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SOLAR HEATED HOME USING AN ATTACHED GREENHOUSE AND A WOODBURNING STOVE

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SUMMARY:

A civil war era residence has been retrofit with an addition and an attached solar greenhouse. There is a flooded subfloor storage/ heat exchanger under the addition and the greenhouse. Water can be circulated from the subfloor storages through the woodstove as the first stage backup. The oil fired second stage backup has not been needed since the system became operational in February 1980.

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ABSTRACT

An important feature of the Rutgers system for solar heating of commercial greenhouses is a flooded sub floor that serves as a massive storage and enables the entire floor surface to act as the primary heat exchanger. Preliminary studies indicate that adapting this concept to a residential space heating system would enable the solar system to operate at low temperatures, about 25 to 30°C, facilitating the use of simple and low-cost solar collection systems.

An addition has been retrofit onto a 125-year old residence with a flooded sub floor, which serves as thermal storage and enables the floor surface to become the primary heat exchange surface. There is also an attached greenhouse on the south side with a similar floor storage. Water from either floor can be heated by solar collectors or a backup system. Warm air from the greenhouse can be circulated through the house during the day. The primary backup system is a woodstove with a water-heating coil, which can be used to heat either the greenhouse or the residence or both. The pre-existing oil-fired heating system is the final stage of backup.

The woodstove backup unit became operational during the first week of February 1980, and the greenhouse was glazed by the middle of March. No attempt was made to keep the greenhouse warm during the late spring of 1980 as construction was still in progress. The greenhouse and the woodstove backup system both were fully operational for the start of the heating season in the fall of 1980. The temperatures in the residence and operation of the oil burner were monitored since the spring of 1980. Since the fall of 1980 the temperatures in the greenhouse and of the floor storage systems have also been monitored and the thermal performance of the system determined. Air temperature in the residence has been maintained above 20°C, the greenhouse above 10°C and the oil-fired backup has not been used since early February 1980. All space-heating needs are met by the woodstove and passive gain from the greenhouse.

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INTRODUCTION

Research at Rutgers focusing on energy conservation and alternative energy sources for commercial greenhouses has been underway since 1972. The concept of utilizing a flooded floor, as the primary heat source in a greenhouse was first presented publicly in 1974 (Mears et al.) and the concept was developed into a practical component of a greenhouse solar heating system in 1975 (Roberts et al.). The greenhouse floor system is constructed by laying a plastic swimming pool liner over a layer of insulation board, which serves primarily as mechanical protection for the liner. A 23 cm deep layer of nominal 2 cm stone is then placed in the liner. Void spaces in the stone are usually 45 to 50% and when flooded with water provide most of the thermal storage. Usually the greenhouse floor is then capped with a 7.5 cm layer of porous concrete. The water in the floor can be pumped through solar collectors or heated by a fossil fuel backup system in cloudy weather.

In working with this floor storage/heat exchange system in greenhouses a number of advantages have manifested themselves which should also apply to residences and other heated buildings. The construction of the floor storage system is not difficult and is inexpensive per unit storage capacity. The concrete floor is often used in non-solar installations. Therefore, the extra materials required are the insulation board, swimming pool liner, stone and some perforated plastic drainage pipes to distribute the water. The storage is relatively massive providing a capacity for exchanging large quantities of heat with low storage temperature changes. As the floor is also the primary heat exchanger and is large in area, there is a high degree of thermal coupling with the heated space so the storage temperature can be relatively low. Typically, in greenhouse applications the storage temperature is on the order of 25°C and the temperature change throughout a daily collection/utilization cycle is about 50°C. The system is completely unobtrusive. The floor surface is identical to that in a non-solar greenhouse with the exception that it is warm. It has been found that one of the most important advantages of this system is that most plants benefit from having their root zone warmed and that in a warm floor situation air temperatures can be reduced significantly with no adverse results on the plants. Also, the research workers have noted that we are very comfortable when working on a warm floor even though air temperatures may be about 5°C lower than normally considered adequate. If comfort can be achieved with lower air temperatures, then energy loss from the heated space can be proportionally reduced.

