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# APPLICATION OF ICE STORAGE FOR PEAK POWER REDUCTION

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## ABSTRACT
Cool storage assisted air-conditioning systems can be very helpful in reducing the peak power demand growth, currently, estimated at around 350 MW per year. Ministry of Energy can save well over quarter million Kuwaiti Dinars by attenuating up to 750 MW. This paper presents a summary of cool storage concept, system options and our experiences in this field for over two decades.

## KEY WORDS
Peak power, air-conditioning and cool storage.

## Introduction

The climate in Kuwait, like the rest of the arid zone countries, is hostile. The summer season extends from six to seven months and the ambient temperature often exceeds 50$^{o}$C [1]. Therefore, cooling of all types of buildings is, essential. Indeed, in the hot and arid countries of Arabian Peninsula and the Middle East, the peak power demand to meet the growing demand of A/C is a critical problem. In Kuwait, air-conditioning (A/C) of buildings entails over 70% of the annual peak and nearly 45% of total annual electricity consumption [2]. During the past five years, the power demand grew from 6160 MW in 1999 to 7480 MW in 2003 [3] and nearly 250 MW power was added every year only to satisfy the growing demand of the A/C systems. Furthermore, an analysis of the hourly power demand profile for the days of peak power demand highlighted that the daily average power demand is nearly 90% of its peak value for all the years. This offers an opportunity to shave up to 10% of the peak power, i.e., nearly 750 MW of peak power with cool storage and other power management techniques at the building and the equipment levels. Also, leveling of power production, will improve the energy efficiency of the power plant due to an improvement in the load factor, this is an added advantage for the utilities. Thus, constituting savings in operating expenses and investment.

In countries around the world, incorporation of cool storage with the A/C system has been proposed as a way to even out the electrical power demand on utilities, to cut down the size of A/C equipment and to reduce energy consumption [4] and [5]. This paper presents a summary of cool storage concept and system options and our experiences in this field for over two decades including the findings of an ice storage assisted A/C system installed and tested for the first time in an actual application in Kuwait.

## Cool Storage Concept and System Options

In a cool storage assisted A/C system, a programmable timer instead of a room thermostat operates the chiller of the A/C system to produce the required cooling. The chiller, thus, does not cool the building directly on an instantaneous demand basis; instead, it chills water or makes ice during the off-peak period of the utilities. The stored cooling effect in the form of chilled water or ice is used hours later, when cooling is needed especially during the peak hours [6]. Cool storage options are based on the operation mode and the cooling storage medium.

### Operation Mode

Under the “full storage concept”, the chiller is completely off during the peak demand period of the utilities, and cooling of the building is provided by the stored cooling effect, thus, resulting in maximum reduction in the power demand during the utilities peak demand period since chilled water or the brine circulating pump and fans of the air-handling units are the only consumers of electricity. The full load operation of the large capacity chillers with centrifugal/screw compressors, ensuring better energy-efficient cooling production, is an added advantage. Furthermore, for the air-cooled A/C systems, chiller operation during the night hours under favorable weather conditions enhances the possibility of achieving an overall reduction in electricity consumption. In a “partial storage concept”, the chillers continue to operate at full capacity around-the-clock, including the peak period of utilities. This scheme is helpful in selecting the cooling plant of the smallest capacity, although it has limited power shaving. Buildings with part-day occupancy, such as offices, clinics, schools, commercial complexes and entertainment centers, are best suited for such applications.

**Choice of Storage Medium**
Commonly used cool storage systems are of chilled water and ice storage. The chilled water system consists of a thermally stratified reservoir. The cooling transport medium to the building or to the AHUs is chilled water. Design and construction of the incoming and outgoing headers from the chilled water storage tank are crucial to ensure minimum disturbance during the cooling storage (charging) and cooling withdrawal (discharging) processes and keeping the mixed or disturbed zone to a limited depth. Since the cooling effect is stored in a sensible form, for a temperature differential of 6-10$^oC$, the storage capacity of the water is limited to around 2.5 RTh/$m^3$. Storage capacity of an ice storage system compared with the chilled water storage system is significantly higher since the cooling effect is stored in latent form. Based on the design configuration, it can range between 10 and 15 RTh/$m^3$. However, in this case, the chiller has to produce cooling a few degrees below the ice-freezing temperature of $0^oC$, thereby necessitating the use of a secondary fluid (brine), such as 25% ethylene glycol solution in water. More importantly, operation of the chiller at lower temperature adversely affects the cooling production and power demand of the compressor. Several types of ice storage are available commercially in the market. These are classified as ice bank system, ice on coil system and ice ball system.

