CONCEPTUALIZATION OF UTILIZING WATER SOURCE HEAT PUMPS WITH COOL STORAGE ROOFS

by

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ABSTRACT

This is a concept paper which discusses the potential integration of a ground-coupled water source heat pump with the Cool Storage Roof (CSR) to provide full year thermal comfort at reduced energy costs.

Prior CSR research efforts in Omaha, Nebraska and Davis, California have concentrated upon the physical phenomena related to maximizing summer radiative and evaporative heat loss from exposed CSR surfaces. Although performance results have been highly favorable, the CSR will not supply full building cooling demands for many applications. Coupling of the CSR with auxiliary cooling/heating systems may offer additional energy conservation opportunities. Combination with the ground-coupled heat pump may be particularly attractive for its utility load control features in addition to energy conservation advantages.

In particular, the relatively constant ground source/sink condition can provide predictable daily peak cooling and heating output from the heat pump, allowing reduced heat pump sizing and potentially eliminating resistance auxiliary heating. This concept paper develops a preferred CSR-ground coupled heat pump schematic configuration, and evaluates both system advantages and probable sizing implications for a Midwest U.S. application.

1. INTRODUCTION

The Cool Storage Roof concept has been under development both by the Davis Energy Group and (as the Nebraska Modif ied Roof Pond) by UNL's Passive Solar Research Group (PSRG) since 1982. The primary goal of prior DEG work has been CSR development for application as an improved commercial building roof system which extends roof life and reduces cooling loads. PSRG work has concentrated on evaluating both heating and cooling energy savings in the Nebraska climate.

While previous papers consider the CSR as a passive, buildingintegrated energy conservation technology, potential also exists for a "hybrid" CSR which is integrated with the building HVAC system. In the hybrid or CSR "Type 211 configuration, water under the floating insulation layer may be cooled either by natural means or with an auxiliary chiller; and may also be used for heat storage in winter. The Type 2 CSR is lightly insulated between water and occupied space below to limit storage heat transfers, and to prevent summer condensation on the roof underside.

Coupling the Type 2 CSR with a ground-coupled heat pump offers particularly attractive opportunities for both energy conservation and electric utility load control. Using the CSR as an "active" thermal storage reservoir when necessary allows off-peak electricity to be used for auxiliary cooling, eliminating or minimizing on-peak compressor operation. In winter, CSR storage potentially eliminates the need for auxiliary resistance heating in heat pump applications. This paper discusses one attractive approach to integrating CSR and ground-coupled heat pump technologies.

1.1 CSR DESCRIPTION

CSR development has been discussed in earlier papers (see references (1), (2), (3) and (4)). Figure I shows the basic CSR configuration. A roof membrane is placed atop of the roof deck with rigid insulation panels floating a water layer over the membrane. For cooling, a pump distributes the storage water over the insulation panels at night. The water temperature drops as heat is radiated to the night sky and lost due to evaporation. During the winter, passive solar heat via direct gain or thermosiphon can can help satisfy heating loads.as shown in Figure 2.

Extended CSR roof life is projected because the roof membrane is protected from the sun, wind, temperature extremes, drain clogging debris, and falling objects. Building cooling loads are reduced by pumping the water at night onto the floating panels, where it is cooled evaporation and night sky radiation before draining back through panel joints. The cool water remains below the panels in the daytine and may be used in several ways to provide full or partial building cooling.

In the most economical CSR configuration (called "Type 111) the roof membrane is not insulated from occupied space below, permitting direct building cooling through the roof deck. The Type 1 "Passive" CSR provides direct building cooling and its buildingcoupled thermal mass can reduce winter heating loads if properly controlled. However, the Type 1 CSR cannot be used to accomplish latent cooling ("dehumidification") because dripping water could cause interior damage if the ceiling surface were allowed to be colder than the indoor dew point temperature. This ' limitation will typically prevent mechanical chilling of the Type 1 CSR to shift auxiliary cooling loads off-peak, since this strategy would usually require water temperatures below the dew point.