A small, insulated instrumentation shed was constructed on the Rutgers Campus as a prototype for the adaptation of the greenhouse heating system to a residential system. The foundation was modified to accept the floor storage system. A 0.51-mm-thick polyvinylchloride swimming pool liner was laid over 2 cm of plastic foam insulation board. The liner was filled with 15 cm of nominal 2 cm crushed rock and another layer of swimming pool liner was laid over the top and glued to the edges of the bottom liner enclosing the gravel in a sealed bag. This was then capped with 7.5 cm of concrete for a finished floor. An access to the floor was left in one corner so water could be pumped in and out of the void spaces in the gravel.

Tests were conducted to determine the thermal coupling of the heated space to outdoors, of the floor storage system to the heated space and the floor storage to the ground. These values were found to be 0.40 W/m^2K for the building to outside including infiltration, 5.0 W/m^2K between the water in the floor storage and the air in the heated space, and 2.5 W/m^2K between the storage and ground. This last figure is much higher than would be expected for a well-designed foundation. The building is very small and there was no perimeter insulation. The insulation under the liner is only 2 cm thick and is open cell. Normal practice would require the installation of at least 5 cm of closed cell plastic board insulation around the perimeter of the foundation.

Based upon the measured thermal coupling between the storage and the heated space, a theoretical study was done to evaluate the application of this system to a single-family residence. Utilizing the entire floor as a heat transfer/storage area and assuming the building was reasonably well insulated (double windows, 15 cm of insulation in the walls and 30 cm of insulation in the ceiling), calculations indicated that the building could be maintained at a comfortable temperature inside when it was -18^{o}C outside with water in the floor at 28^{o}C. Calculations for winter conditions in New Jersey indicate that inside temperature levels can be maintained in the range of 17-20^{o}C with floor water temperatures of 25-30^{o}C.

DESIGN OF A RETROFIT RESIDENTIAL APPLICATION

A solar heating system for an existing residence was designed utilizing the information obtained in the experimental program outlined above and data and experience from the commercial greenhouse work. The residence to be retrofit was a 2-story balloon frame house 8.5 m by 8.5 m. The existing foundation consists of fieldstone walls laid up in clay. Full thick fiberglass batt insulation had been previously retrofit into the wall cavities and attic floor. Over the past several winters, the fuel oil consumption of the residence has averaged about 4500 liters for space heating and domestic hot water.

The first part of the retrofit involved the construction of a 2-story addition coming out 4 m from the existing west wall and running the entire 8.5 m width of the house. The second part involved the addition of a 3 m wide by 8 m long lean-to style greenhouse on the south side, overlapping the old and new parts of the house. The flooded sub floor system for heat storage and transfer is incorporated under both the addition and the greenhouse. Figure 1 illustrates the solar energy utilization concepts of the system. During the day, surplus heat in the greenhouse can be circulated directly to the residence. If there is more heat available than required by both buildings, the normal greenhouse vent will take over.

