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COMMUNITY ANNUAL STORAGE ENERGY SYSTEM

A new form of heating and cooling uses buildings instead of expensive devices to collect solar heat, which is then removed during the cooling process in summer, stored, and used as a primary source of heating in winter.

Approximately a fourth of the energy demand in the United States is for heating and cooling buildings. Traditionally, we regard heating and cooling as two unrelated problems. In summer we consume electric power to run air conditioners that cool by pumping heat out of buildings and into the surroundings. In winter we consume precious and irreplaceable fossil fuels to generate about the same amount of heat as was thrown away during the previous summer. This is illustrated in Fig. 1, a typical seasonal pattern of heating and cooling in a moderate climate (Washington, D.C.). This wasteful procedure is left over from the era of cheap energy and can no longer be afforded.

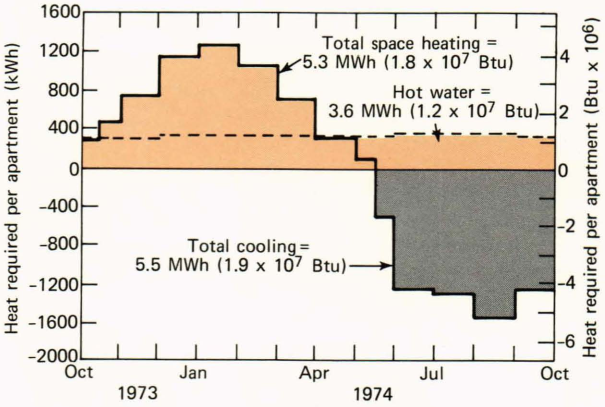

Fig. 1—Seasonal pattern of heating and cooling. Note that total annual space heating and space cooling demands are nearly equal. The actual thermal demand is based on a 406 unit apartment complex in Washington, D.C. Detached houses require more heating and less cooling.

CASES CONCEPT

The Community Annual Storage Energy System (CASES) is a new form of heating and cooling using solar energy. Instead of expensive solar collectors, the buildings themselves are used to collect solar heat, giving CASES a tremendous economic advantage over conventional solar energy systems. CASES stores the surplus heat removed from buildings during the cooling process in summer for use as a primary source of heat for winter. CASES also collects the excess heat that is produced in some community buildings even in winter and distributes it to the community to further reduce overall fuel consumption. At times, CASES obtains a portion of the heat required by the community directly from the winter environment. By using that heat, the stored summer heat, excess building heat, and heat released when water changes from the liquid to the solid phase instead of conventional heating fuels, the consumption of scarce fuel resources can be greatly reduced.

Water is used to transfer excess building heat to storage. In order to collect heat from the building, the water must enter and leave the building at a temperature lower than the temperature desired in the building. Likewise, when this heat is returned to warm the building in winter, the fluid used must be hotter than the building. Thus, a heat pump is required to elevate the temperature of the water. CASES uses water as both the heat transfer fluid and the storage medium.

Figure 2 illustrates how CASES works, using a specific example. Because buildings are heated by water-source heat pumps and cooled by cold water, furnaces, air conditioners, flue pipes, and fires are not needed. Every building in the community has continuous access to a warm water and a cold water distribution line. In principle, a building could draw warm water to heat its north face and, at the same time, use cold water to cool its southern exposure.

Aquifer Storage

Generally, we cannot immediately use the waste heat and waste cold that are available in summer and winter, respectively. Figure 3 shows one of the most desirable ways to store excess warm and cold water. If natural underground water supplies (aquifers) are available, we inject the excess cold water produced in winter into the ground so that it will be available the following summer for cooling. Note also that we may collect additional cold water using natural cooling in winter and inject it along with the cold water produced by the heat pumps in the community. This ensures that there will be enough cold water for nonelectrical air conditioning even if the current winter happens to be a mild one and the succeeding summer is unusually hot.