The Type 2 CSR provides insulation between CSR water and occupied space below to prevent ceiling condensation in extreme cooling conditions with CSR water mechanically chilled "off-peak". This configuration allows all cooling loads to be satisfied from the CSR and is ideal for climates where summer dehumidification is needed. The Type 2 CSR may be fully integrated into the building climate control system, as subsequently detailed.

I.'2 THERMAL LOAD SHIFTING WITH HEAT PUMP - COOL STORAGE ROOFS

Air and ground-coupled heat pumps have had limited market success in many areas of the country in competition with natural gas for space heating loads. Air-coupled heat pump efficiencies are penalized by the need for auxiliary resistance heating, which can generate unfavorable "morning spike" load patterns. Groundcoupled heat pumps offer higher efficiencies and need less auxiliary heat than air-coupled pumps, but are more expensive to install.' In heating climates, residential heat pumps sized for cooling are usually inadequately sized for heating, whether airor ground-coupled. Non-residential buildings offer improved heat pump markets in applications where building internal gains reduce heating loads.

Coupling "downsized" heat pumps with thermal energy storage (TES) can reduce heat pump capacities, eliminate winter auxiliary heating requirements, and shift heat pump electrical energy consumption to off-peak periods. For non-residential applications, the Cool Storage Roof (CSR) presented offers a more promising TES/heat pump coupling because of the CSR's dual function and lower cost compared to packaged thermal storage components.

The heat pump-coupled Type 2 CSR can benefit an electric utility in.two significant ways:

1. By Reducing Future Capac ity Requirements: Building cooling loads may be shifted fully or partially off-peak, depending on chiller sizing, water depth, cooling loads, and on-peak period length.

2. By Improving Annual Load Fadtors: Use of CSR for heating seasonal thermal storage offers off-peak savings to commercial building owners who normally heat with natural gas; the electric utility can realize increased winter revenues without increased peak capacity requirements.

These significant utility benefits may only be realized if CSR economics are favorable for the building owner. While detailed "Type 2 CSR" value estimates have not been completed, excellent paybacks are anticipated for the following reasons:

1. Type 1 CSR's show less than two year paybacks due to extended roof life, cooling energy savings, extended HVAC equipment life, and electrical demand savings.

2. Conventional thermal energy storage (TES) systems show favorable paybacks in the U.S. without relative CSR advantages of free cooling in mild weather, cost reduction from combining TES and roof membrane & insulation functions and shorter piping runs, reduction of roof heat gains and losses, and TES space requirements.

2. <u>THEORY OF OPERATION: HEAT PUMP-COUPLED CSR SYSTEM DESCRIPTION</u>

The Type 2 CSR to be evaluated in the proposed project will be integrated with a heat pump-based HVAC system as shown in Fig. 3. Three major components comprise the system, as shown. The CSR roofing system shown at the top of Fig. 3 includes the roof membrane, f loating roof insulation panels, piping and heads to distribute water onto the panels, and inlet/outlet connections to the CSR. The heat pump (upper dotted line) may be either air or ground coupled, although the latter offers superior efficiency. Refrigerant-to-water indoor heat exchange is provided, allowing .off-peak storage in the CSR of heat pump cooling and heating output, for subsequent use "on-peak".

The fan coil (lower dotted line) provides hydronic heat exchange from both the heat pump and CSR to the building. The fan coil includes a centrifugal blower and two water-to-air heat exchange coils (Cl and C2). A microprocessor controller determines operating mode based on weather and system data.

