



ENERGY & ENVIORNMENT

MODULE 2

ENERGY MANAGEMENT

THE VALUE OF ENERGY MANAGEMENT:

- ❑ *Business, industry and government organizations have all been under **tremendous economic and environmental pressures** in the last few years.*
- ❑ *Being **economically competitive** in the global marketplace and **meeting increasing environmental standards** to reduce air and water pollution have been the major driving factors in most of the recent operational cost and **capital cost investment decisions** for all organizations.*
- ❑ ***Energy management** has been an **important tool** to help organizations meet these critical objectives for their **short term survival and long-term success**.*

ENERGY MANAGEMENT

BENEFITS OF ENERGY MANAGEMENT:

- ❑ Energy management **reduces the load** on power plants as **fewer kilowatt hours** of electricity are needed.
- ❑ If a plant burns coal or fuel oil, then a significant amount of **acid rain** is produced from the sulphur-di-oxide emitted by the power plant.
- ❑ Acid rain problems then are **reduced** through energy management, as are Nox problems.
- ❑ Less energy consumption means **less thermal pollution** at power plants and **less cooling water discharge**.
- ❑ Reduced cooling requirements or more efficient satisfaction of those needs means **less CFC usage** and **reduced ozone depletion** in the stratosphere.

ENERGY MANAGEMENT

BENEFITS OF ENERGY MANAGEMENT:

- ❑ *The list could go on almost indefinitely, but the bottom line is that energy management helps **improve environmental quality**.*
- ❑ *Becoming - or continuing to be - **economically competitive** in the global marketplace, which requires **reducing the cost** of production or services, reducing industrial energy intensiveness, and meeting customer service needs for quality and delivery times.*
- ❑ ***Significant energy and monetary savings** are available through energy management.*
- ❑ *Energy management in the form of **implementing** new energy efficiency technologies, new materials and new manufacturing processes is also helping companies improve their **productivity** and increase their product or service **quality**.*

ENERGY MANAGEMENT

BENEFITS OF ENERGY MANAGEMENT:

*Most facilities (manufacturing plants, schools, hospitals, office buildings, etc) can **save** according to the profile shown in Figure 1.1.*

- Low cost activities first year or two: 5 to 15%
- Moderate cost, significant effort, three to five years: 15 to 30%
- Long-term potential, higher cost, more engineering: 30 to 50%

**Figure 1.1 Typical Savings
Through Energy Management**

ENERGY MANAGEMENT

Principles of Energy Management:

- ❑ *The **first principle** is to **control the costs** of the energy function or service provided, but **not the Btu of energy**.*
- ❑ *In 1978, the aggregate industrial expenditure for energy was \$55 billion in United States.*
- ❑ ***Thirty-five** percent of that was spent for machine drive from electric motors, 29% for feedstocks, 27% for process heat, 7% for electrolytic functions, and 2% for space conditioning and light.*
- ❑ *As shown in Table 1.1, this is in blunt contrast to measuring these functions in Btu. Machine drive, for example, instead of **35% of the dollars**, required only **12% of the Btu**.*

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Principles of Energy Management:

Table 1.1 Industrial Energy Functions by Expenditure and Btu, 1978

Function	Dollar Expenditure (billions)	Percent of Expenditure	Percent of Total Btu
Machine drive	19	35	12
Feedstocks	16	29	35
Process steam	7	13	23
Direct heat	4	7	13
Indirect heat	4	7	13
Electrolysis	4	7	3
Space conditioning and lighting	<u>1</u>	<u>1</u>	<u>1</u>
Total	55	100	100

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Principles of Energy Management:

- ❑ *In addition to energy costs, it is **useful to measure** the depreciation, maintenance, labor, and other operating costs involved in providing required services.*
- ❑ *These costs add as much as **50% to the fuel cost**. It is the total cost of these functions that must be managed and controlled, not the Btu of energy.*
- ❑ *The **large difference in cost** of the various Btu of energy can make the commonly used Btu measure extremely misleading.*
- ❑ *In November 1979, the cost of 1 Btu of electricity was **nine times** that of 1 Btu of steam coal.*

ENERGY MANAGEMENT

- Controlling the **total cost** of energy functions is much more closely attuned to one of the principal interests of the executives of an organization— **controlling costs**.

Table 1.2 Cost of Industrial Energy per Million Btu, 1979 and 2005

Fuel	Cost (1979)	Cost (1979) Adjusted to 2004 Dollars	Cost (2005)	Pct Change in 25 years (constant dollars)
Industrial Coal	1.11	2.32	1.78	<-23%>
Natural Gas	2.75	5.75	8.41	+46%
Residual Fuel	2.95	6.17	8.74	+41%
Distillate Fuel	4.51	9.65	10.82	+12%
Electricity	10.31	21.58	17.57	<-18%>
		Approximated as 3% inflation per year over 25 years	Source: EIA Annual Energy Outlook, 2004 dollars per million Btu	

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Principles of Energy Management:

- 1. The **second principle** of energy management is to control energy functions as a **product cost**, not as a part of manufacturing or general overhead.*
- 2. It is surprising how many companies still lump all energy costs into one general or **manufacturing overhead** account without identifying those products with the **highest energy function cost**.*
- 3. In most cases, energy functions must become **part of the standard cost system** so that each function can be assessed as to its specific impact on the product cost.*

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Principles of Energy Management:

- ❑ *The minimum **theoretical energy expenditure** to produce a given product can usually be determined en route to establishing a **standard energy cost** for that product.*
- ❑ *The seconds of 25-hp motor drive, the minutes necessary in a 2200°F furnace to heat a steel part for fabrication, or the minutes of 5-V electricity needed to make an electrolytic separation, for example, can be determined as **theoretical minimums** and **compared** with the **actual figures**.*
- ❑ *As in all production cost functions, the **minimum standard** is often **difficult to meet**, but it can serve as an **indicator** of the **size of the opportunity**.*

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Principles of Energy Management:

In comparing **actual values** with **minimum values**, four possible approaches can be taken to **reduce the variance**, usually in this order:

1. An hourly or daily **control system** can be installed to keep the function cost at the desired level.
2. Fuel requirements can be switched to a **cheaper** and **more available** form.
3. A **change** can be made to the **process methodology** to reduce the need for the function.
4. **New equipment** can be installed to **reduce the cost** of the function.