## Our Experience with Cool Storage Systems

Under the first phase of a general program on the use of cool storage for power management in buildings with A/C, the Department of Building and Energy Technologies, Kuwait Institute for Scientific Research (KISR), completed a 12-month project entitled, “Cool Storage Assessment Study in Kuwait” in 1985 [7]. The investigation involved a systematic analytical study to establish suitability and economic viability of using different types of A/C systems in combination with ice and chilled water cool storage for different types of buildings having different occupancy schedules and cooling demand profiles. Important findings of this study were:

- Application of cool storage for all types of buildings using chilled water for distribution of cooling is economically viable. For the direct expansion systems, advantages are, however, limited.
- Comfortable availability of heavily subsidized electricity offers very little benefit to the user adopting cool storage and its’ major beneficiary is the government.
- Changes in tariff structure for power and energy are necessary to promote the use of cool storage as an effective tool for power management.

Under the second phase of the general program, a two-year project on the experimental investigation of the ice and chilled water storage techniques was completed in 1986 [8]. Under the project, a cool storage-assisted cooling system, both with ice and chilled water storage was designed, installed and tested. The project provided valuable experience and necessary expertise for design, installation and operation of cool storage-assisted cooling systems. Major findings of the project were:

- Storage systems promise excellent economics, such as a 50% reduction in the capital cost and an over 35% reduction in the cost of cooling.
- Performance results of the ice and chilled water storage systems closely matched the analytical estimates made earlier.
- Electricity consumption by the cool storage-assisted systems using ice is 25% more than the system using chilled water storage.

## Sheikh Salem Al-Ali Al-Sabah, Center of Speech and Audio Therapy (CSAT)

For the first time in the country, an ice storage-assisted A/C system designed by KISR was installed in Sheikh Salem Al-Ali Al-Sabah Hospital, Center of Speech and Audio Therapy (CSAT). CSAT, a two-storey building with an area of nearly 3180 $m^2$ is located within the Al-Sabah Hospital complex. During the summer 2003, performance of this system was monitored and field data were collected and analyzed. The findings are presented in this paper.

**Description of A/C System**
Concept of a cool storage assisted A/C system was introduced to achieve peak power shaving and reduce the size of the conventional cooling system since the building has part day occupancy, from 07:00 to 14:00 h. The A/C system is comprised of three air-cooled reciprocating chillers and two-ice storage systems and the media of cooling transfer is 25% ethylene glycol brine. Two of the chillers, York model YCAZ74LD2 are identical with a rated cooling capacity for the Kuwaiti conditions of 51.7 tons, for an ambient temperature of 46.1°C and leaving brine temperature at +6.67°C, while the third chiller is of larger capacity (78 tons). During the summer, only the larger chiller operated on a continuous basis. This York chiller, model YDAJ44MR7, as per the catalogue, was supposed to produce cooling of 78 tons of refrigeration (tons) under similar operation conditions. For the ice-making mode for leaving brine temperature at –4°C, the cooling capacity was to reduce and the power rating, the power demand per unit of cooling (kW/ton) was to increase considerably regardless of favorable ambient temperature. In the temperature range of 5-8°C, an increase in power rating of 2.5%/°C is reported in the manufacturer’s catalogue.

The ice storage system comprises two units from Dunham Bush, each one of 240 ton-hour’s capacity. It is of internal melt type wherein a secondary coolant is used to both freeze (charge) and melt (discharge) the storage material, which is water. A schematic diagram of the A/C system is shown in Fig. 1.