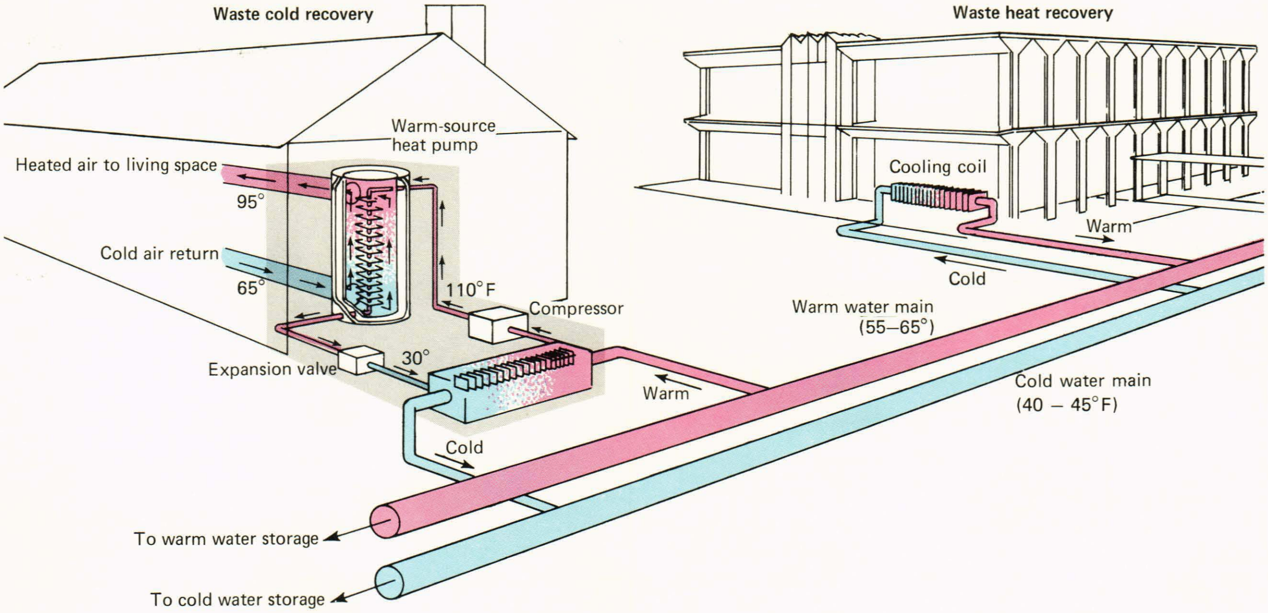

Fig. 2—Synergistic interactions between buildings in a CASES community save energy and cost.

By the end of winter, there is an ample supply of cold water in storage, while the supply of warm water is diminished.

Ice Storage

If local factors do not permit seasonal storage by means of an underground aquifer, it is necessary to provide an artificial method of storing the surplus summer heat and winter cold until they are needed. It does not appear economically feasible to store all of the cold water that is produced in winter as a by-product of heating with "water-source" heat pumps. Instead, the cold water flowing back to the central CASES facility is heated and returned to the community in a closed-loop flow pattern.

The heat required can be extracted from water by an ice-making machine. For each cubic foot of cold water converted into ice by a machine, more than 10,000 Btu are made available for reheating the water circulating in the community distribution pipelines. Ice-making machines that take heat out of a cold pond will deliver more heat to the circulating water than could be obtained directly from the same pond if it were full of boiling water! Ice machines are simply heat pumps that also produce ice.

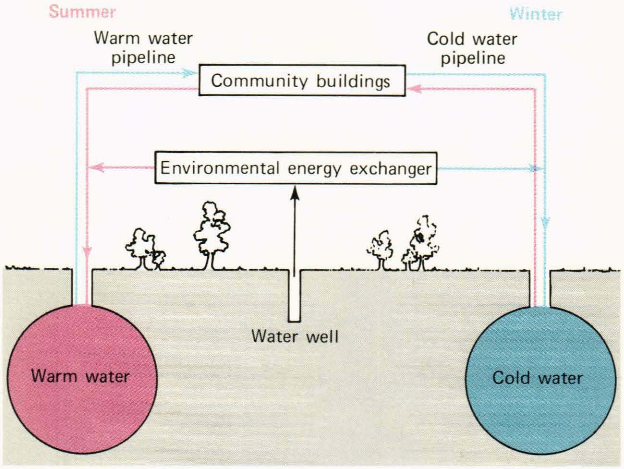

Fig. 3—Aquifer flow patterns. Cold water for summer use accumulates in winter; warm water for winter use accumulates in summer.

