AN INTRODUCTION TO THE USE OF STRATIFIED CHILLED WATER STORAGE IN SAUDI ARABIA FOR ELECTRICAL DEMAND REDUCTION AND ENERGY CONSERVATION IN LARGE AIR CONDITIONING SYSTEMS.

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Thermal Energy Storage (TES) technologies particularly chilled water storage are being applied increasingly by Services Engineers in the Kingdom of Saudi Arabia to reduce electrical demand and lower energy consumption in buildings. This development has received added impetus by the introduction in 1995 of the Load Reduction Programme by the electricity supply authority. The programme aims at managing the shortfall between available electrical supplies and the rapidly increasing demand. Limits are being imposed on electrical supplies to new buildings, and new and existing projects are being subjected to restrictions on the power available to operate chillers during peak periods. This paper shows how chilled water TES offers a means of reducing the electrical demand in large commercial buildings and, by load shifting, dealing with restrictions on chiller operation. Additionally it is seen that power bills can be reduced as air cooled chillers are run overnight in cooler air when their operating efficiencies are higher. The "favouring factors", that is the conditions that must exist before T.E.S. can be considered viable are examined, as are the concepts behind chilled water based T.E.S.; its operating strategies, applications and design features. TES economics are considered and a cost analysis presented to illustrate the potential savings that can be achieved by the use of Thermal Energy Storage.

INTRODUCTION

For some years, Services Engineers in Saudi Arabia have been applying Thermal Energy Storage (TES) technologies particularly chilled water systems as a way of reducing electrical demand and of lowering energy consumption in buildings.

This development has received added impetus by the introduction in 1995 of the Load Reduction Programme by the electricity supply authority. This programme aims at managing the shortfall between available electrical supplies and the rapidly increasing demand. According to statistics published by the Ministry of Industry and Electricity the power generated in 1995 was 75 million megawatt hours, 15 times that is produced in 1975. Annual output is increasing at a rate of 12%, a far greater figure than is found in the USA or Europe. Limits are being imposed on electrical supplies to new buildings, and new and existing projects are being subjected to restrictions on the power available to operate chillers during peak periods.

TES provides a means of reducing the electrical demand in buildings and, by load shifting, dealing with restriction on daytime chiller operation. Additionally chilled water storage allows power bills to be reduced as chillers are run overnight, in cooler air, when their operating efficiencies are higher.

CHILLED WATER STORAGE:

The Concept:

Chilled water storage systems utilise liquid chilled water as the stored medium. During overnight charging the chillers operate to cool the chilled water to 0.5 to 1.0 deg. C below the required building system flow temperature. This chilled water is released during daytime operation, either directly to the building circuits or through the primary side of a flat plate heat exchanger, depending upon the building height.

The basic circuitry of a chilled water storage system is shown in Fig. 1.

The air conditioning systems incorporate conventional air handling plant and chillers. Typically, chilled water will be stored at 6°C resulting in a 7°C flow to the building if a heat exchanger is used.

The chilled water storage tanks can be constructed from mild steel, aluminium or concrete. The tanks are thermally insulated and an inner waterproofing membrane is provided on the inside surface of internal insulation.

The most common form of water storage is the stratified chilled water system. During discharge water is drawn from the bottom of the tank and the warmer return water is introduced at the top. If non-turbulent flow conditions are achieved a transition layer forms between the warmer water and the cooler water, effectively separating the 2 masses. This layer is called a "thermocline" and varies in depth from 300 to 750 mm depending upon its age and the location and design of the inlet and outlet diffusers through which water enters and leaves the tank. See Fig. 2.

It is essential that the entry and exit water velocities are maintained at a very low value (0.1 m/s) to prevent turbulence and the mixing of the warm and cool layers.

During charging, the direction of flow is reversed and the warmer water is drawn from the top of the tank, the chilled water entering at the bottom.

CHILLED WATER STORAGE:

Operating Strategies

Two types of operating strategies are used in chilled water based systems: "load levelling" and "load shifting".

Load Levelling

This is the application most suited to installations in the Middle East. Chilled water is released during the day and is used in combination with "live" chillers to cope with the building cooling requirements. The installed chiller capacity is reduced to approximately 65% of that required if no TES is provided. This results in an electrical demand reduction of between 10 and 15 % for the building. Chiller plant capital costs are reduced as are the associated maintenance costs. Electrical energy usage is less than with total "live cooling" as the chilled water tanks are charged when cooler, night time temperatures prevail resulting in more effective condenser heat exchange and a lower "kW per kW cooling" ratio.