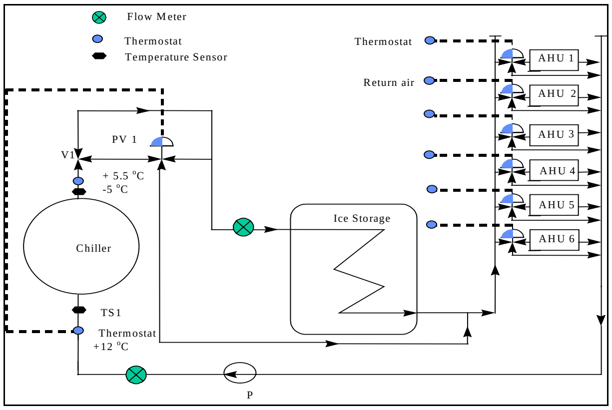


**Fig. 1. Schematic of Ice storage Assisted A/C System in CSAT Building System Performance Assessment: Concept and Methodology**

## Instrumentation and Data Collection

The instrumentation was incorporated to measure quantum of cooling generated by the chiller, cooling load of the building and the system, flow of cooling to and from the ice storage unit during the charging and discharging process and the electric power consumption. Important instruments were used to collect flow measurements of water-ethylene glycol mixture (brine), temperature measurements of the brine at the inlet and outlet of cooling producing and using devices, instantaneous power consumption by the motors of the compressors and outdoor temperature and humidity. The data was recorded through a data logging devices. Full details of the instruments are given in Table 1.

**Table 1. A List of Instruments and Data Logger Used for Performance Assessment**

| Instrument | Performance Parameter | Type/make | Remark |
|---|---|---|---|
| Hygro-thermometer | Ambient condition | Temperature | |
| Thermocouples | Cooling production and utilization; storage charging and discharging | Co-Cu | Laboratory Calibrated with ±0.1ºC accuracy |
| Brine flow meter | Cooling production and utilization; storage charging and discharging | Turbine | ±0.2% |
| Power transducer | Power consumption of chillers | Power | Accuracy =± 2% |
| Data logger | Data logging | | |
| | Space temperature and relative humidity | Hobo | Temperature =±0.3ºC Relative humidity=± 5% |

### Data Collection and Analysis

A/C system was operated as conventional and as an ice storage assisted system. In both of the options, cooling supply to the building was restricted to only for the occupancy period with an additional three hours of pre-cooling. The one small chiller in addition to the big chiller maintained cooling during the conventional mode. For the ice storage mode, the charging started at 17:00 h and not at 14:00 h, which is the end of the occupancy period. However, in view of shorter on-peak period in Kuwait, considered to be between 13:00 and 17:00 h, this scheme offered the advantage for maximum on peak power reduction for most of the on-peak period with a modest increase in chiller capacity. A summary of equipment in action, duration of their operation and brine flow rate for different modes of operation is given in Table 2.

**Table 2. A/C System Operation Details at CSAT during 2003**

| Period | | Operation Mode | Chillers in Operation | Schedule | | Brine Flow l/s | |
|---|---|---|---|---|---|---|---|
| From | To | | | Normal | Ice Making | Normal | Ice Making |
| 26/6 | 9/8 | Conventional | Large and small | 04:00 –14:00 h | NA | 290 | |
| 17/8 | 4/10 | Storage Assisted | Large | 04:00 –14:00 h | 17:00 –04:00 h | 250 | 230 |

Brine temperatures at the inlet/outlet of every chiller and the main supply and return headers feeding water to the ice storage, the air-handling/fan coil units and the ambient dry bulb temperature were measured with the laboratory calibrated Cu-Co thermocouples. The power demand by the chillers in operation was measured using individual power transducers. The data were recorded every 10 m using a data logger. Additionally, portable temperature and relative humidity measuring devices with a built-in data logging facility were installed in four different places of the building for round-the-clock monitoring of the indoor environment in critical locations. Brine flow though the main system and the ice storage was measured by the turbine flow meters installed in the main headers feeding brine to the ice storage and the air-handling units/fan coil units. Their values were recorded manually.

