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**PASSIVE SOLAR HEATING OF BUILDINGS WITH ATTACHED
GREENHOUSE**

Progress Report for February 29—April 29, 1980

By
Robert W. Jones

April 1980

Work Performed Under Contract No. AC02-79CS30242

University of South Dakota
Vermillion, South Dakota

U.S. Department of Energy

Solar Energy

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PASSIVE SOLAR HEATING OF BUILDINGS
WITH ATTACHED GREENHOUSE

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for Period February 29, 1980-April 29, 1980

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Prepared for
THE U.S. DEPARTMENT OF ENERGY
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Abstract

Research is being conducted on the attached-greenhouse type of passive solar heating system in the north-central region. The thermal performance of attached-greenhouse buildings is being analyzed in order to determine the component sizes and configurations which optimize performance. The analytical method is dynamic computer simulation using a thermal network model and actual hourly meteorological and solar radiation data from the north-central region. Progress in this, the third quarter, of the project has consisted of a large number of additional computer simulation runs and resulting performance estimates for certain designs. Conclusions on design guidelines are emerging from the results. The overall aim of the project is the development of specific design guidelines useful to architects and builders.

Progress Report

Research is being conducted on the attached-greenhouse type of passive solar heating system in the north-central region. General goals of the research are:

- 1) To evaluate attached-greenhouse passive solar heating in terms of the expected fraction of the total heating load provided by solar energy.
- 2) To investigate the constraints imposed on performance by traditional, wood-frame design and construction practices, especially for use of an insulated frame wall between the greenhouse and the residence.
- 3) To develop specific design guidelines for an attached greenhouse incorporated in new construction, or in a retrofit to an existing building, of traditional design and construction.
- 4) To investigate non-traditional designs appropriate to optimum performance, and to develop specific guidelines for any such designs.

The analytical method is dynamic computer simulation using a thermal network model of the building. Actual hourly meteorological and solar radiation data from selected cities in the north-central region will drive the computer simulations. The principal progress in this, the third quarter, of the project is additional computer simulations for certain attached-greenhouse designs using the hourly typical meteorological year (TMY) data for Bismarck, North Dakota. For details about the models used, and the definitions and values of certain reference design parameters, refer to the second quarterly progress report for the period November 20, 1979 to February 28, 1980, document number DOE/30242-2.

Preliminary conclusions are now available on all of the above listed goals:

- 1) An evaluation of attached-greenhouse passive solar heating in terms of the expected solar savings fraction (SSF) is provided for Bismarck by Figure 1, a plot of the SSF versus the load/collector ratio (LCR). The LCR is the single most important design parameter affecting heating performance. It is defined by

$$LCR = BLC/A_c$$

where BLC, the building load coefficient, is the steady-state heat loss through all building surfaces

except the south solar wall, and A_s is the solar collection area which is the area of principal greenhouse south-facing glazing or glazings projected on a vertical surface. Since LCRs in the range of 10-20 are available without radical departures from standard construction practices, SSFs in the range .25-.65 should be available for Bismarck.

- 2) There are no severe constraints imposed on performance by traditional, wood-frame design and construction practices. In particular, the use of an insulated frame wall between the greenhouse and the residence, with thermo-circulation vents for heat transfer, has a comparable performance to other types of solar walls. Figure 2 illustrates the performance compared to a water wall. The performance is similar for small storage volumes, about 0.1 to 0.2 cu ft/sq ft, but the water wall outperforms the insulated wall by 8-14% for large storage volumes, above 0.5 cu ft/sq ft. Some of this difference is accounted for simply by the chosen shape of the storage container in the insulated-wall reference design. A high, thin container performs more nearly like a water wall. (See Figure 4 for the sensitivity of the solar savings fraction to storage shape.)
- 3) Specific design guidelines follow from the studies of the SSF sensitivity to the variation of design parameters shown in Figures 3-19. Under the design parameter headings which follow, I have indicated the Figures from which the conclusions are drawn.

Storage volume (Figure 3 and Figure 4 of previous report). Performance increases sharply with storage volume for all glazing systems up to about 0.2 or 0.3 cubic feet of water per square foot of wall area, after which the performance continues to improve but more slowly. This suggests a minimum storage volume of 0.2 or 0.3 cubic feet per square foot of wall area, and a maximum storage volume limited only by other considerations such as available space.

Glazing system (Figure 3 and Figure 4 of the previous report). The options studied were double and triple glazing both with and without night insulation. The percentage improvement in solar savings over the double-glazed, non-night-insulated case are as follows (approximate values for storage volumes in the range 0.3 to 1.0 cu ft per sq ft):

triple-glazed, no night insulation	30%
double-glazed, night insulation	65%
triple glazed, night insulation	75%

Adding night insulation to double glazing has more than double the benefit of adding a third pane to the glazing. Adding a third pane to a night-insulated, double-glazed system adds only ten percent to the solar savings. These facts argue for night insulation rather than triple glazing, but the relative inconvenience and/or expense of night insulation is a disadvantage. Which is preferable in a given situation would depend on more specifics than have been studied here.