Table 1 shows the comparative electrical energy consumption in kW per kW (cooling) for an air cooled chiller for differing ambient air temperatures.

Load Shifting:

Load shifting chilled water storage applications are more suited to countries with cooler climates. In such applications sufficient chilled water is generated at night to meet the entire daytime cooling load requirement of the building allowing chiller plant to be shut-down completely.

Full load-shifting applications derive maximum benefit from multi-tier tariff structures and exploit fully the improved nighttime chiller efficiency.

Full load shifting is not practical in hot middle east climates as huge chilled water storage tanks would be necessary, and no tariff breaks are currently offered by the supply authorities.

CHILLED WATER STORAGE:

Design Considerations

Tanks

Steel and aluminium tanks are normally cylindrical whereas concrete tanks can be rectangular, square, cylindrical or octagonal. The shape of the tank and its construction will depend upon how the water can be stored most economically on site.

In a major office development currently being built in the Kingdom, 2000 m^3 of chilled water will be stored in structural concrete chambers formed in the basement levels of the main core. See Fig. 3.

Steel and aluminium tanks are commonly used in above ground applications, cathodic protection being necessary with steel vessels. Prestressed concrete tanks have been used for in-ground applications. External tanks must be designed to withstand static and wind loads.

Tank Thermal Insulation

The thickness of thermal insulation varies between 75 and 150mm. Steel tanks are insulated externally whereas aluminium ones have internal insulation, the waterproofing inner membrane being formed from butyl rubber sheeting.

Internal Flow Diffusers

Several diffuser shapes and configurations have been found to provide effective stratification. Continuous horizontal slots, radial disks and bell-mouth diffuser arrangements can produce the stable, shallow thermoclines necessary for effective separation of the warm and chilled water masses. The size and spacing of the diffusers must be designed to provide turbulence-free conditions in the tank.

Fig. 4, indicates tank internals within a 700m^3 concrete tank contained within a building core.

CHILLED WATER STORAGE:

Favouring Conditions

General

Chilled water based TES systems have been used successfully for many years in North America, enabling building operators to exploit lower night-time electricity costs for chilled water production. Additionally, some utility companies provide cash incentives to developers to incorporate TES schemes as a way of "smoothing" the daytime demand made on the generating plant.

In such applications the "favouring conditions" are clearly:

1) Lower cost night-time electrical energy.
2) Cash incentives from utility companies for demand management measures.

Favouring conditions vary from country to country and perhaps region to region.

In Saudi Arabia at present there is no direct cash benefits offered by the supply authority for demand management measures. However, other favouring conditions apply, some unique to the nation.

Political Factors - Demand Reduction Programme

The electricity supply authorities Load Demand Reduction (LDR) programme aims at limiting the electricity used for non-domestic air conditioning at specified times.

In Riyadh for example the owners of commercial buildings are required to turn off or reduce their chiller capacity in the following manner:

1-2 pm	20%	capacity reduction
2-3 pm	40%	capacity reduction
3-4 pm	40%	capacity reduction
4-5 pm	20%	capacity reduction

The electricity supply authority require appropriate load reduction measures to be taken before supplies are made available to new buildings.

Chilled water storage systems can be sized to provide sufficient cooling capacity to allow buildings to operate without loss of cooling despite the reduction in available chiller capacity.

To illustrate the potential for electrical demand reduction provided by TES systems, a large facility with a cooling load of 7000 kW cooling can be considered.

> A TES system with a discharge rate equivalent to 2500 kW would allow the installed "live" chiller capacity to be reduced to 7000-2500=4500 kW.

The building maximum power demand would be reduced by
2500 kW x 0.51 kW input kW cooling
= 1275 kW (based on 0.51 kW power input per kW cooling output)

This represents an electrical demand reduction of around 10 - 15 % for the building.

Energy Factors

As water is a valuable resource in the Middle East, some authorities prohibit the use of water cooled chillers deriving make-up water from Municipal supplies. Air cooled chillers abound despite their relative inefficiency compared to water cooled units.