## Results and Discussion

Field data were analyzed on a day-to-day basis and findings for 18th July and 22nd August 2003, for the conventional and ice storage assisted A/C systems, respectively. The maximum and daily average temperatures for these two days presented in Table 3 indicated the close proximity of outdoor temperature for these days. Although, the day with conventional operation was slightly warmer, the daily cooling demand supplied between 04:00 and 14:00 h for this day was more by a margin of only 0.28%. The daily cooling demand for the conventional and ice storage assisted were 953.0 and 950.3, respectively.

**Table 3. Summary of Performance Parameters**

| Performance Parameter | | Mode of Operation | |
|---|---|---|---|
| | | Conventional | Ice Storage Assisted |
| Day | | 18th July | 22nd August |
| Ambient Dry Bulb Temperature (ºC) | Daily average | 40.3 | 39.5 |
| | Maximum | 48.6 | 47.7 |
| | Minimum | 32.5 | 32.8 |
| Cooling demand (Time of occurrence) | Daily (ton-hours) | 953.0 | 950.3 |
| | Maximum | 137.0 (04:00 h) | 113.5 (04:00 h) |
| | Minimum | 85.9 (06:00 h) | 81.1 (06:20 h) |
| Average Brine Temperature to AHU (ºC) | | 3.3 | 2.7 |
| Power demand (Time of Occurrence) | Daily (kWh) | 1414.3 | 1347.0 |
| | Maximum | 149.7 (13:00 h) | 82.9 (09:10 h) |
| | Minimum | 124.9 (05:50 h) | 75.9 (00:20 h) |
| | Maximum for utilities peak period | 149.7 (13:30 h) | 81.1 (13:20 h) |
| Average Brine Temperature Leaving Chiller (ºC) | Day operation | 3.3 | 4.6 |
| | Night operation | NA | -3.2 |
| Space temperature (ºC) | Average of occupancy period | 23.6 | 24.2 |
| | Daily maximum | 28.1 | 28.5 |
| | Daily minimum | 23.6 | 24.2 |

A profile of cooling supplied to the building for the two days is giving in Fig. 2. At the start of the cycle at 04:00 h, cooling supplied was at its maximum in both of the operation mode for pulling down the heat built up in the building due to closure of the A/C system. The large difference in the cooling supply for the two-operation mode at this hour should be ignored as it stayed for a very short period, besides there were heavy fluctuations in the brine temperature during this period. A profile of brine temperature fed to the AHUs during the building cooling period for the two operation modes is shown in Fig. 3. Ice storage assisted system provided brine at lower temperatures especially for precooling period and during the critical hours after 10:00 h, thus facilitating better cooling quality. Lower coil temperature assured better indoor relative humidity, although, it is not reflected in the space temperatures which were slightly higher with the ice storage assisted system.

Unlike the conventional mode, the chiller with the ice storage mode, operated between 04:00 and 14:00 h for the normal operation and from 17:00 h onwards for the ice-making mode. The profile of power demand of the chillers is shown in Fig. 4. During the peak hour of the utilities (period between 13:00 and 14:00 h) single chiller in the ice storage assisted mode drew 81.1 kW as compared to 149.7 kW consumed by two chillers in conventional mode of operation. Although, in the ice storage assisted mode, during this period, the single chiller generated 77.5 RT, the cooling delivered by the system was 110.3 RT. Thus, the ice storage assisted system achieved a reduction of 29.7 and 45.8% in the required capacity of cooling production system and in its peak power demand, respectively.