ENERGY MANAGEMENT

Principles of Energy Management:

- ❑ *The **third principle** is to **control and meter** only the **main energy functions**—the roughly 20% that make up 80% of the costs.*
- ❑ ***Few functions** usually account for a **majority of the costs**. It is important to focus controls on those that represent the **meaningful costs** and aggregate the remaining items in a **general category**.*
- ❑ *Many manufacturing plants have **only one meter**, (that leading from the gas main or electric main into the plant from the outside source).*
- ❑ *Regardless of the reasonableness of the **standard cost** established, the **inability to measure** actual consumption against that standard will render such a system useless.*

ENERGY MANAGEMENT

Principles of Energy Management:

- ❑ *The **fourth principle** is to put the major effort of an energy management program into **installing controls** and achieving results.*
- ❑ *It is common to find **general knowledge** about how large amounts of energy could be saved in a plant.*
- ❑ *The missing ingredient is the **discipline** necessary to achieve these potential savings.*
- ❑ *Each step in saving energy needs to be **monitored frequently** enough by the manager or first-line supervisor to **see noticeable changes**.*
- ❑ ***Logging** of important fuel usage or behavioral observations are almost always necessary before any particular **savings results** can be **realized**.*

ENERGY MANAGEMENT

Principles of Energy Management:

- ❑ *Therefore, it is critical that an energy director or committee have the **authority** from the chief executive to **install controls**, not just advise line management.*
- ❑ *Those energy managers who have achieved the **largest cost reductions** actually **install systems and controls**; they do not just provide good advice.*
- ❑ *The **20%** or so improvement in industrial energy productivity since 1972 is just the beginning.*
- ❑ ***Energy productivity** provides an expanding opportunity, not a last resort.*

ENERGY MANAGEMENT

Energy Audits: Purpose

- ❑ *Saving money on energy bills is attractive to businesses, industries, and individuals alike.*
- ❑ *Customers whose energy bills use up a large part of their income, have a strong motivation to initiate and continue an ongoing energy cost-control program.*
- ❑ *No-cost or very low cost operational changes can often save a customer or an industry 10-20% on utility bills.*
- ❑ *Capital cost programs with payback times of two years or less can often save an additional 20-30%.*
- ❑ *In many cases these energy cost control programs will also result in both reduced energy consumption and reduced emissions of environmental pollutants.*

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Energy Audits:

- ❑ *The energy audit is one of the first tasks to be performed in the accomplishment of an effective energy cost control program.*
- ❑ *An energy audit consists of a detailed examination of how a facility uses energy, what the facility pays for that energy, and finally, a recommended program for changes in operating practices or energy-consuming equipment that will cost-effectively save dollars on energy bills.*
- ❑ *The energy audit is a positive experience with significant benefits to the business or individual, and the term “audit” should be avoided if it clearly produces a negative image in the mind of a particular business or individual.*

ENERGY MANAGEMENT

Energy Audit team selection:

- ❑ *Large commercial or industrial customers may hire an engineering consulting firm to perform a complete energy audit.*
- ❑ *Other companies may elect to hire an energy manager or set up an energy management team whose job is to conduct periodic audits and to keep up with the available energy efficiency technology.*
- ❑ *'Certified Energy Auditor' and 'Certified Energy Manager' certifications are available from 'Bureau of Energy efficiency' and 'American Association of Energy Engineers'.*

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Energy Audit Methodology:

- ❑ *The audit process starts by collecting information about a facility's operation and about its past record of utility bills.*
- ❑ *This data is then analyzed to get a picture of how the facility uses—and possibly wastes—energy, as well as to help the auditor learn what areas to examine to reduce energy costs.*
- ❑ *Specific changes—called Energy Conservation Opportunities (ECOs)—are identified and evaluated to determine their benefits and their cost-effectiveness.*
- ❑ *These ECOs are assessed in terms of their costs and benefits, and an economic comparison is made to rank the various ECOs.*

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Energy Audit Methodology:

- ❑ *Finally, an Action Plan is created where certain ECOs are selected for implementation, and the actual process of saving energy and saving money begins.*
- ❑ *To obtain the best information for a successful energy cost control program, the auditor must make some measurements during the audit visit.*
- ❑ *The amount of equipment needed depends on the type of energy consuming equipment used at the facility, and on the range of potential ECOs that might be considered.*

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The Auditor's Toolbox:

Tools commonly needed for energy audits are listed below:

Tape Measures

Light meter

Thermometers

Infrared Cameras

Airflow Measurement Devices

Smoke Generator

Miniature Data Loggers

Voltmeter

Clamp On Ammeter

Wattmeter/Power Factor Meter

Combustion Analyzer

Blower Door Attachment

Safety Equipment

Vibration Analysis Gear

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Preparing for the Audit Visit

- ❑ *Some preliminary work must be done before the auditor makes the actual energy audit visit to a facility.*
- ❑ *Data should be collected on the facility's use of energy through examination of utility bills, and some preliminary information should be compiled on the physical description and operation of the facility.*
- ❑ *This data should then be analyzed so that the auditor can do the most complete job of identifying Energy Conservation Opportunities during the actual site visit to the facility.*

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Data to be collected

- ❑ *Energy Use Data*
- ❑ *Physical and Operational Data for the Facility*
 1. *Geographic Location/Weather Data:*
 2. *Facility Layout*
 3. *Operating Hours*
 4. *Equipment List*

Audit Interviews

Getting the correct information on facility equipment and operation is important if the audit is going to be most successful in identifying ways to save money on energy bills.