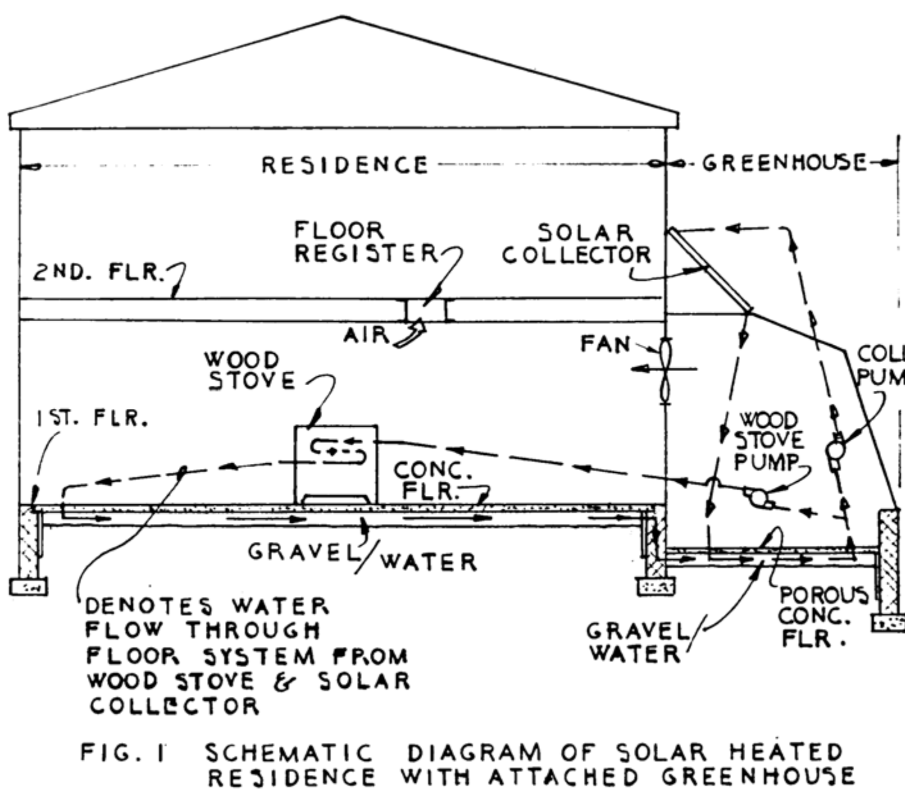

FIG. 1 SCHEMATIC DIAGRAM OF SOLAR HEATED RESIDENCE WITH ATTACHED GREENHOUSE

The operation of the water-based solar heating system can also be followed in Fig. 1. Water in the greenhouse floor can be pumped through vertical curtain solar collector/heat exchange units hanging inside the greenhouse against the north wall and/or pumped to external collectors. Water from the greenhouse floor can be pumped through water heating coils in a woodstove located in the addition to the floor storage under the addition. There is an overflow to return this water to the greenhouse floor. Thus, solar energy collected in the greenhouse can be transferred to the storage in the residence.

By operating the pump in the greenhouse and firing up the wood stove, which is the first stage backup system, energy can be added to the residence and the greenhouse. A second pump is installed in a pit in the storage area under the residence floor. This pump can circulate water from the residential storage through the woodstove to add energy to the residential storage without adding any to the greenhouse. Check valves are installed after each pump so that either pump will only circulate through the stove. The receptacle for the pumps is energized through a thermostat which senses temperature in the water coil in the woodstove so that whichever pump is being used will only run when the stove is hot. The final stage of backup is the preexisting baseboard hot water system. Details of construction of the sealed sub floor storage system under the residence portion are shown in Fig. 2.

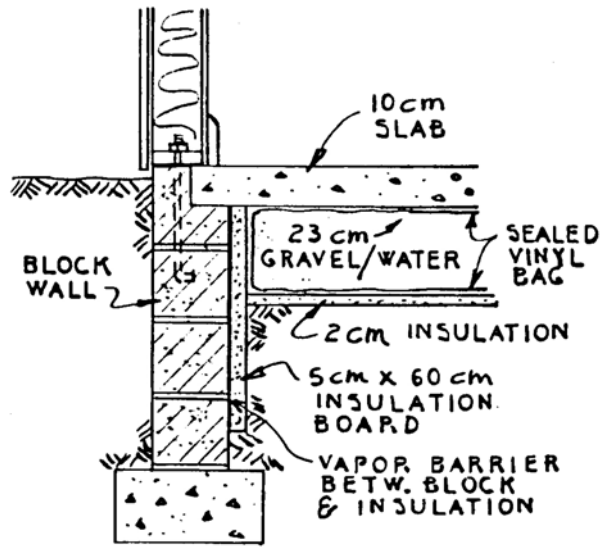

FIG. 2 DETAIL OF RESIDENTIAL FLOOR STORAGE SYSTEM

CONSTRUCTION AND OPERATION

The construction of the floor storage systems and the addition to the residence proceeded smoothly and on schedule. However, the greenhouse did not arrive until a month after schedule and broken glass was not replaced for another month. There was a break in the weather in mid-February 1980, which was utilized to complete the greenhouse frame.