The heat pump-integrated Type 2 CSR system allows two stage heating and cooling from a combination of stored and direct heat pump output, and also allows the heat pump to provide either direct heating at the fan coil when the CSR is cool or direct cooling when the CSR is warm. As shown in Fig. 3, two pumps (Pl and P2), three motorized diverting valves (Vl, V2, and V3), and two check valves (CV) are required to provide the full range of desired system features. operating modes by season are as follows:

1. Summer: In normal weather, Pump P2 operates at night and directs CSR water through the'filter and valve V3 port B to be distributed and cooled above the floating insulation panels. When the indoor thermostat calls for cooling, pump P2 sends filtered water through valve V3 port A to the fan coil, from which it returns to the CSR through valve V2, either via port A (daytime, below panels) or Port B (night, for distribution above panels). When night cooling fails to drop the CSR to its programmed target, pump Pl and the heat pump are activated, with flow returning to the CSR via valve Vl port B, to mechanically chill the CSR during offpeak hours. When first stage cooling via coil Cl fails to satisfy the cooling load, the heat pump and Pump Pl are activated with flow directed in a closed loop from the heat exchanger through valve Vl port A into coil C2 (second stage cooling). See figure 3.

2. Winter: The heat pump is run continuously during off-peak hours to charge the CSR toward a precalculated temperature target, using pump Pl and valve Vl port B. Vi port A is activated to direct heat pump output to coil C2 upon offpeak heat demand by the building thermostat. The heat pump and direct coil C2 may also respond to winter afternoon cooling loads (as may develop in buildings with high internal gains) if the CSR is warm. During on-peak hours, space heating is provided by warm water stored in the CSR and circulated by pump P2 through coil Cl, returning through valve V2 port A to the CSR. See figure 3.

3. Spring and Fall: The CSR is maintained at a cool temperature using pump P2 and the upper roof return; the heat pump and pump PI provide heating or additional cooling as needed via valve Vi port A and coil C2.

3. CONCLUSIONS

Previous papers by the authors have discussed thermal performance results and full year performance simulations for direct coupled thermal storage roof applications without considering potential integration with auxiliary heating and cooling systems. Prior work suggests that substantial energy savings may be realized with the direct-coupled "Type 111 thermal storage roof applications. This paper presents a concept for integrating the Type 2 CSR (which is insulated from the space below) with the building HVAC system, to gain additional energy and electrical load control advantages.

Funding is being solicited for modification of the University of Nebraskals, Energy Research Test Facility (located in Omaha) to test the proposed ground-coupled heat pump, Type 2 CSR concept. Research schedules favor Type 2 testing upon completion of Type 1 testing and ongoing CSR subsystem development work in 1991.

4. REFERENCES

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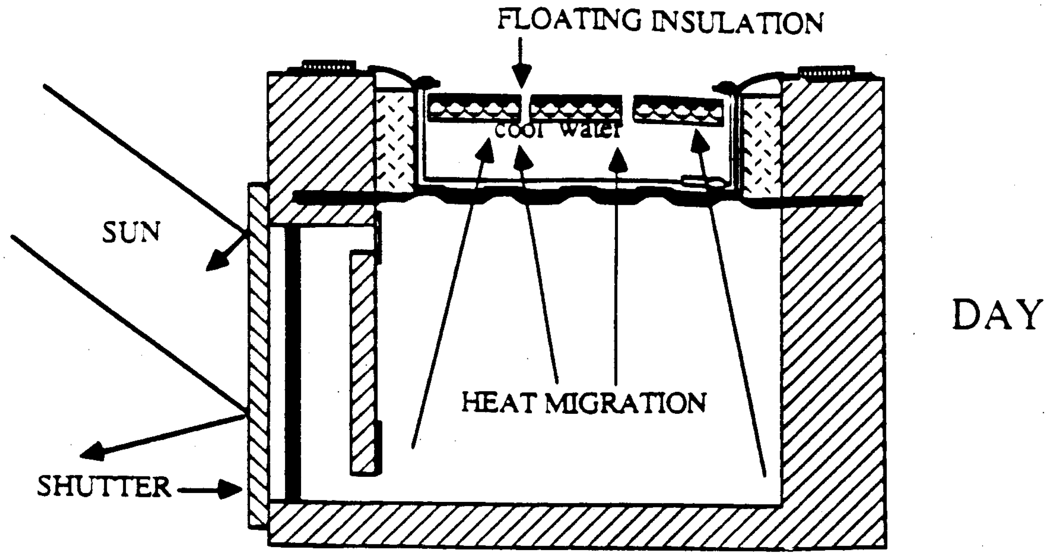
(3) Chen. B. et. al., "COOLING PERFORMANCE CURVE FOR THE NEBRASKA MODIFIED ROOF POND", Proceedings from the Combined 1987 Passive Solar Conference and Annual American Solar Energy Society Meeting, Portland, Oregon, August 1987.

