A COMPARATIVE STUDY OF TWO COMMERCIAL BUILDINGS USING ICE STORAGE AIR-CONDITIONING SYSTEMS

K.H. Yang and Y.H. Wang
Mechanical Engineering Department, National Sun Yat-Sen University, Kaohsiung, Taiwan 80424

(Received 28 August 2002; Accepted 15 October 2002)

ABSTRACT

In this study, two commercial buildings using ice-storage air-conditioning (ISAC) systems have been analyzed followed by full-scale experimental investigation. System diagnostics indicated that design problem and operational strategy accounts for most of the inefficiency in their energy use. Remedial countermeasures were proposed and are discussed in detail in this paper.

1. INTRODUCTION

The ice storage air-conditioning system has been identified as one of the most efficient methods in power demand side management, especially for load shifting. The local power tariff has enlarged the price differences between the on-peak and off-peak hour at the rate of 5 vs. 1 in two-tiered rate, and up to 7 vs. 1 in three-tiered rate in providing an incentive to promote ISAC systems in Taiwan.

Two office buildings were selected in this study, both with ISAC systems installed, to evaluate their operational performances through full-scale experiment.

They are briefly introduced as the following.

2. SYSTEM DESCRIPTIONS OF CASE 1 - THE T BUILDING

The T building is a 14-floor office building with 19738 m² floor area. Fig. 1 gives a bird’s eyes’ view of its façade. The T building, being located in hot and humid area, has been designed with effective external shadings to reduce the cooling load. The building is installed with 225 tons of refrigeration (RT) cooling capacity ISAC system with the design schematics as shown in Fig. 2. Among them, there are one water chiller, and two brine chillers. The basic design is to run the two brine chillers during the night to generate ice in five storage tanks. Ice is melted during the daytime on-peak hours, coupled with the water chiller to meet the cooling demand of the building, essentially a typical partial storage ISAC system design. “Total Freeze-up” ice storage system was adapted so that brine is the working medium between the ice storage tanks and the chillers separated by plate heat exchangers.

Chilled water is distributed by primary-secondary loops, boosted by zone pumps, to the air-handling units to meet the cooling load.

Fig. 1: A bird’s eyes’ view of the T building

3. SYSTEM DIAGNOSTICS OF CASE 1 THROUGH FULL-SCALE EXPERIMENT

To evaluate the cooling system performances, the following operational data should be measured [1-3]:

- The supply and return water temperatures of the chillers and ice storage tanks
The mass flow rate of the chillers and through the ice storage tanks
The power consumption of the chillers

Essentially, the combination of item 1 and 2 will provide the actual cooling capacity supplied by these major components, and thus system COP when further compared with the item 3 results.

Cooling was provided in the T building from Monday to Friday 8 a.m. to 6 p.m. Fig. 3 shows the operational data of chiller-1. On the average, 0.8 kW/RT specific power consumption during the daytime was identified, which is considered satisfactory while the chiller is running on a direct cooling supply mode.

On the other hand, the ice-melting mode indicated that a major problem existed, as shown in Fig. 4. As designed, the ice storage tanks, when ice was melted should provide 4°C chilled water to meet the cooling demand, and returned at 10°C as shown as the two solid lines in the diagram. Instead, actual measurement showed that chilled water was supplied at around 1 to 2 °C, and returned at 4 to 5°C. More importantly, the temperature difference between the two approached from 3 p.m. and finally met at 6 p.m., meaning no more cooling can be provided by ice-melting any more. Apparently, the ice storage tanks provided inadequate cooling, resulting in over-loading of the brine chillers, which are now kicked-in, costing extra on-peak power to supplement for the cooling capacity shortage. By investigating the ice inventory on site, it appeared that the tanks were still 40% filled with ice. Consequently, both brine chillers 2 and 3 at their ice-generating period, were running from 22:00 at night till 04:00 in the morning only, but not till 07:30 as designed. The un-melted ice stayed there for days and even weeks, causing inadequate charging at night and providing insufficient cooling (melting) throughout the day [4,5].
4. SYSTEM DESCRIPTIONS OF CASE 2 - THE C BUILDING

The C building is a 5-floor office building with 65972 m² floor area as shown in Fig. 5. Cooling was provided by an ISAC system with two brine chillers of 260 RT capacities each. Similar to case 1, the system is also designed based on partial storage concept, but with chiller-priority operation mode. That is, return water from cooling load was cooled down partially by the brine chiller first, and then running through the ice storage tanks sequentially until the supply chilled water temperature was met. A motorized valve has been provided to control the brine flow rate through the ice tanks and the by-pass line, so that ice-melting rate can be controlled. Furthermore, the brine then exchanged heat at the plate heat exchanger, so that chilled water was pumped out to meet the cooling demand. Fig. 6 shows a schematic diagram of the ISAC system.