The woodstove system became operational in early February 1980 and at the end of the first week, timers were installed to monitor operation of the backup furnace. The same oil burner is used for space heat and domestic hot water. A timer is installed on the circulator for the baseboard hot water heating system and another on the oil burner so the fuel use for each system can be

Figure 3 Water pre-heat coils in greenhouse

ascertained separately. Since the timers were installed in February 1980 the baseboard circulator has not operated. Therefore there has been no oil consumption for space heat. The oil burner has operated a total of 260 hours over a 58-week period to provide domestic hot water and standby losses. At a firing rate of 3.2 liters per hour, daily oil consumption for these functions is 2.0 liters. A pipe coil to preheat domestic hot water was laid in the greenhouse floor but only recently connected. Figure 3 shows this coil, distribution pipes, and gravel being added to the greenhouse floor. In the first month of operation this coil has been preheating the domestic hot water about 12^{o}C and the indicated fuel savings are approximately 20%. An active solar collection system for the domestic hot water system is planned. The completed greenhouse and addition to the residence are shown in Fig. 4. (The solar collector is now shown)

Figure 4. This photo taken in the winter of 2004 replaces the original black and white photo.

THERMAL PERFORMANCE

Data have been collected on the thermal performance of the system. During the spring of 1980 temperatures in the greenhouse and in the residence were recorded continuously. The woodstove only acted as an air heater as the pumps to circulate water from the floors under the greenhouse and residence had not been connected. The temperature in the residence was maintained between 20 and 22^{o}C most of the time. On sunny days after the greenhouse was completed, the temperature in the residence rose to 26^{o}C. The coldest weather of the winter of 1979-80 was in the last week in February 1980. On the coldest night, it was -14^{o}C outside and the lowest temperature in the residence was 18^{o}C.

Although a fan to circulate air from the greenhouse through the residence was provided, experience has shown that this is not needed. The greenhouse communicates with the residence through a window and a sliding glass door. There is a floor register over the woodstove in the residence as shown in Fig. 1. It has been found that natural air circulation through greenhouse and residence is adequate to maintain desired temperatures during the day. In cloudy weather air circulation from the woodstove is adequate for all rooms in the residence except the den, which is in a cul-de-sac at the northeast corner of the ground floor.

In the fall of 1980 the pumps were hooked up so that the woodstove could provide floor heat to the residence and the greenhouse. The major advantage of the system described in this paper is the use of the flooded floor for storage and heat exchange. As soon as heat was added to the residential floor the improvement in the comfort level in that room was clearly evident. The floor system gives off heat slowly; carrying the heat load of the building over a long time period after the fire in the stove has been allowed to go out. The warm floor gives an excellent environment to the room and one is comfortable even if air temperatures are lower than normally desired.

In the fall of 1980 a multipoint thermocouple recorder was installed to monitor air temperatures at several strategic locations. The thermal performance of the total system is shown for a 24-hour period during Christmas 1980, the coldest period of the 1980-81 winter. Figure 5 shows the outside temperature and the temperatures in the residence and greenhouse. Also, as the stove was operating during this period the temperatures of the water coming into and leaving the stove are also shown. Both pumps were used during this time interval and it can be seen that when the pump from the greenhouse floor is on, the water coming into the stove is cooler than when the inlet water comes from the residence. Although the data are not shown on the figure, the water, which leaves the residence floor to circulate through the greenhouse floor, is normally at a temperature about midway between the exit from the stove (entrance to residence storage) and the inlet to the stove (exit from greenhouse storage). Thus the residence and the greenhouse roughly divide the heat contributed by the stove to the water storage system. The amount of heat delivered varies depending upon the temperatures being maintained in the greenhouse and residence. Throughout the winter the greenhouse has usually been held at 10 to 16°C nighttime with the minimum of 8.5°C shown in Fig. 5 being the lowest for the year. Normally the residence was held at 21°C, and again the low for the year of -19°C is shown in Fig. 5.