(4) Chen. B. et. al., "NEBRASKA MODIFIED ROOF POND: 1985 SUMMER PERFORMANCE RESULTS", Proceedings from the Combined 1986 Passive Solar Conference and Annual American Solar Energy Society Meeting, Denver, CO, June 1986.



COOL STORAGE ROOF

COOLING MODE

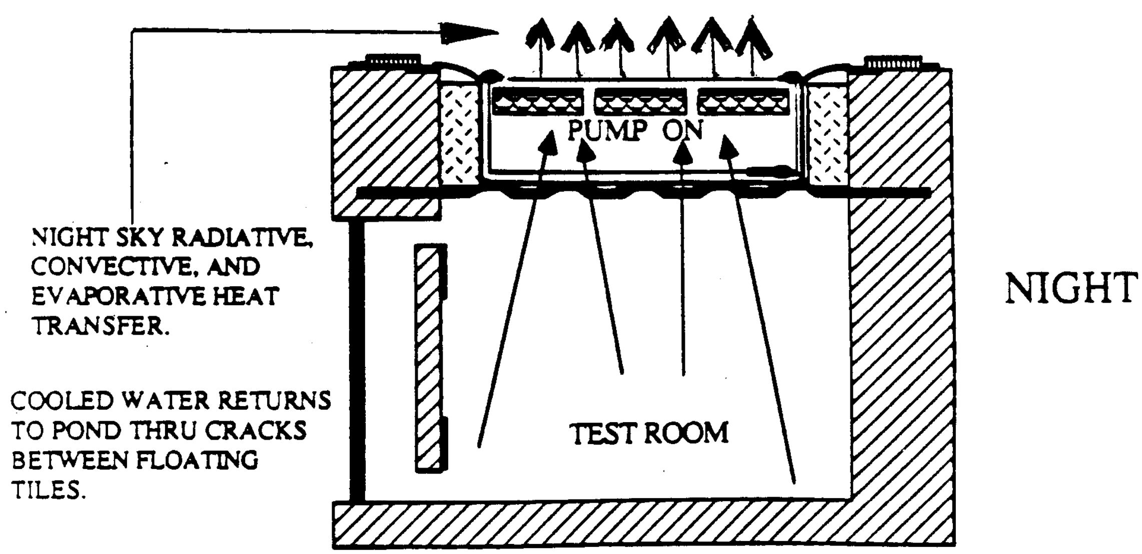
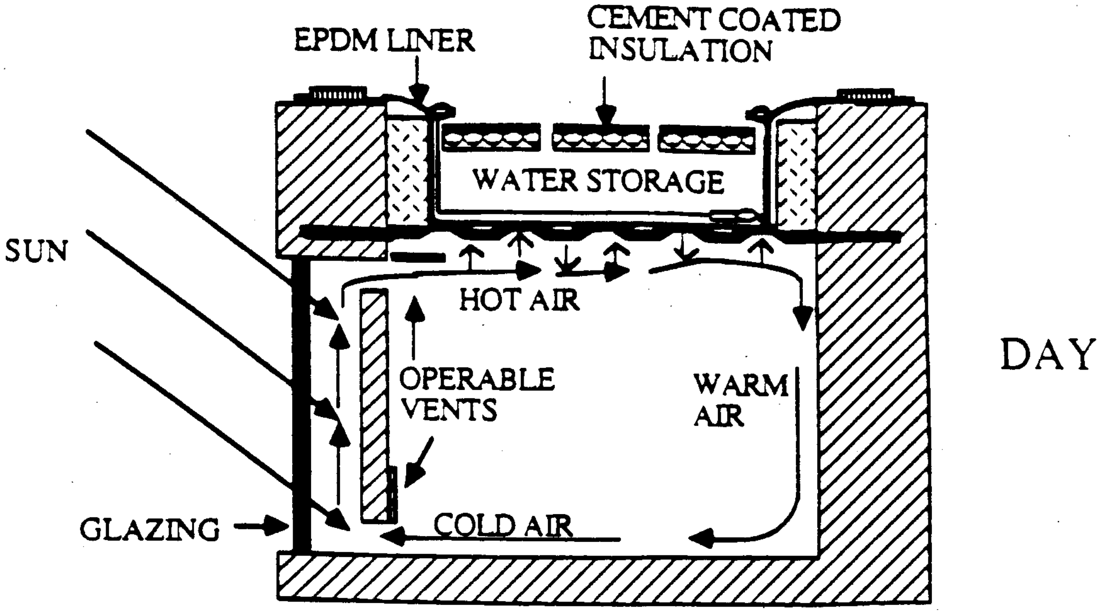