During the ice-generating mode at night, brine was the working medium for thermal energy storage. But the by-pass line was closed to prevent freezing at the plate heat exchanger.

The chilled water distributing system is quite similar to that of case 1, also by primary-secondary system coupled with zone pumps.

5. SYSTEM DIAGNOSTICS OF CASE 2 THROUGH FULL-SCALE EXPERIMENT

The same field measurement procedure has been performed at the C building to evaluate its thermal performances. Fig. 7 shows the measured supply and return brine water temperature at the ice storage tanks. It indicated that the designed operating range, shown as two dotted lines in the diagram was closely followed, namely, between 4°C to 7°C, although the measured supply temperature was about 1°C lower, or at 3°C. The ISAC system sizing and designs have been successfully validated by the performance data. However, the operational data also indicate that the temperature difference of the two begins to approach at 13:50, and finally approaches zero at around 15:00. That means, the ice inventory has run out much quicker as designed, and the chillers have to complement the shortage by running at full capacity afterwards. Essentially, after 3 p.m., when the peak-cooling load occurs, the C building is essentially operating with a conventional air-conditioning system at the cost of extra power and operation fee due to the on-peak hours running by chillers [4,5].
Fig. 6: The schematic diagram of the air-conditioning system in the C building site

Fig. 7: The operational data of inlet and outlet brine temperature during the ice-melting mode of the C building
6. A COMPARATIVE STUDY OF OPERATIONAL MODES ON BOTH CASES WITH REMEDIAL COUNTER-MEASURES

In the T building, ice melting occurred at the right time, but not at the right amount. On the other hand, in the C building, ice melting occurred by the right amount, but not at the right time. Fig. 8 shows an interesting comparison of the two systems. In the T building, due to inadequate ice melting, the chillers have to provide larger share of cooling capacity then designed, causing over-loading problems and introduces tariff penalty when it eventually exceeds the power demand. The owner of the building, in an attempt to “enforce” ice-melting, intentionally lifts up the returned water temperature to the ice tank by 4°C temperature difference, anticipating that the “warmer” return water can melt more ice in a shorter period of time, and thus providing more cooling capacity from ice tanks, instead of supplemented by chillers after-wards. This strategy got out of control in a hot summer day in August 2001, that all chillers had to run on full capacity, causing the peak demand being exceeded. Since it occurred during the on-peak hours, the penalty was three-fold, costing a fine of 300,000 USD, which almost doubled the annual operating cost of the whole cooling system.

Actually, the ice melting was constrained by the inadequately designed heat exchangers causing excessive ice inventory in tanks, which is unable to provide cooling when most needed. Further diagnostics by us proved that the brine pumps had been running at full speed, but the ice could not be melted accordingly. A new plate heat exchanger has to be added to tackle this problem.

On the other hand, in the C building, the sizing of chillers, ice tanks, and the plate heat exchangers, were all in good order. But the operation mode failed to control ice-melting rate, which is essential to achieve the appropriate proportion of cooling provided by chillers and ice storage tanks. An inverter-driven pump has to be installed to substitute the original brine pump.

The combination of both cases will generate an ISAC system, which works nicely as designed.

![Fig. 8: A comparative study of operational modes on both cases with the remedial countermeasures](image-url)
7. CONCLUSIONS

ISAC systems, as demonstrated in this study, could become a very effective means for peak load shifting, but its performances would degrade significantly if appropriate operational strategies were not followed closely. To tackle this problem, system performance analysis through full-scale experimental investigation provides an important method for diagnostics. The fault detection process sometimes identified itself as a design problem, such as the building T in our study, or could be purely an operational problem such as the building C. In either case, remedial measures could be proposed quickly and effectively, once the problems were identified through field measurement.

The analytical process proposed in this study warrants itself a powerful tool for engineering applications.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to the Energy Commission of Taiwan for sponsoring this research project.

REFERENCES