Glazed end walls (Figure 3). Glazed east and west end walls are a clear thermal disadvantage. For the reference design, they reduce the solar savings by 15% when there is night insulation and by 35% when there is no night insulation. The end walls taken together comprise 35% of the south glazing area. The design rule is to avoid east and west glazings unless they are considered important for non-thermal reasons such as added light for plant growth.

Storage shape (Figure 4). The solar savings fraction is not strongly sensitive to storage shape, at least within the limits of this study, in which the height-to-depth ratio of the container was varied. The range of solar savings variation with shape is about 5% without night insulation and 10% with night insulation. The design rule is that a low, flat container which covers the sunspace floor (provided that such a container is practical and can be directly illuminated), or a tall, thin container which covers the wall (such as a row of Kalwall water tubes), or (presumably) both, are the best shapes, but relatively square shapes do not reduce the solar savings by more than about 5% without night insulation or 10% with night insulation.

Color of wall and storage container (Figures 5-8). The solar savings increases linearly with wall and storage container absorptances, at least within the range of normal variability of these parameters. Between 0.9 (corresponding roughly to black paint) and 0.3 (corresponding roughly to white paint) the solar savings reduction is about 6% when the wall color is changed and about 12% when the storage container color is changed. The effect is almost exactly linear: if both the storage container and wall color are changed from absorptivities of 0.9 to 0.3, the solar savings reduction is 18%. These results apply to the reference design in which the storage container covers 47% of the wall area. The design rule is that, area for area, the color of the storage container is twice as important as that of the wall. Both should be made as near to flat black as is compatible with other design considerations, such as even illumination of plants, but other dark colors such as brown or blue can be used without a substantial performance penalty.

The effect of a selective surface on the storage container was investigated with the result that the solar savings is slightly improved by a low infrared emissivity, but the effect is so small as to be negligible. The design rule is that selective surfaces need not be considered.

Color of floor (Figure 9). The solar savings depends significantly on the absorptivity of the floor. For the reference design the solar savings is reduced by 22% if the absorptivity is reduced from 0.9 to 0.3. Area for area the floor color is as important as the wall and storage container color. The same design rule which applies to the wall and storage container applies to the floor.

Color of end walls and ceiling (Figure 10). The solar savings increases only slightly with increased absorptivity of these surfaces. Their color may be chosen on some other basis than thermal performance such as light colors chosen for more uniform plant illumination.

Wall conductance (Figure 11). An uninsulated wall performs marginally better than a well-insulated wall in a night-insulated system and marginally worse in a non-night-insulated system, but the difference is so small as to be negligible. The design rule is that the average performance does not depend significantly on the wall conductance. Therefore, in new construction the insulation may be omitted. In a retrofit, the existing wall may be either insulated or not.

Vent area (Figure 12). The thermocirculation vent area is expressed as the area of either the upper or lower vents (assumed to be equal) divided by the wall area. As such, the solar savings increases with vent area up to at least a vent area of 0.1. The increase is rather abrupt up to a vent area of about 0.01 or 0.02, then is very slow after about 0.03. The design rule is to size the vents at 0.03 of the wall area or more.

Glazing tilt (Figure 13). The optimum glazing tilt for Bismarck (47°N) is approximately 58°. The optimum is quite broad, the reduction in solar savings being about 5% for tilts of $\pm 15\%$ from the optimum. For a vertical glazing the reduction is about 25%. There is probably a good correlation between optimum tilt and latitude, but only Bismarck has been studied so far. A preliminary design rule which is consistent with the Bismarck result is the glazing tilt should equal the latitude plus 10°.

Sunspace geometry

a) One glazing plane (Figure 14). The design variable in question is the glazing tilt. Unlike the study shown in Figure 13, a designer would probably have no reason to

keep the glazing area constant for various tilts. So, the variation in solar savings with glazing tilt is also partly due to the variation in glazing area. In fact, the glazing area decreases with increasing tilt, so the optimum glazing tilt is shifted to a smaller angle. Without night insulation the optimum is approximately 50° . With night insulation the optimum is much less well defined but is in the vicinity of 30° - 40° . A preliminary design rule for a single-glazing-plane geometry is that the glazing tilt should equal the latitude for a non-night-insulated system, and equal to or greater than the latitude for a night-insulated system.

b) Two glazing planes (Figures 15 and 16). A designer often decides to use two glazing planes in a sunspace geometry, one vertical and one tilted. There are legitimate design reasons for this decision, but a substantial performance penalty is incurred. In the case of the reference design for Bismarck, retaining the same sunspace depth but using a six-foot vertical glazing and a tilted one above it reduces the solar savings by about 25% for a night-insulated system and 40% for a non-night-insulated system.