FIG. 1

OPERATION OF THE CSR SYSTEM DURING THE COOLING MODE



COOL STORAGE ROOF

HEATING MODE

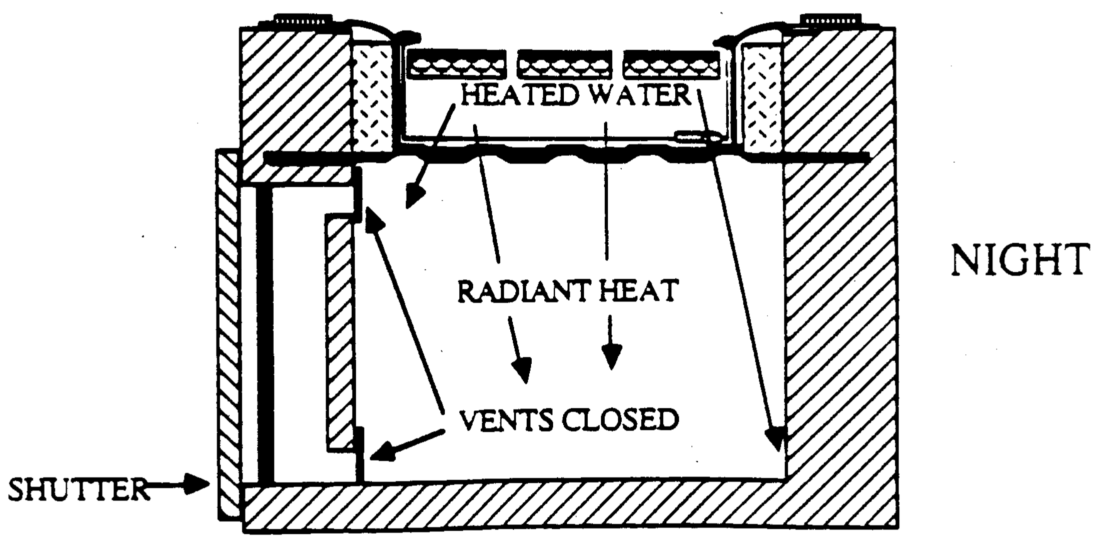


FIG. 2