The ice produced during winter is saved for non-electrical "energy-free" cooling the following summer (Fig. 4). It is stored under a floating insulated roof in the same pond from which the ice machines remove heat in winter. As the winter progresses, more and more of the pond is converted into ice. During summer, this ice is melted while cooling the community. The size of the pond is chosen to be large enough to store all of the ice produced in winter and required for summer cooling.

System Components

Environmental Energy Exchanger — Part of the heat used to reheat the water circulating in the community when CASES employs ice machines and a pond for annual storage can be collected energy-free directly from the environment with an environmental energy exchanger (EEE). This exchanger is more economical than most solar heaters because it has no cover glass and, operating at a lower temperature, it is more efficient than most solar collectors. It can also be used after sunset to collect heat from the air any time the air temperature is significantly higher than the cold water temperature.

In northern communities, the EEE can collect heat to melt ice in the pond any time the air

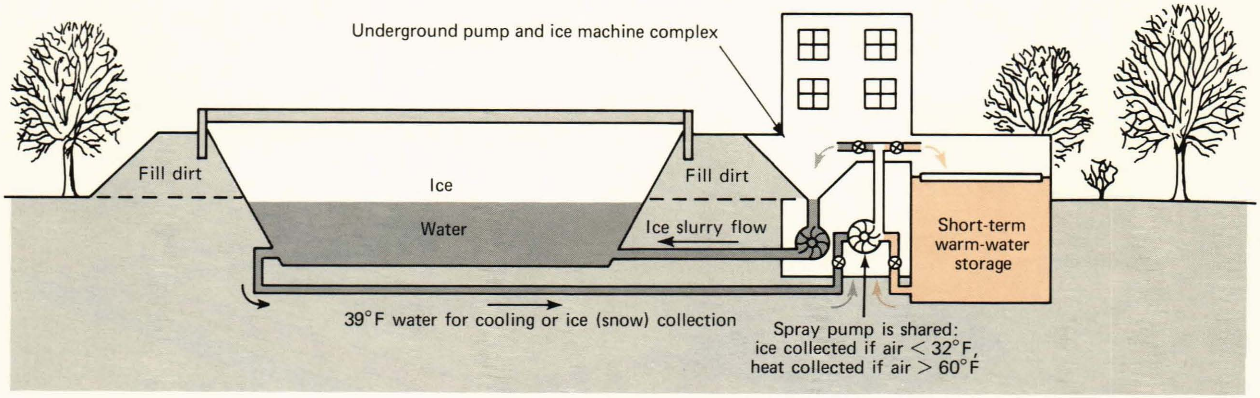

Fig. 4—Pond annual storage system with ice or heat collection via spray-type environmental energy exchanger.

temperature is above freezing. By melting excess ice, it is possible to freeze the water in the pond several times during one winter and obtain as much heat as if the pond were several times larger. Thus in locations where more heat is needed for heating buildings during winter than is removed from buildings during summer cooling, the exchanger can be used both to substitute cost-free environmental heat for ice-machine heat and to reduce the size and cost of the pond.

In southern locations, the heat removed from buildings in summer exceeds the heat required in winter. The design of the EEE would correspondingly differ from that used in a northern location. The exchanger might be a water spray cooling pond. The exchanger can be used to discharge the seasonally excess heat in winter without using electrically driven air conditioners if aquifer storage is feasible (Fig. 3). However, if a pond is used for annual storage, the exchanger can be designed to produce and collect ice in winter, using a water spray and natural cooling, to supplement the ice produced as a by-product of winter heating.

Thus the EEE is used to achieve an annual balance in the heating and cooling loads and to reduce both energy consumption and costs. An exchanger used for both ice and heat collection is part of the central CASES facility illustrated in Fig. 4 and schematically represented in Fig. 5.