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Energy Pricing and Energy Demand Estimation

- ❑ *The energy auditor should start by **collecting data** on energy use, power demand and cost for at least the previous **12 months**.*
- ❑ ***Twenty-four** months of data might be necessary to adequately understand some types of billing methods.*
- ❑ ***Bills** for gas, oil, coal, electricity, etc. should be compiled and examined to determine both the amount of energy used and the cost of that energy.*
- ❑ *This data should then be put into **tabular** and **graphic** form to see what kind of **patterns** or **problems** appear from the tables or graphs*

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Rate Structures

- ❑ *To fully understand **the cost of energy**, the auditor must determine the **rate structure** under which that energy use is billed.*
- ❑ *Energy rate structures may go from the **extremely simple ones**—for example, \$1.00 per gallon of Number 2 fuel oil, to very complex ones.*
- ❑ *For example, **electricity consumption** which may have a customer charge, energy charge, demand charge, power factor charge, and other miscellaneous charges that vary from month to month.*
- ❑ *Few customers or businesses **really understand** the various rate structures that control the cost of the energy they consume.*

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Electrical Demand Estimation and Charges:

- ❑ *The **demand charge** is based on a **reading** of the **maximum power in kW** that a customer demands in one month.*
- ❑ *Electric utilities **average** the power reading over intervals from **fifteen minutes to one hour**, so that very short fluctuations do not adversely affect customers.*
- ❑ *Thus, a customer might be billed for demand for a month based on a **maximum value of a fifteen minute integrated average** of their power use.*

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Ratchet Clauses:

- ❑ *Some utilities have a ratchet clause in their rate structure which stipulates that the minimum power demand charge will be the highest demand recorded in the last billing period or some percentage (i.e., typically 70%) of the highest power demand recorded in the last year.*
- ❑ *The ratchet clause can increase utility charges for facilities during periods of low activity or where power demand is tied to extreme weather.*

Discounts:

Utilities generally provide discounts on their energy and power rates for customers who accept power at high voltage and provide transformers on site.

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Penalty for Power factor :

- Power companies also commonly assess penalties when a customer has a power factor less than 0.9.*
- Inductive loads (e.g., lightly loaded electric motors, old fluorescent lighting ballasts, etc.) reduce the power factor.*
- Improvement can be made by adding capacitance to correct for lagging power factor, and variable capacitor banks are most useful for improving the power factor at the service drop.*
- Capacitance added near the loads can effectively increase the electrical system capacity.*
- Turning off idling or lightly loaded motors can also help.*

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Energy Bills:

- ❑ Energy bills should be **broken down** into the components that can be controlled by the facility.
- ❑ These cost components can be listed **individually** in tables and then plotted.
- ❑ For example, electricity bills should be broken down into power **demand costs** per kW per month, and **energy costs** per kWh.

The following example illustrates the parts of a rate structure for an industry in Florida.

Example:

A company that fabricates metal products gets electricity from its electric utility at the following general service demand rate structure.

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Rate structure:

<i>Customer cost</i>	<i>= \$21.00 per month</i>
<i>Energy cost</i>	<i>= \$0.051 per kWh</i>
<i>Demand cost</i>	<i>= \$6.50 per kW per month</i>
<i>Taxes</i>	<i>= Total of 8%</i>
<i>Fuel adjustment</i>	<i>= A variable amount per kWh each month</i>

- ❑ *The auditor must be sure **to account** for all the taxes, the fuel adjustment costs, the fixed charges, and any other costs so that the true cost of the **controllable energy cost** components can be determined.*

The energy use and costs for that company for a year are summarized below:

ENERGY MANAGEMENT

Summary of Energy Usage and Costs

Month	kWh Used (kWh)	kWh Cost (\$)	Demand (kW)	Demand Cost (\$)	Total Cost (\$)
Mar	44960	1581.35	213	1495.26	3076.61
Apr	47920	1859.68	213	1495.26	3354.94
May	56000	2318.11	231	1621.62	3939.73
Jun	56320	2423.28	222	1558.44	3981.72
Jul	45120	1908.16	222	1558.44	3466.60
Aug	54240	2410.49	231	1621.62	4032.11
Sept	50720	2260.88	222	1558.44	3819.32
Oct	52080	2312.19	231	1621.62	3933.81
Nov	44480	1954.01	213	1495.26	3449.27
Dec	38640	1715.60	213	1495.26	3210.86
Jan	36000	1591.01	204	1432.08	3023.09
Feb	42880	1908.37	204	1432.08	3340.45
Totals	569,360	24,243.13	2,619	18,385.38	42,628.51
Monthly Averages	47,447	2,020.26	218	1,532.12	3,552.38

ENERG



ಚಾಮುಂಡೇಶ್ವರಿ ವಿದ್ಯುತ್ ಸರಬರಾಜು ನಿಗಮ
ವಿದ್ಯುತ್ ಬಿಲ್ / ELECTRICITY BILL

O/o. Asst. Executive Engineer (Ele.)
CHAMUNDIPURAM

Account Details

ಆರ್.ಆರ್.ಸಂಖ್ಯೆ/ RR No 440524
ಖಾತೆ ಸಂಖ್ಯೆ/Acc Id 6798831000
ಮಾ.ಓ. ಸಂಕೇತ/ M. R Code 34000911