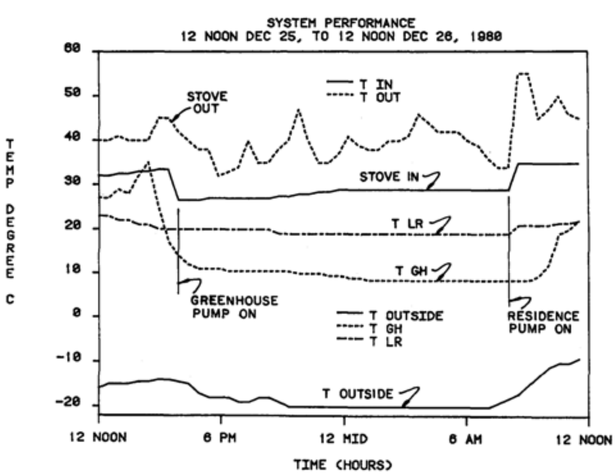

Figure 5. System performance with the woodstove running

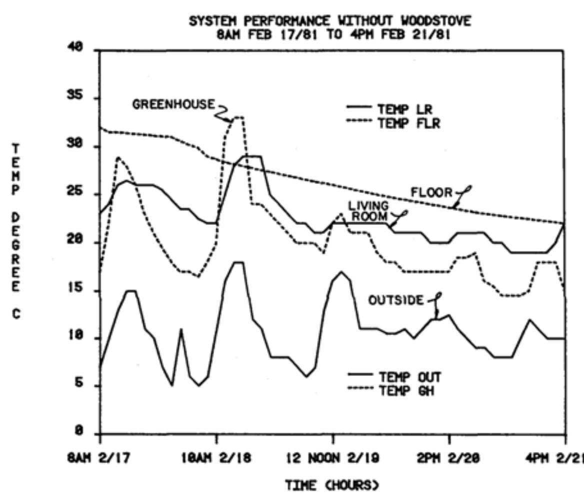

Figure 6. System performance with the woodstove off and coasting

The fluctuations in the output temperature from the stove shown in Fig. 5 are largely due to operator intervention. The house was full of company and there were many demonstrations of 'how to adjust the thermostat on the stove door' and how to add fuel. Normally, if the temperature settings are not changed, the output of heat from the stove is much more constant. It should be noted that in this system the stove thermostat regulates on air temperature. Thus when the weather is very cold, the stove will burn hotter to maintain air temperature and therefore heat output to storage will increase. Thus after an extended period of cold weather the storage will be at its highest temperature.

The data shown in Fig. 6 represent the thermal performance of the system for a four-day period of relatively mild weather, which followed an extended cold period. At the start of this period the temperature of the storage under the residence at the exit was 32^oC and during this four-day period storage temperature dropped 10^oC to 22^oC. Three of the four days were generally overcast and one was moderately sunny as can be seen from the greenhouse temperatures. During the four days shown there was no fire in. the woodstove, so all of the heat required to maintain the greenhouse and residence temperatures shown came from storage and from the solar input from the greenhouse on the one sunny day. This situation demonstrates the advantage of having a relatively large storage system tied to a woodstove and/or solar collector system.

ENERGY BALANCES

It should be noted that energy balances for this system are difficult to determine and that more instrumentation would be required for a detailed energy balance. The fossil fuel input was carefully monitored, but since the total input for space heat was zero, the care taken to obtain that measurement was not needed. The thermal output of the stove to water storage is also accurately measured as the water flow and temperature difference of the water across the stove are both continually monitored. No direct measure of heat input by the woodstove to the air or of the solar contribution to the residence from the greenhouse can be directly measured with available instrumentation.

