greater or lesser degree. In the case of a building, the structural materials are almost always in the process either of absorbing heat from or delivering heat to the interior space. This effect is more pronounced in cooling operation where greater air temperature variation is tolerated. Storage tends to reduce the rate of temperature change and helps in some measure to reduce the peak equipment requirements. In this sense every heating and cooling system can be said to involve heat storage in some degree.

Many attempts have been made, particularly in recent years, to increase the heat-storage effect by using special heat-storage materials as part of the heating or cooling system. The result is to reduce the size of the heating or cooling equipment necessary to take care of peak demands.

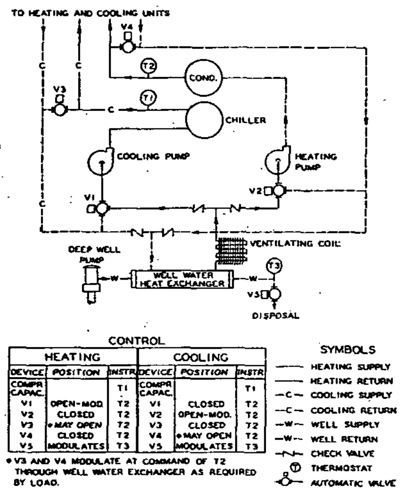

Fig. 9 . . . . Flow Diagram of Central-Type Heat-Pump System

In the case of the heat pump, a provision for heat storage can serve not only to reduce the size of the heat pump necessary for a given load, but also to provide a more desirable electrical load by shifting part of the load to the time of day when the cost of power is least. The off-peak electric hot water heater is a common example of such a heat-storage application.

In general, there are two types of heat-storage systems that have been employed: (1) sensible heat-storage systems and (2) latent heat-storage systems. Usually the latter is actually a combination of the two, making use of some sensible heat storage in addition to the latent effect. Heat storage in a heat-pump system may be utilized on the *high side*, when heat is available at a temperature suitable for direct heating; or on the *low side* as an intermittent heat source at temperatures lower than the heated space.

Table 5 . . . . Properties of Various Specific Heat Type Storage Materials

Material	*Specific Heat Btu per (lb) (cu ft) (F deg)*	*Density lb/cu ft*	*Heat Capacity Btu per (cu ft) (F deg)*
Water	1.00	62.4	62.4
Iron	0.11	490.0	53.9
Concrete	0.27	140.0	37.8
Brick	0.20	120.0	24.0
Gravel	0.20	100.0	20.0

Sensible Heat Storage

Water, with the highest sensible heat storage capacity on a weight basis, is an obvious first choice and has the advantage of low cost, easy storage, and good heat exchange properties. The danger of freezing can be reduced by various types of antifreeze solutions. In some cases, however, freezing may be desirable. The maximum temperature is limited by the cost of maintaining water under pressures when over 212 F, but this temperature is high enough for most heating systems. Rock and gravel beds have also been employed, and have a heat content per unit volume approximately 20 percent of the value for water. The earth has been utilized for heat storage, both for heating and cooling in a number of instances. A problem with most solid media such as these is one of heat transfer into and out of the medium.

Table 5 lists the thermal properties of some of the common materials used, or considered, for sensible-heat storage.

Latent-Heat Storage Systems

Because of the relatively large volumes required for all sensible-heat storage systems, many attempts have been made to utilize the latent heat of fusion of certain materials. Most materials have some capacity to absorb heat when changing from a solid to a liquid, and some materials have a large capacity to do so. Ordinary ice changing to water is a prime example of this kind and the possibility exists of utilizing it as low-side storage. For most heating applications, however, the temperature of this change is too low to be useful.