Personal Details

ಹೆಸರು ಮತ್ತು ವಿಳಾಸ/Name and Address
GURUPADADEVARU, 1037J P NAGARJP NAGAR NACHANA
HALLIPALYA

Connection Details

ಬಕಾತಿ /Tariff 3LT2A1-N
ಮಂ. ಪ್ರಮಾಣ/Sanc Load 3KW+OHP

Billing Details

ಬಿಲ್ ಅವಧಿ/Bill Period 15/08/2018 - 15/09/2018
ರೀಡಿಂಗ್ ದಿನಾಂಕ/Rdng. Date 15/09/2018
ಬಿಲ್ ಸಂಖ್ಯೆ/Bill No 111209020398

Consumption Detail

ಇಂದಿನ ಮಾಪನ/Pres. Rdg. 11160
ಹಿಂದಿನ ಮಾಪನ/Prev. Rdg. 10992
ಮಾಪನ ಸ್ಥಿರಾಂಶ/Constant 1
ಬಳಕೆ/Consumption(Units) 168
ಸರಾಸರಿ/Average
ದಾಖಲಿತ ಬೇಡಿಕೆ/Recorded MD 0KW
ಪವರ್ ಫ್ಯಾಕ್ಟರ್/Power Factor 0.0
ಸಂ. ಪ್ರಮಾಣ/Connected Load 0.0KW

ನಿಗದಿತ ಶುಲ್ಕ/Fixed Charges (Unit, Rate, Amount)

1 KW 50 50.00
2 KW 60 120.00

ವಿದ್ಯುತ್ ಶುಲ್ಕ/Energy Charges (Unit, Rate, Amount)

30 3.45 103.50
70 4.95 346.50
68 6.5 442.00

ಇಂಧನ ಹೊಂದಾಣಿಕೆ ಶುಲ್ಕ/FAC Charges (Unit, Rate, Amt)

168 0 0.00

Additional Charges

ಸೋಲಾರ್ ರಿಯಾಯಿತಿ/SOLAR Rebate -50.00
ಪಿ ಎಫ್ ದಂಡ/PF Penalty 0.00
ಹೆ.ಲೋ.ದಂಡ/Ex. Load/MD Penalty 0.00
ಬಡ್ಡಿ/Interest 0.00
ಇತರೆ/Others 0.00
ತೆರಿಗೆ/Tax 80.28
ಬಿಲ್ ಮೊತ್ತ/Bill Amt 1092.28
ಬಾಕಿ/Arrears 0.00
ಜಮೆ/Credits & Adjustment 0.00
ಸರ್ಕಾರದ ಸಹಾಯಧನ/GOK Subsidy 0.00

ಮಾ ಮೊತ್ತ/Netl Amt Due ₹ 1092.00
ಮಾಪನಿಗೆ ಕಡೇಯ ದಿನಾಂಕ/Due Date 29/09/2018



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AGEMENT

ENERGY MANAGEMENT

Walk-through Tour

*A walk-through tour of the facility or plant tour should be conducted by the facility/plant manager, and should be arranged so the auditor or audit team can **see the major operational and equipment features** of the facility.*

Getting Detailed Data

- Following the facility or plant tour, the auditor or audit team should **acquire the detailed data** on facility equipment and operation that will lead to **identifying the significant (ECOs)** that may be appropriate for this facility.*

ENERGY MANAGEMENT

What to Look for

Lighting

Electric Motors

Air Compressors

Refrigerators

Water Heaters

Furnaces

Other Energy-Consuming Equipment

HVAC Equipment

Mixers / Fans / Blowers

Pumps

Ovens

Boilers

Waste Heat Sources

Data on types, sizes, capacities, fuel use, electrical characteristics, age, Peak Equipment Loads and operating hours should be recorded for all of this equipment.

ENERGY MANAGEMENT

Preliminary Identification of ECOs

- ❑ *As the audit is being conducted, the auditor should **take notes** on potential ECOs that are evident.*
- ❑ *Identifying ECOs requires a good knowledge of the available energy efficiency technologies that can **accomplish the same job with less energy and less cost.***

Post-Audit Analysis

- ❑ *The preliminary ECOs identified during the audit visit should now be **reviewed**, and the **actual analysis** of the equipment or operational change should be conducted.*
- ❑ *This involves **determining the costs and the benefits** of the potential ECO, and making a judgment on the cost-effectiveness of that potential ECO. (solar Panel vs solar heater)*

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Post-Audit Analysis

- ❑ Often, **Simple Payback Period (SPP)** is used to measure cost-effectiveness, and most facilities want a SPP of **two years** or less.
- ❑ The SPP for an ECO is found by taking the initial cost and dividing it by the annual savings. This results in finding a **period of time** for the savings to repay the initial investment, without using the **time value of money**.

The Energy Audit Report

- ❑ The next step in the energy audit process is to prepare a report which details the **final results** and **recommendations**. The length and detail of this report will vary depending on the type of facility audited.
- ❑ A residential audit may result in a **computer printout** from the utility. An industrial audit is more likely to have a **detailed explanation** of the ECOs and **benefit-cost analyses**.