Prior to remodeling, the residence had an established energy requirement of 20 GJ per year for domestic hot water and 100 GJ per year for space heat. The space heat requirement was calculated to be 440 W/K. The addition increased the residence volume by 50%; the exposed surface area by 30% and the calculated space heat requirement was calculated to increase to 572 W/K. The space heat requirement for the single glazed greenhouse with an operating thermal curtain was calculated to be 128 W/K. Thus if the greenhouse were held at the same temperature as the house, the space heating requirements for the residence would be 159 GJ per year and for the greenhouse 29 GJ per year for a total space heating requirement of 188 GJ per year.

The greenhouse is insulated with a movable curtain insulation system and the design peak heating load of 28 K delta T, will be about 3.6 kW. This requirement can be met by heat transfer from the 22 m^2 floor alone if the water in the greenhouse is at least 34^oC. This minimum floor temperature requirement is reduced due to a heat contribution from the warmer residence to the greenhouse.

ENERGY FLOWS

The water flow rate through the stove was measured with an integrating flow meter and found to be 8.6 liters per minute for either pump. The temperature rise of the water passing through the stove depends upon the intensity of the fire, which is controlled by a thermostat-operated air inlet. Typically, when the fire is banked down to a minimum, the water is heated 5 K and when the fire is burning at its hottest the temperature rise of the water passing through the stove is 10 to 15 K. Thus heat inputs to storage range from 11 MJ per hour when the fire is low to a maximum of 55 MJ per hour when the fire is hottest. Typically the heat rate to storage is in the range of 22 to 33 MJ per hour.

The thermal mass of the greenhouse floor storage and the residence floor storage have been determined by measuring the mass of the stone and concrete used in construction and by metering in the water required to fill each. The thermal mass of the residence floor storage is 21 MJ/K and that of the greenhouse floor storage 23 MJ/K.

Estimation of the heat transfer rates from storage to the residence and greenhouse is difficult as the thermal masses are so large and it is very difficult to maintain steady state temperature conditions in the residence, the greenhouse and both storages over a period of many hours. A temperature change in storage of 0.2 K per hour is roughly equivalent to the total heat transfer from the floor surface. The best estimates obtained so far for the heat transfer coefficients are: 5.2 W/m^2K for the residence floor and 6.9 W/m^2K for the greenhouse floor based on the temperature difference between the air in the heated space and the stored water. The measured heat transfer coefficient of the greenhouse to outside with the thermal curtain pulled closed is 3.4 W/m^2K. These values determined at different times vary about 10%.

SUMMARY AND CONCLUSIONS

It should be noted that this retrofit was based primarily on the desire of the residents to add to their living space and to add an attached greenhouse for houseplants. Given these objectives the design was prepared to utilize solar energy and a woodstove backup to minimize fossil fuel consumption.

The most important feature of the system is the flooded sub floor storage/heat exchanger. The most important aspect of this feature is the comfort level associated with floor heating. Also, the massive thermal storage works well with both solar and woodstove heat inputs.

The thermal curtain and reduced night temperatures in the greenhouse to 10^oC are essential to reducing the total heat requirement of the greenhouse. Floor heating in the greenhouse provides a better plant environment for those plants on the floor than would a 10^oC greenhouse with a cold floor.

The retrofit has provided extremely pleasant living space and enabled fossil fuel consumption for space heat to be eliminated.

Improved data monitoring techniques enabling a more precise determination of internal energy flows to be made would be extremely beneficial.

ACKNOWLEDGMENTS

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REFERENCES

1. Mears, D.R., W.J. Roberts and J.C. Simpkins. 1974. New Concepts in Greenhouse Heating. ASAE Paper No. NA 74-112, ASAE, St. Joseph, Michigan.
2. Roberts, W.J., J.C. Simpkins and P.W. Kendall. 1976. Using Solar Energy to Heat Polyethylene Film Greenhouses. Proceedings of the Solar Energy, Fuel and Food Workshop, University of Arizona, Tucson, Arizona.
3. Mears, D.R. Residential application of the Rutgers system for solar heating of greenhouses. 1980. Proceedings of the 1980 Annual Meeting of AS/ISES. Vol. 3.1 pp 247-250.

