 4 and 5 February. This surplus energy was left from the previous days. The fraction of solar radiation which was stored in the PCM store was about 30 %.

4. CONCLUSIONS

The thermal performance of the experimental greenhouses showed that frost protection was provided on days with frosty outside air. If the melting temperature of the PCM was lower, say about 5 ^oC, then it would be possible to store more energy than the PCM investigated here with 8 ^oC melting temperature. Such a PCM would need a freezing temperature of about 2 to 3 ^oC to be able to maintain the inside air temperature over 0 ^oC, which would have to be developed.

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