"Water-Source" Heat Pumps — The water-source heat pumps used in CASES buildings remain highly efficient even in cold weather because warm water from the pipeline is always available to them as a source of heat. By contrast, "air-source" heat pumps tend to condense water vapor from the air and freeze up in cold weather so that periodic defrost cycles are required. Also they become less efficient as the weather becomes colder. In subfreezing weather, most air-source heat pumps deliver no more heat than simple resistance heaters, whereas the water-source heat pumps used in CASES typically give 3.5 times more heat than electric resistance heaters or air-source heat pumps at the time of peak demand. It should be noted that some energy is consumed at the central CASES facilities to keep warm water continuously available, but much of it is produced cost-free or is recovered as excess heat from buildings with cooling needs. The water-source heat pumps are similar in design to air-source heat pumps except that their input heat exchanger is smaller and no outside fan-coil unit is required. They should be more economical than air-source heat pumps when produced in the same volume. The absence of outside fan-coil units reduces installation costs and lessens the chance for fluorocarbon leaks to the environment. Water-source heat pumps can be hermetically sealed at the factory, but air-source heat pumps typically require field connections for fluorocarbon lines between the inside and outside units.

Short-Term Storage Facilities — Even when aquifers are available, short-term warm and cold water storage facilities at ground level may be desirable to buffer the flow of warm and cold water into the aquifers. Typically, their volume is large enough to permit a major portion of the demand for heating water during the hours of peak electric usage on cold winter days to be satisfied directly from stored warm water with minimal use of electric power. The well pump and well-field borehole costs can be reduced if part of the peak

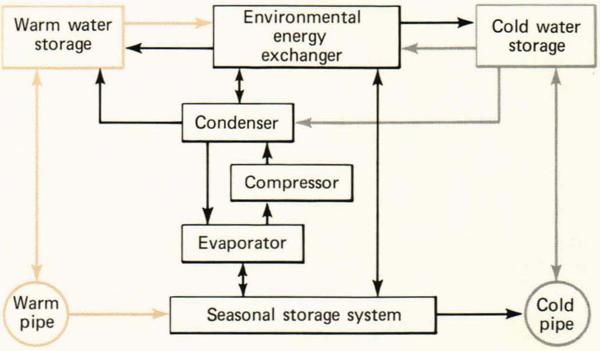

Fig. 5—Heat and fluid flow diagram for CASES central plant with ice-machine heat pump.

flow is into and out of water storage basins on the surface. Excessive flow rates result in greater pumping power requirements and can damage the aquifer if the pressure rise ruptures a natural clay seal. An ice-collecting EEE can be useful even with aquifer storage if it is coupled to these short-term storage facilities. On the coldest winter nights, ice can be collected rapidly and then can be converted into cold water for injection into the aquifer at lower flow rates.

The savings in peak power or "demand" charges possible with short-term storage facilities are most important when the ice machines can be operated at night or at other times when electric power is cheap.

Many electric utility companies have recognized that the cost of thermal storage can be less than the cost of expanding peak generation and transmission facilities. Central energy storage can reduce the cost further because the large scale results in a more economical surface-to-volume ratio. The cost of separate electric meters for off-peak electric power is reduced, and only one meter for each rate period is required for the entire community.

The short-term storage facilities available at the central CASES plant could be operated to produce a more cost-effective form of load control for the electric utility. The ability to take all ice-machine heat pumps off line for a few hours in power emergencies could prevent a blackout in the community. During this period, all of the central plant thermal output would be drawn from the short-term storage facilities.

Water Distribution Pipelines. — The principal disadvantage of CASES is its requirement for a water distribution system. Because the warm and cold water circulating in these lines is only a few degrees different from ground temperatures, insulating the pipelines does not appear cost effective. Although the lines would be essentially identical in construction with potable water lines, they would be cheaper because the water used in CASES pipelines is not consumed nor is it processed to potable water standards. The heat lost (or gained) during distribution in the uninsulated pipes is estimated to be less than 10% of the delivered resource.

Long-Term Storage Facilities — Electric utility companies usually have a seasonal imbalance in the demand for electric power as well as daily peaks in the electric demand curves. The fact that CASES provides air conditioning nonelectrically (either by cold water from an aquifer or by melting ice stored from winter) can reduce the chance of blackouts or the need for expansion in generating capacity to service peak loads. The fact that CASES would replace present gas and oil furnaces with electrically powered heat pumps is also attractive by adding electric demand in winter for summer peaking utilities.

For an electric utility with a wintertime peak demand, the surplus heat collected in summer is the attractive long-term storage feature. Together with proper use of short-term storage facilities for diurnal load management, this permits the peak electric heating demand to be about 3.5 times less than if air-source heat pumps were employed.