ENERGY MANAGEMENT

Energy Audit Report Format

- Executive Summary*
- Table of Contents*
- Introduction*
- Facility Description*
- Energy Bill Analysis*
- Energy Conservation Opportunities*
- Action Plan*
- Conclusion*

ENERGY MANAGEMENT

HVAC ECO's

Operational

1. *Setback Control / Turn on and Turn off HVAC at scheduled times*
2. *Resetting Chiller Supply Water Temp*
3. *Resetting furnace heating set point*
4. *Commissioning*

Retrofits

6. *Demand Control Ventilation (CO₂ sensor in the return air duct)*
7. *VFD on HVAC Fans, Variable refrigerant flow*
8. *Economizers (Wet bulb or enthalpy control and dry bulb control)*
9. *Mix return air with incoming air, Heat recovery ventilators, Enthalpy Wheel*
10. *Single pane to Double pane, Add Glazing*

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HVAC ECO's

Retrofits

11. Reduce Infiltration, Ex-filtration
12. Weatherization – To close the gaps / Improve Indoor Air Quality, Weather Stripping, Caulking
13. Add / Repair Insulation
14. Reduce Ceiling height if possible / Install de-stratification high-volume fans
15. Reduce window sizes if possible

Upgrades

16. Replace Old inefficient Chillers, vfd/ multi stage compressor
17. Upgrade HVAC

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Lighting ECO's

17. Incandescent to CFL to LED
18. T12 to T8
19. HID to T5
20. Outside/parking/Exit lights to LED
21. Motion/Occupancy Sensors
22. Photo Sensors for fluorescent lighting
23. Timers on outside lights
24. Add Day lights / Solar tube

Operational

25. Turn on and turn off lights at scheduled times

ENERGY MANAGEMENT

Boiler Recommendations

26. *Adjust Air to Fuel Ratio*
27. *Boiler Economizer / Preheat Combustion Air*
28. *Replace old burners (#2, #4, #6 Fuel Oil burners have to be replaced with NG burners due to some state codes)*
29. *Inspect, Repair and Maintain Steam Traps*
30. *Insulate hot surfaces/pipes*
31. *Return Condensate to the boiler*
32. *Boiler Management for multiple boilers*

ENERGY MANAGEMENT

Furnace Recommendations

33. *Preheat Combustion Air / Recuperation*
34. *Regenerative Burners*
35. *Replace old inefficient burners with poor air to fuel ratio controls*
36. *Close openings / Insulate bare surfaces*
37. *Preheat charge using exhaust gases*

ENERGY MANAGEMENT

Compressor Recommendations

38. Sequencer
39. VFD on Screw Compressor
40. Recover waste heat
41. Replace Centrifugal Compressor with Blow off Control with Screw compressor
42. Vortex nozzles
43. Sensors to stop compressed air supply when no parts on the conveyor
44. Reduce pressure
45. Booster compressor for high pressure demand
46. Reduce air leaks
47. Outside air on oil free compressor
48. Use unloading controls
49. Add receiver volume
50. Adjust cascading set points

ENERGY MANAGEMENT

Motor and Pump Recommendations

- 51. VFD
- 52. Motor Master
- 53. Vibration
- 54. V Belts
- 55. Cascading pumps

General Recommendations

- 56. Micro-turbines
- 57. Reduce demand / Enroll in demand response
- 58. Thermal Energy Storage
- 59. Add building Automation System for old buildings with poor building Controls
- 60. Enroll in better rate schedule if available
- 61. Power factor reduction

ENERGY MANAGEMENT

Thermal Energy Storage

- ❑ *A majority of the technology developed for energy management has dealt with the more **efficient consumption of electricity**, rather than **timing the demand** for it.*
- ❑ *The management of demand charges deals very little with conservation of energy, but mainly with the **ability of a generator to supply power** when needed.*
- ❑ *It is this **timing of consumption** that is the basis of demand management and the focus of thermal energy storage (TES).*
- ❑ *Experts agree that demand management is actually not a form of **energy conservation** but a form of **cost management**.*
- ❑ *Utilities often **charge more for energy and demand** during certain periods in the form of on-peak rates and ratchet clauses.*

ENERGY MANAGEMENT

Thermal Energy Storage

- ❑ Thermal energy storage (TES) is the concept of **generating and storing energy** in the form of heat or cold for use during peak periods.
- ❑ For the profile in Figure 19.1, a cooling storage system could be implemented to **reduce or eliminate** the need to run the chillers during the on-peak rate period.
- ❑ By running the chillers during off-peak hours and storing this capacity for use during the on peak hours, a **reduction in energy** costs can be realized.
- ❑ If this type of system is implemented **smaller capacity chillers** can be installed, since the chiller can **spread** the production of the total load over the entire day, rather than being sized for peak loads.