Suppose certain non-thermal criteria have led the designer to choose two glazing planes, one vertical and one tilted. The question then is what sunspace depth, or equivalently what angle for the tilted glazing segment, leads to an optimum performance. For Bismarck there is a broad maximum in the solar savings for a tilt in the range of 50 to 60 degrees. An entirely vertical glazing reduces the solar savings by about 8% for either a night-insulated system or a non-night insulated one.

Ceiling depth (Figure 8 of the previous report). The sunspace may have a horizontal, unglazed ceiling. Some benefits include an increase in the useable floor space for a given glazing geometry and a decrease in summer over-heating. The penalty in terms of winter heating performance is not great, being about a 1% reduction in solar savings per foot of ceiling depth.

Resistance of night insulation (Figure 17). The solar savings increases as the thermal resistance of night insulation on the greenhouse glazing increases, rapidly at lower R-values, more slowly at higher R-values. Half of the solar savings increase obtained at R9 is obtained at R2, and three-fourths is obtained at R4. No clear design rule emerges from these facts alone. Cost and convenience factors must be taken into consideration, too. For instance, if R3 or R4 can be exceeded only at considerable additional cost or inconvenience, then it may not be advisable. On the other hand, if R9 can be achieved as easily as R5 with only modest cost increase (as might be the case with moveable panels), then the R9 may be preferable.

Lower thermostat set points (Figures 18 and 19). The solar savings is very sensitive to the living space lower thermostat set point. A 10°F decrease in the set point from 65°F to 55°F increases the solar savings fraction by 20%. But the reference load has also been reduced by 29%. The total solar savings compared to the 65°F reference load is 39%. These facts do not bear directly on design except to show that performance is not a matter of design only, but occupant behavior can have a large impact. The greenhouse lower thermostat set point has a negligible effect on solar savings up to about 50°F, and a negligible effect for night-insulated systems up to 60°F or more. The point is that very little auxiliary heat is required by the reference design up to these temperatures. The design rule is that no special consideration need be given to a minimum temperature requirement in the greenhouse (due, for instance, to plants which are intolerant of low temperatures). This is not to say that an occupant need not protect the greenhouse against occasional low temperatures, but that the occurrence is rare enough that it does not affect the average annual performance of the system.

- 4) Non-traditional designs appear to be unnecessary for good thermal performance, meaning primarily that an insulated wall with vents performs almost as well as a thermal-storage wall (see Figure 2). But it also appears that a thermal-storage wall does perform somewhat better and so might be preferable in new construction if the cost differential is not large.

Many more parametric studies of the type reported here are needed before reliable and general design guidelines can be advanced with confidence. Of the greatest need are studies using locations and loads other than Bismarck and $LCR=24 \text{ Btu/DD ft}^2$. As many such studies as possible will be performed in the next quarter.

A design tool of great importance is the Los Alamos Scientific Laboratory (LASL) solar/load ratio (SLR) method of performance estimation. This method allows a designer to estimate the performance of a design on the basis of just one parameter, the solar/load ratio. This method has been extended to include attached-greenhouse systems, as one aspect of the present project, jointly with LASL.

Figure 1. Solar savings fraction as a function of load/collector ratio.

Figure 2. Performance comparison between insulated-wall and water-wall systems.

Figure 3. Sensitivity of solar savings fraction to glazing system.

Figure 4. Sensitivity of solar savings fraction to storage shape.

Figure 5. Sensitivity of solar savings fraction to the optical absorptivity of the south wall.

Figure 6. Sensitivity of the solar savings fraction to the optical absorptivity of the storage container.

Figure 7. Sensitivity of the solar savings fraction to the optical absorptivity of the south wall and storage container, varied simultaneously.

Figure 8. Sensitivity of the solar savings fraction to the infrared emissivity of the storage container.

Figure 9. Sensitivity of the solar savings fraction to the optical absorptivity of the floor.

Figure 10. Sensitivity of the solar savings fraction to the optical absorptivity of the ceiling and end walls.

Figure 11. Sensitivity of the solar savings fraction to the thermal conductance of the greenhouse-to-residence wall.

Figure 12. Sensitivity of solar savings fraction to thermocirculation vent area.

Figure 13. Sensitivity of solar savings fraction to glazing tilt, constant area.

Figure 14. Sensitivity of solar savings fraction to glazing tilt, variable area.

Figure 15. Sensitivity of solar savings fraction to extent of vertical glazing.

Figure 16. Sensitivity of solar savings fraction to tilt of upper glazing in a two-glazing-plane system, variable area.

Figure 17. Sensitivity of solar savings fraction to thermal resistance of night insulation of greenhouse glazing.

Figure 18. Sensitivity of solar savings fraction to lower thermostat set point in living space.

Figure 19. Sensitivity of solar savings fraction to lower thermostat set point in greenhouse.