Ice Machines — The ice machines used in CASES are designed to produce flake ice because heat transport through thick ice would make the machines less efficient and more costly. Flake ice can be pumped as an ice/water slurry to the storage pond. The slurry would be discharged into the storage pond at the bottom to keep the discharge pipe clear of ice. Because ice machines are not needed for heating in summer, they could be used to manufacture ice for sale to defray part of their costs, if a local industrial customer (e.g., a food processor) is available.

ANALYSIS

Evaluation of any annual storage energy system requires data for a full year. The costs and performance characteristics of CASES have been determined using a simulation model that consists of 8760 hours (one year) of sequential steady states. The simulation model assumes that a pond rather than aquifers is used for annual storage. It thus sets an upper limit on costs and a lower limit on efficiency, because ice machines are more expensive and less efficient than pumping warm and cold water into and out of the ground.

Cases Model

The first program module in the simulation is called HCLOAD. It produces a file of hourly heating and cooling loads (Btu/h) for each of nine building types and two core zones. In addition , certain monthly and annual peak and total loads are recorded that are used in subsequent program modules to determine efficiently the size of heating and cooling equipment required in each building and the size of various energy storage facilities needed at the central CASES plant.

The second module (CDIST) requires as input the distribution water temperatures in addition to the files written by HCLOAD. It calculates the size and cost of the heating and cooling equipment needed for each building. It produces an hourly record of the electric power required to operate the heating and cooling equipment. It also converts the load data into a demand (pounds of water per hour) data file, which depends on the water temperatures and the efficiency of the equipment selected for each building.

CDIST uses the water-demand file and data on the pipeline route to each terminal building to determine the size and capital cost of all pipes and trenches in the distribution system. More refined editions also calculate pumping and thermal losses and the associated costs. The current simulation model doubles costs of the pipe and trench to form a conservative estimate of pipeline and other cost details omitted from the distribution system. Finally, it reduces all the demand data to a single user or net demand file.

The third module (CAPS) simulates hourly operation of the central CASES plant as it services the user under an assumed set of operating rules. It determines the size and cost of the various energy storage facilities and ice machines required at the central plant and also computes the hourly requirements for electrical power.

The final module (COST) processes all the various cost and energy consumption files. Various financial rates and Btu prices are used to determine the total cost of CASES and the expected rate of return on invested capital. COST totals all energy consumption and compares it to the heating and cooling services supplied in order to evaluate the efficiency and annual energy savings. COST does not presently exist. Instead, hand calculations are used to combine the results of CDIST and CAPS. In lieu of detailed economic analysis, it is assumed that 15% of the capital is recovered annually.

Reference Community

To obtain reliable information about costs, the community must be specified in considerable detail. The selected model community was similar to Wilde Lake Village in Columbia, Md. It has 8000 residents (2500 households) and 866 buildings in three neighborhoods that share a common village center, all on 1500 acres of land. Each neighborhood has its own elementary school and civic/commercial center. The community's middle school, high school, office buildings, factory, shops, and CASES facility are located in the village center. These buildings and clusters of residential units comprise the 43 zones (local load centers) shown in Fig. 6, which also illustrates the route of major distribution lines but not the connections to individual buildings in each zone. Hourly weather records for 1967 were used.

RESULTS

The results predicted by the simulation model for the standard reference community are given in Table 1. The capital invested to provide heating and cooling services to both residential and non-

Table 1

MONTHLY SUMMARY FOR STANDARD COMMUNITY

Month	*Services Provided (1967)* Heating (Btu × 10^6)	Cooling (Btu × 10^6)	*Efficiency, Combined Coefficient of Performance*
January	59,460	15,150	4.509
February	69,430	13,130	4.001
March	43,240	16,190	5.279
April	25,780	17,410	6.707
May	38,170	16,100	5.414
June	8,285	21,110	12.142
July	4,809	22,220	17.216
August	7,000	20,210	13.411
September	11,120	19,500	10.515
October	30,230	17,310	5.783
November	49,760	14,880	4.972
December	60,580	14,870	4.586
Total for year	407,864	208,290	5.524
Capital cost at central plant			$5,097,000
Capital cost for pipelines			1,435,000
Capital cost in buildings			8,758,000
Total capital invested (Electrical utility capital excluded)			$15,290,000
Total electric cost			$1,047,000
15% of capital total as annual cost			2,294,000
Total revenue required annually			$3,341,000