ENERGY MANAGEMENT

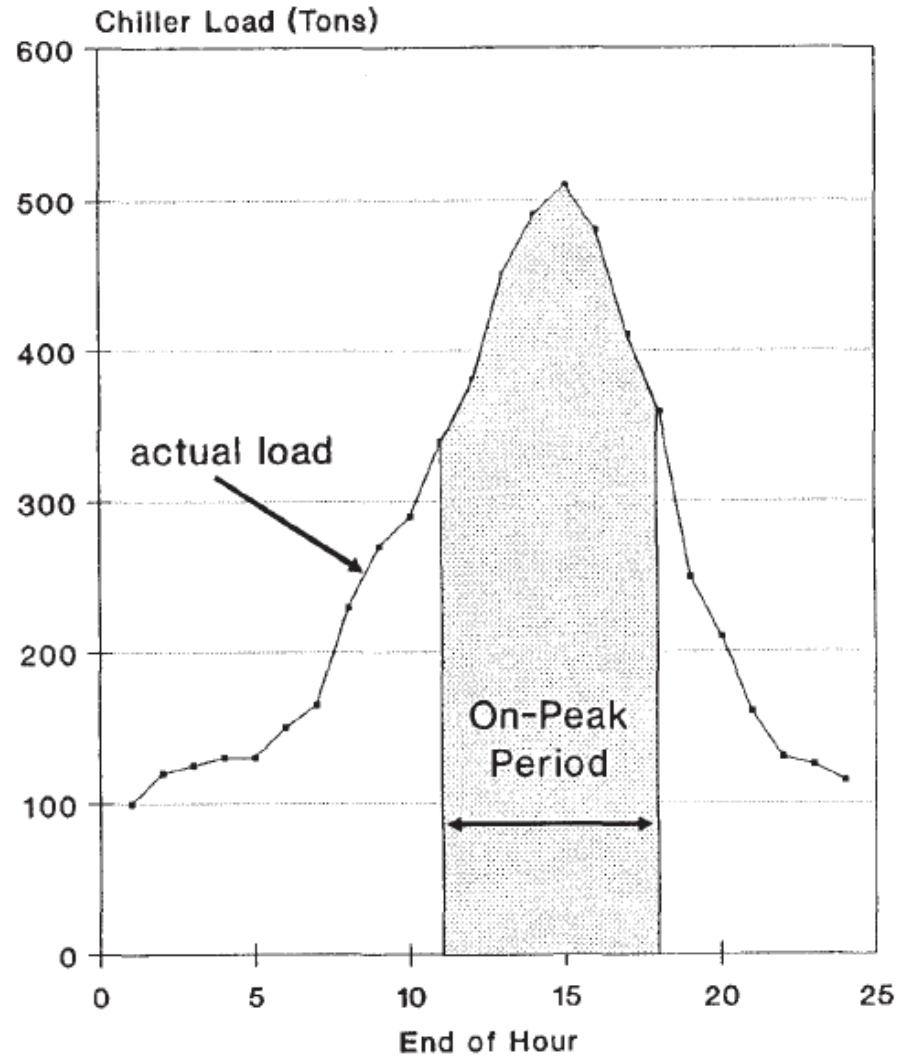


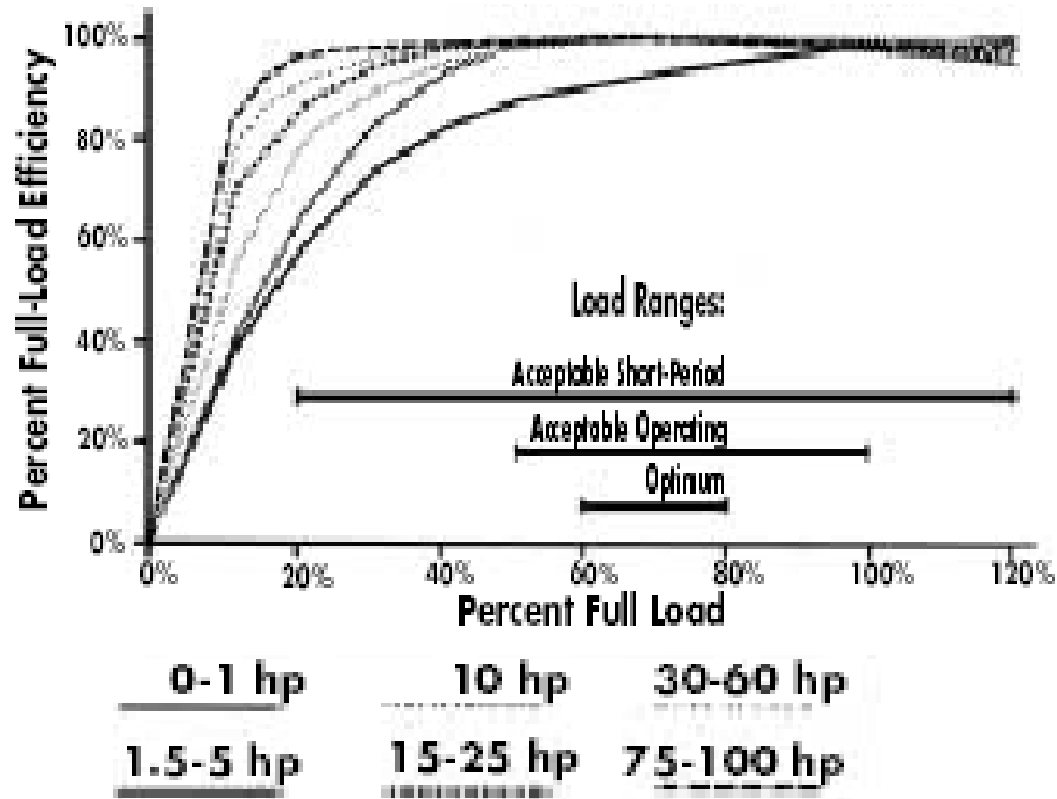
Figure 19.1 Typical office building chiller consumption profile.