The average energy requirement for an air cooled chiller is approximately .5 to .53 kW per kW cooling output compared to the 0.14 to 0.16 kW per kW cooling required by water cooled plant.

The energy savings resulting from overnight chiller operation has already been mentioned, but this issue is of particular importance in the Middle East where summer time daily dry bulb temperature swings can exceed 20°C. In Riyadh during June, July and August this is the case and the expected kW input per kW cooling ratio improvement for night time operation would be 25 to 30%.

Significant reductions in energy cost can therefore be achieved by incorporating a load levelling TES system on air conditioning plant.

2 "favouring factors" evident in Saudi Arabia are therefore seen to be:

1) The government's electricity Demand Reduction Programme.

2) The energy savings resulting from improved chiller efficiency during night-time operation.

CHILLED WATER STORAGE:

Applications:

The following list of projects illustrates the extent of which TES is being applied to new projects in Saudi Arabia:-

NCCI Headquarters Building / Riyadh	-	25,000 kWH
Disabled Children Centre / Riyadh	-	14,000 kWH
Major Shopping Centre / Jeddah	-	26,000 kWH
Sabic Headquarters / Riyadh	-	35,000 kWH
Justice Court / Riyadh	-	39,000 kWH

T.E.S. Economics

Project: Festival Market, Riyadh

Data:

Total cooling load	5200 kW (cooling)
Ambient air temperature	43.3°C max.
Elevation:	591m above sea level
Using rotary chiller largest frame size gives	1400 kW (cooling) nominal and 1050 kW (cooling) actual, corrected for site

Comparison of Initial Cost: 100% live cooling versus TES

100% "live" cooling requires 5200 kW (cooling).

TES cooling option requires 63% of cooling load to be met by chillers and 37% by TES output

Reduction in installed chiller capacity

5200 x 0.37 = 1924 kW (cooling)

Cost of chiller plant GBP 150/kW (cooling) installed

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1924 kW (cooling) x 150 = GBP 288,600

Cost of TES tanks, internals and control
(based on approx. 4 hours peak load storage) GBP 550,000

to store 20,000 kWH (Cooling)

Comparison of Electrical Demand Requirements

Chiller selection gives absorbed power requirements as 0.38 kW per kW (nominal cooling)
Using TES enables 2 chillers to be omitted.
Each machine has a total power requirement of 535 kW
Power reduction for chillers using TES
= 2 x 535 = 1070 kW
or approx. 1.3 MVA
Therefore a demand reduction of approximately 1.3 MVA can be achieved by the use of T.E.S.
Savings on utility connection charges 1.3 x 1000 x 70 = GBP 91,000
Savings on transformer and switchgear = GBP 15,000

Savings on Energy Costs

Conventional hydronic system:

The stored cooling of 15230 kWH will be produced instantaneously based on the cooling demand of the building, with an ambient condition of 43.3 deg. C.

Total kWH used = 15330/1150 x 500 = 6623 kWH, based on chiller outlet temperature of 6°C

TES based hydronic system:

The stored cooling of 15230 kWH will be produced at night when the average ambient condition will be 29.5 deg C.

Total kWH used = (15230 / 1350) x 418 = 4716 kWH

i.e. the Reduction in electricity consumption - kWH during a typical summer day

= 6623 - 4716 = 1907 kWH / Day

SAVINGS ON MAINTENANCE COSTS

The average cost of maintaining an air cooled chiller in the Middle East is around GBP 6 per kW (cooling) per annum based on 20 years of useful chiller life.

The reduction of 1924 kW (cooling) in the chiller capacity will reduce the maintenance cost by,

6 x 1924 = GBP 11,544 (per year)

CONCLUSIONS

This paper has provided an introduction to chilled water based Thermal Energy Storage systems and their application in the Kingdom of Saudi Arabia.

TES is a potent technology and used intelligently by Services Engineers it can reduce energy expenditure within buildings and lessen electrical power demand.

An economic study has been presented to illustrate the type of analysis that is necessary before TES is applied to future buildings.

ABBREVIATIONS

GBP	Pound Sterling
kW	kilo-Watts
MW	Mega-Watts
kWH	Kilo-Watt Hours
Deg.C	Degree Celsius
CFC	Chlorofluorocarbons
HCFC	Hydrochlorofluorocarbons
TES	Thermal Energy Storage
LDR	Load Demand Reduction

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