OPERATION OF THE CSR SYSTEM DURING THE HEATING MODE

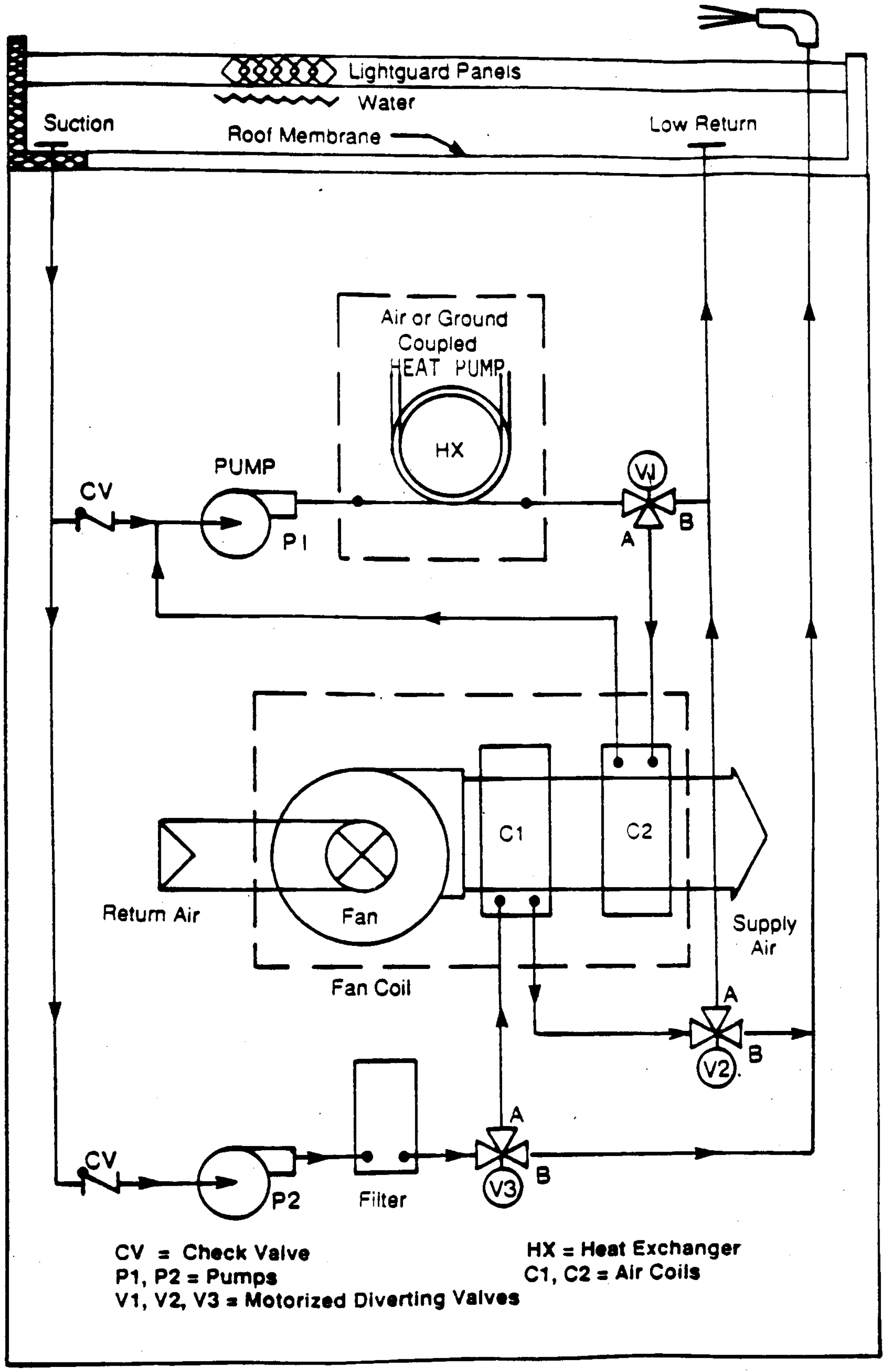


Fig. 3

Heat Pump - Cool Storage Roof Basic Configuration