ENERGY MANAGEMENT

Thermal Energy Storage

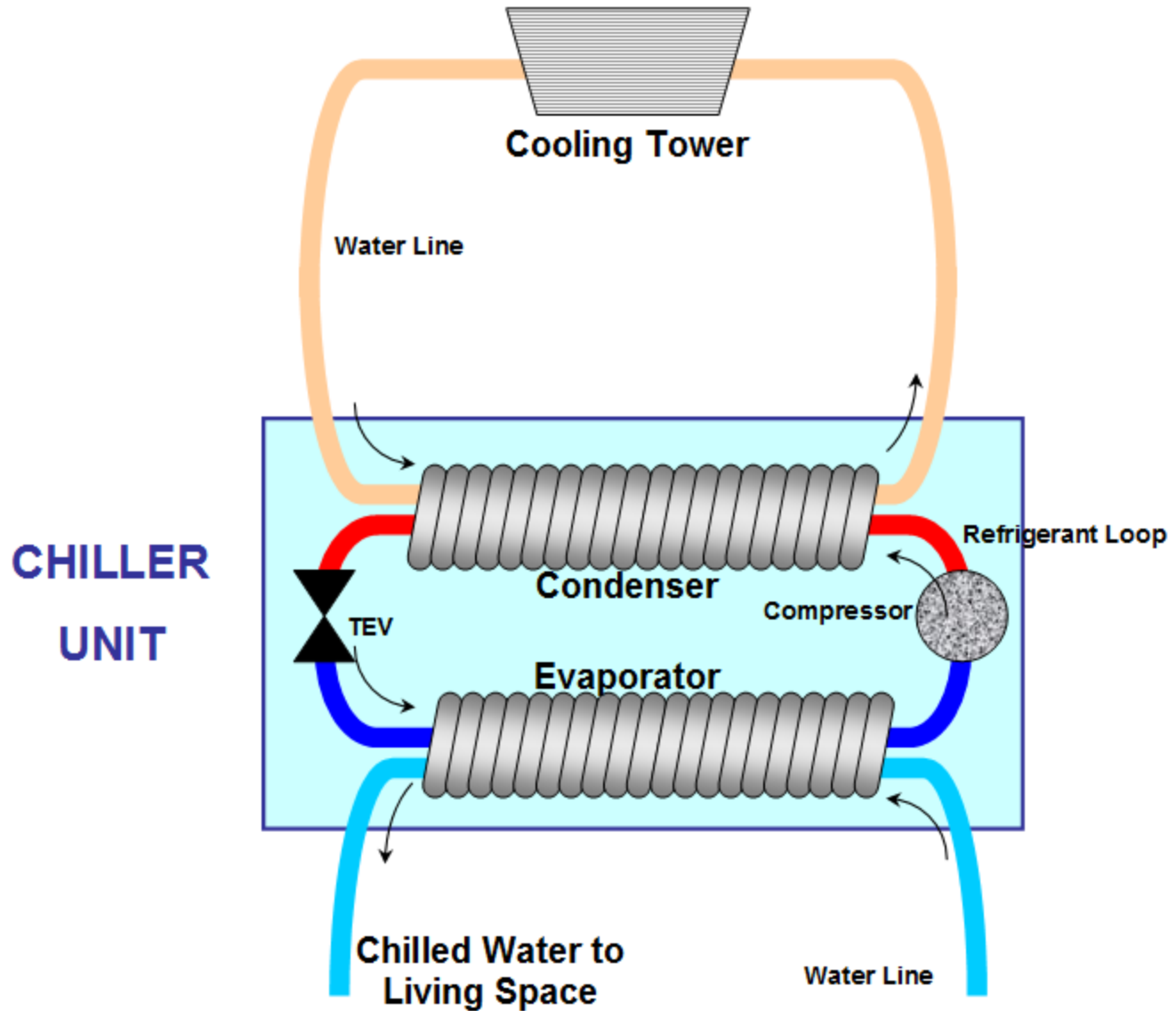
- ❑ *Often the chiller load and efficiency follow the chiller consumption profile, in that the chiller is **running** at high load, i.e. **high efficiency, only a small portion** of the day.*
- ❑ *This is due to the HVAC system having to produce cooling when it is needed as well as to be able to handle **instantaneous peak loads**.*
- ❑ *With smaller chiller systems designed to handle the **base and peak loads during off peak hours**, the chillers can run at higher average loads and thus at **higher efficiencies**.*

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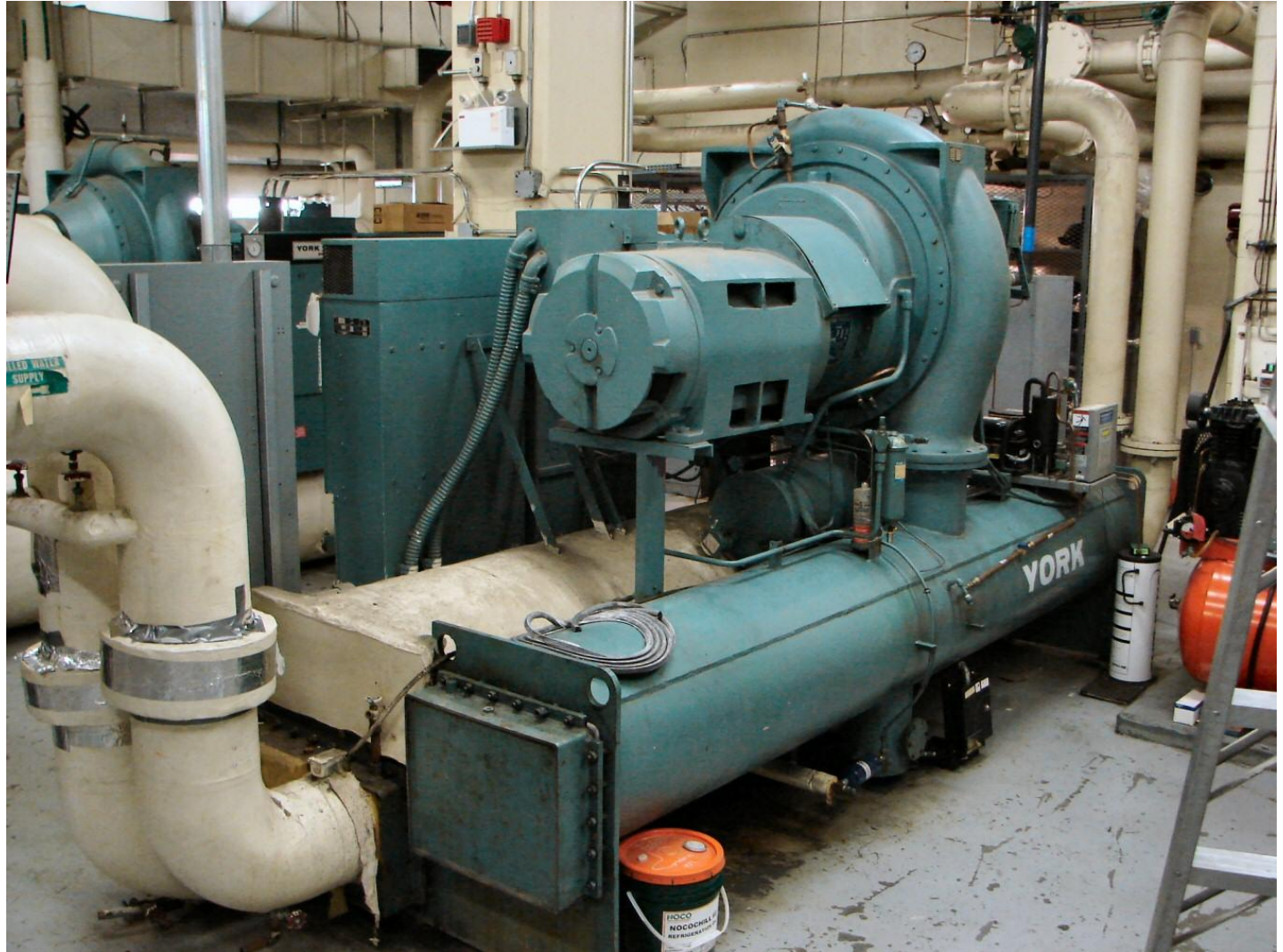