ADDENDUM 2004

As of the summer of 2004 the system described in this paper, has been run continuously since it was first constructed and put into operation. During this time the combination of solar energy and the woodstove have provided all of the space heating requirements when the residents were at home. Several times when the house has been unoccupied for a few days in the winter and the woodstove was allowed to go out, the oil fired back up heating system in the house has come on. If the woodstove is left on with a full charge of wood it will burn for most of a day, even in the coldest weather. After the fire burns out, the stored heat in the floor will maintain the house above the oil furnace's thermostat set point for some time as shown in Figure 6, though not for as many days in much colder weather. While away for an extended period, the practice has been to set this thermostat to come on at about 14^oC so that the house will warm up reasonably quickly when firing up the stove upon return. Except for these periods of extended absence, no heating oil has been required for space heat.

Experience has shown that an effective and simple management system for the greenhouse and residence floor heating storages is to operate them separately most of the time. In late fall to early spring the solar collector is used to heat the greenhouse floor and the rest of the year it is used for domestic hot water heating. The domestic hot water heating system consists of an open storage tank heated by the solar collector with a preheat coil in the tank. Potable water enters the preheat coil from the pressure tank and then passes through the oil fired furnace which is set up for both space heating and domestic hot water heating. There is a bypass line so when there is sufficient heat in the storage, the oil furnace can be shut off, thereby saving the standby losses from that unit. The fan shown in Figure 1 has proven to be unnecessary and has been removed.

The major use of heating oil is now for the backup for the domestic hot water in the warm months, which is very little, and for providing the domestic hot water in the winter when the solar collector is dedicated to the greenhouse. Oil consumption is on the order of 1,000 liters per year recently. In the early years when more attention was paid to system operation and bypassing the back up when there was adequate solar energy in storage, oil consumption was closer to 500 liters per year. The domestic hot water system back up heating requirement could have been significantly reduced had an energy efficient oil-fired hot water heater been installed to use for this purpose.

The greenhouse was kept close to a minimum of 10^oC most of the time in the first several years but with experience some changes in greenhouse management have been implemented. As the major function is maintaining a wide variety of household plants in good condition rather than maximizing growth, it has been found that infrequent drops to as low as 5^oC are acceptable. After adding a second layer of curtain material to the movable insulation curtain it has been found that, in almost all conditions, this temperature and more can be maintained with the solar energy stored in the floor alone. Some heat does come in through the door and window connecting the greenhouse to the house. In extremely cold nights the window and sliding door between the greenhouse and house can be kept partially open to allow for some circulation with the warmer house.

The heating systems for the residence floor and the greenhouse floor have been essentially decoupled as noted above. The woodstove heats the residence floor storage with the 40-watt circulating pump installed in the floor storage reservoir running whenever the stove is burning. The solar collector is used to heat the greenhouse floor in the wintertime. One other change allows some heat provided from the woodstove to the residence floor to be delivered to the greenhouse floor storage. The domestic hot water preheat coil in the greenhouse floor has been taken out of that line and put into a loop with a 40 watt pump that can circulate warm water from the residence floor that has been heated by the woodstove. This enables some heat provided by the woodstove to be added to the greenhouse floor storage. This is not required every winter but has been used several times when there has been extremely cold outside temperatures following an extended sunless period. If this situation has caused the greenhouse floor storage to cool below the temperature needed to keep the greenhouse at the desired air temperature some addition of heat from the residence floor storage increases greenhouse floor temperature slightly.

In summary, over the last 16 plus years there has been essentially no fossil fuel requirement for space heating beyond the need for electricity for a 40-watt pump, i.e. essentially 1kWhr per day during the heating season. Wood consumption has been between 3 and 4 cords of wood per year all harvested from dead trees on the property, which is 2.8 hectares.

The residence was requiring 4500 liters of fuel oil per year for space heat and domestic hot water before the additional living space that increased the house floor space by 50% and the greenhouse. It is estimated that these additions would have increased annual fuel consumption to at least 7000 liters per year so the fuel oil savings is on the order of 2500 liters per year. At $0.40 per liter for home heating oil, this represents an annual saving of $1000 per year.