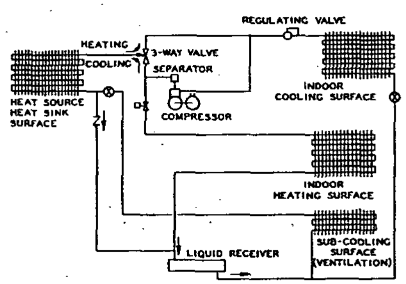

Fig. 10 . . . . Flow Diagram of Air-to-Air Heat Pump for Simultaneous Heating and Cooling

Table 6 . . . . Materials for Heat Storage Listed According to Latent Heat per Unit Volume[a] of All Materials Having Melting Points between 72 F and 176 F, Listed in Chemical Handbooks

Material	*Formula*	*Melting Point F*	*Heat Content G-cal per g*	*Specific Gravity*	*Latent Heat of Fusion per Unit Volume (Theoretical)*	
					G-cal per cc	Thousands of Btu/cu ft
Nitrogen pentoxide	N_2O_5	85	76.7	1.63	125.0	14.0–
Gallium	Ga	86	19.0	5.88	113.8	12.7–
Sodium phosphate, dodecahydrate	$Na_2HPO_4 12H_2O$	94	66.8	1.52	101.5	11.4
Sodium sulfate, decahydrate	$Na_2SO_4 10H_2O$	90	57.1	1.46	83.4	9.4
Water	H_2O	32	79.1	1.00	80.0	9.0
Nickel nitrate	$Ni(NO_3)_2 6H_2O$	132	36.4	2.05	74.7	8.4
Calcium chloride	$CaCl_2 6H_2O$	86	40.7	1.68	68.4	7.7
Osmium tetroxide	OsO_4	104	13.5	4.91	66.3	7.5
Zinc nitrate	$Zn(NO_3)_2 6H_2O$	98	31.1	2.06	64.3	7.2
Calcium nitrate	$Ca(NO_3)_2 4H_2O$	108	33.9	1.82	61.7	6.9

[a] Nine materials having melting points between 72 and 176 F listed according to latent heat of fusion. Selected as highest on a list of 100 organic and inorganic materials listed in chemical handbooks.

Prolonged searches have been made for materials which pass through a change of state as reliably and regularly as ice and water, but at temperatures high enough to be used for direct application to space heating. In order to be much superior to water, the latent heat capacity of such materials must be high. Most organic materials are eliminated from consideration on this basis alone. Furthermore, the absorption and release of heat must occur in predictable fashion. Many materials which have been tried exhibit the defect of subcooling, delayed change of state, or decomposition through time and repeated cycles. A study of all materials, both inorganic and organic, listed in chemical handbooks resulted in a list of over 100 materials having a fusion temperature between 72 F and 176 F. Most of these materials are extremely unpromising as heat storage media because of cost, corrosiveness, instability, or unavailability. For many of them, data on their heat of fusion are unavailable. All of these materials, where such data are available, have been listed in order of heat capacity per unit volume. Table 6 gives the nine materials which were highest on this list, and it is interesting to note that there are few common or low cost materials among this group. Others, notably the first two, are academic curiosities.

The material disodium phosphate is high on the list and has been used in a number of experimental installations. Results for the most part indicated a considerable unreliability at least in the particular form of the material which was used. Such factors as the rate of heat addition or release, size and shape of container, presence of nucleating media, and temperature gradients proved important in determining the percentage of heat storage actually available compared with the theoretical. In several small house heating installations employing heat pumps with condenser-side storage, the amount of disodium phosphate actually used was 3300 lb with theoretical latent heat storage capacity of 400,000 Btu. Indications were that the material was only partially effective in actual heat-storage performance. A method which makes use of a mixture of this material suspended in oil has been successfully tested in the laboratory, and through use of forced circulation of the oil, has exhibited high rates of heat transfer.[9]

Low-Side Storage

With a heat-pump system the possibility also exists of storing heat at relatively low temperature on the low side (heat source side) of the system. The freezing of water has already been mentioned as one possibility. Heat pumps with solar energy as the heat source have been studied with low-side storage.[10]

A limitation present with this type of storage system as compared to high-side storage is that the peak heating capacity of the system is limited to the heat-pump capacity when operating with the low-temperature storage reservoir as the heat source. In many structures, particularly in colder climates where the benefits of heat storage are potentially greatest, this is less than the peak heating load.

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