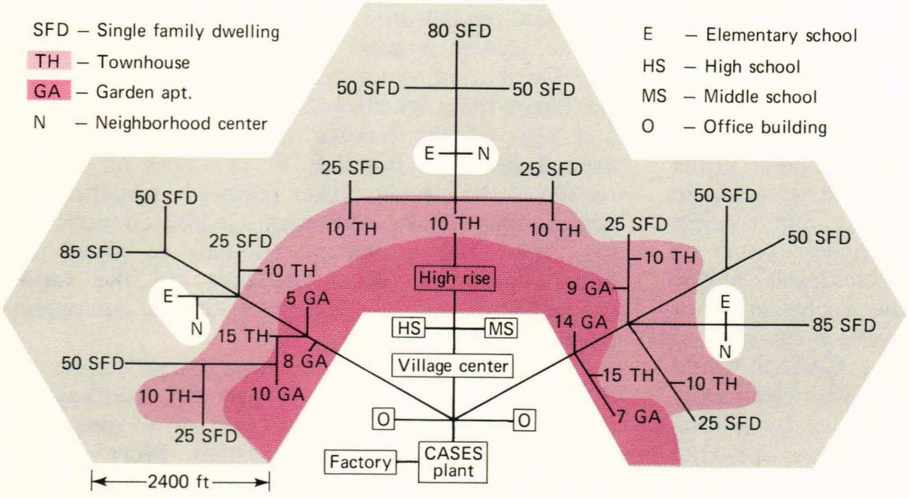

Fig. 6—Layout of 866 buildings and pipeline route in standard reference community.

residential buildings in the standard reference community is less than $6200 per resident household. Typically, conventional residential solar-electric hybrid systems costing this amount would require more electric energy for back-up heating on cloudy days and would not provide any cooling. Thus CASES provides more services to more buildings with less capital and lower energy consumption than does a conventional solar heating approach.

The reference community requires a total investment of about $15 million. If an electric utility company with a wintertime peak load could produce an increment of new capacity at a cost of $700 per kilowatt, then $20 million of electric plant expansion would be needed to supply the increased peak demands of the community if it were electrically heated and cooled. The reference community requires twice as much total annual heating as cooling; however, four times as much is charged per unit of cooling than of heating, so that two-thirds of the system's revenues come from cooling. (People currently pay about four times more to remove a Btu than to add one to their homes when equipment costs are properly included in the comparison.) In the model, electric power costs about $10 per million Btu if consumed at the central plant, where industrial rates and "off-peak" power rates are assumed to be available. The net effect of these and other factors is that our model predicts heat costs of $2.69 per million Btu. This is less than the cost of the fuel alone in most conventional systems. All costs are in 1978 dollars.

Neither the standard reference community nor the design parameters and control strategy assumed has been selected to optimize the cost and performance characteristics of CASES. Work in this area is incomplete, but some preliminary results indicate that other communities and other designs may be more efficient and economical. The standard reference community model assumed that the temperature of cold water was 40°F but parametric studies indicate that 45°F water may be more economical. (Ideally, the temperature of both the cold and warm water pipelines should vary with the weather for optimum results, but the computer code required to simulate this variation is not yet operational.)

CASES is most attractive in thermally diverse communities where the annual cooling requirements are about two-thirds of the annual heating requirements. There it can profitably deliver three units of heating and two units of cooling for every unit of electricity consumed. It is especially attractive in such applications if the local electric grid is summer peaking or if electric resistance heating makes it a winter peaking grid, because CASES can reduce peak electric demand in either case. It appears to be economically feasible in new suburban areas if large buildings or other winter cooling demands are present, provided that the gross population density is five people per acre or greater. Its technology is suitable for an urban retrofit site because heat pumps can be selected individually to match existing ducts or radiators. The thermal storage facilities can be placed under existing facilities such as athletic fields and parks, and public fountains can provide controlled heat exchange with the environment.