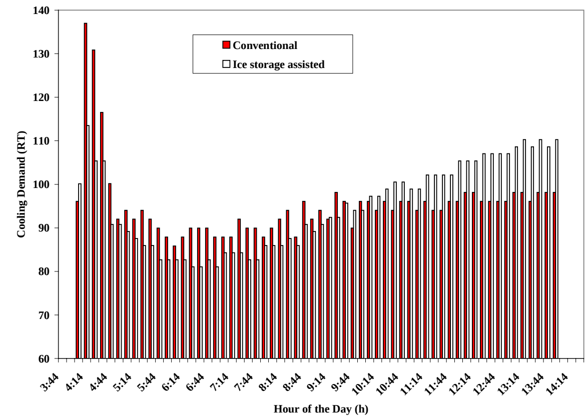


**Fig. 2. Cooling demand profiles for conventional and cool storage assisted cooling modes.**

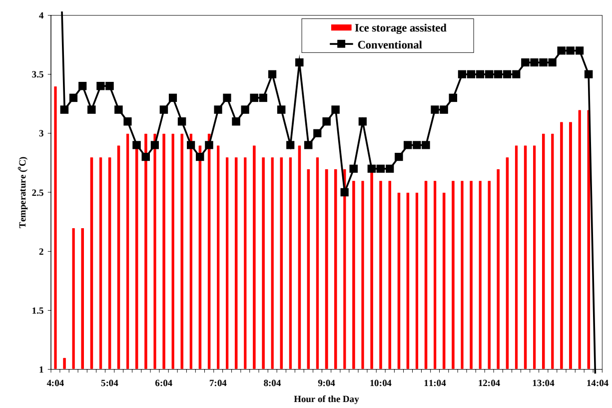


**Fig. 3. Brine temperature to AHUs for days with conventional and ice storage assisted cooling modes.**

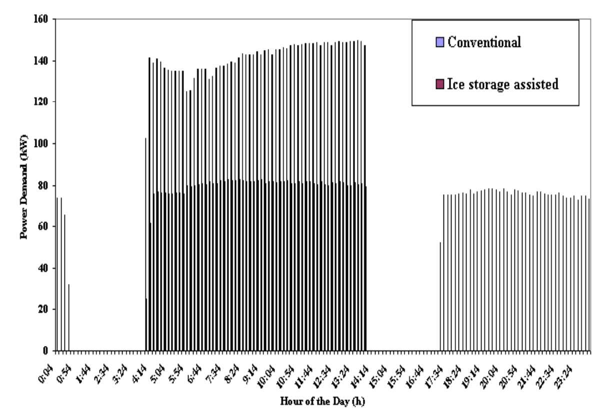


**Fig. 4. Power demand profiles for chillers with conventional and ice storage assisted cooling modes.**

Energy consumption of by the chillers for the ice storage assisted and conventional operation modes was 1347.0 and 1414.3 kWh/d, respectively. The significantly improved energy efficiency of the cooling production system in the ice making mode is attributed to lower leaving brine temperature during the day and mild outdoor temperature for the ice making mode during the night (Fig. 5). However, this finding has to be evaluated cautiously considering that there could be variations in the volume of ice used during the day and generated during the night, as controller monitoring the automatic closure of the chiller after the completion of the charging operation may not be very sensitive.

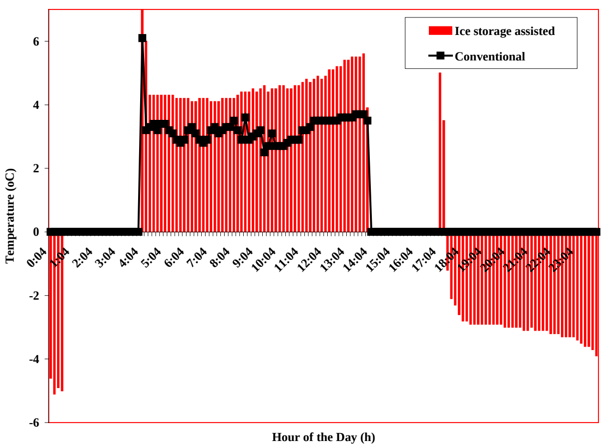


**Fig. 5. Chiller leaving brine temperatures for days with conventional and cool storage assisted cooling.**

## Conclusion

1. Findings based on the reported field trial runs promise a great benefit of using cool storage assisted A/C system in partial storage mode.
2. The benefits include substantial reductions in the capacity of cooling production system and its peak power demand. At the site in Kuwait, the respective reductions were 29.7 and 45.8%.
3. Ice storage systems may result reduction in energy consumption as well.

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