General Motor Performance Curve

ENERGY MANAGEMENT



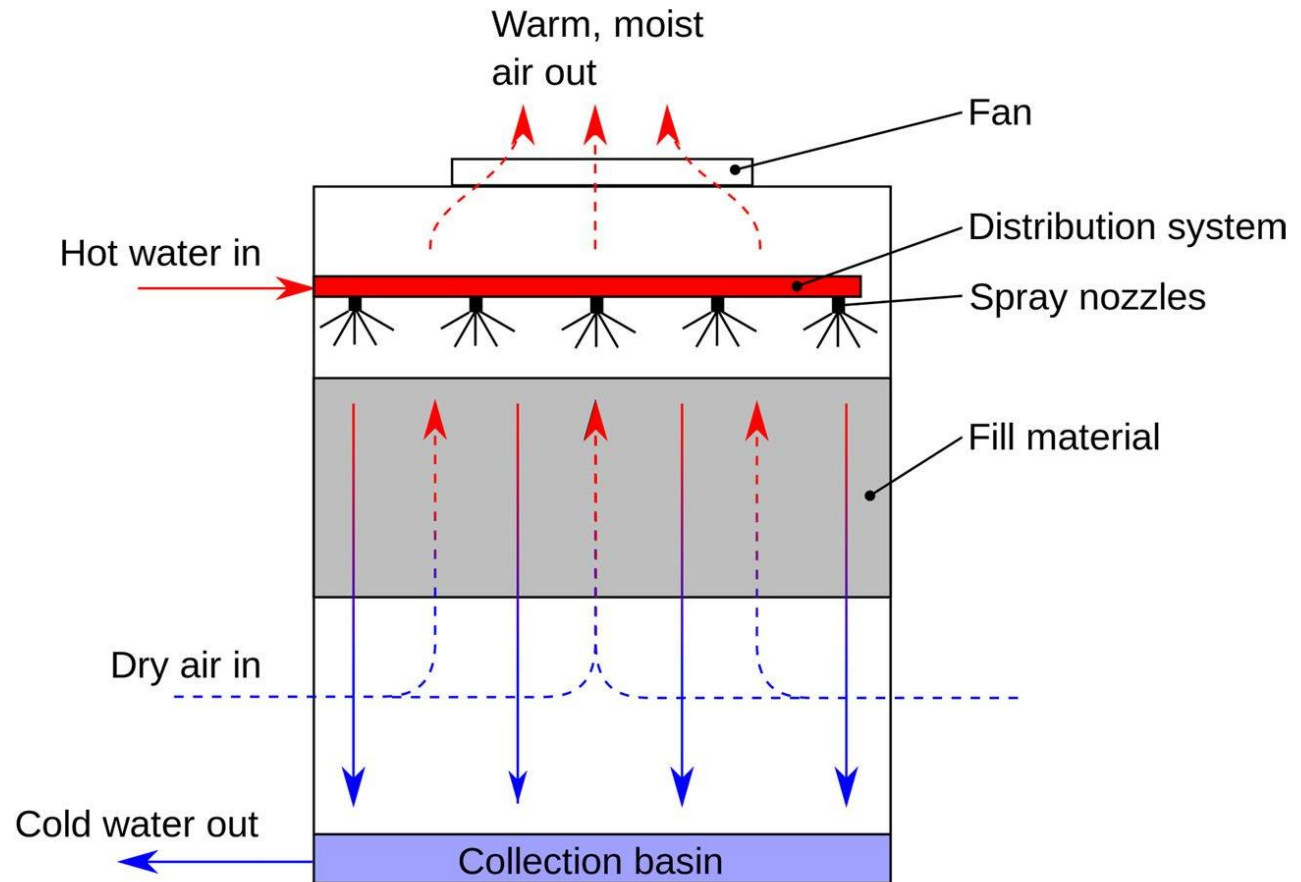
ENERGY MANAGEMENT



Chiller

ENERGY MANAGEMENT

HOW COOLING TOWERS WORK

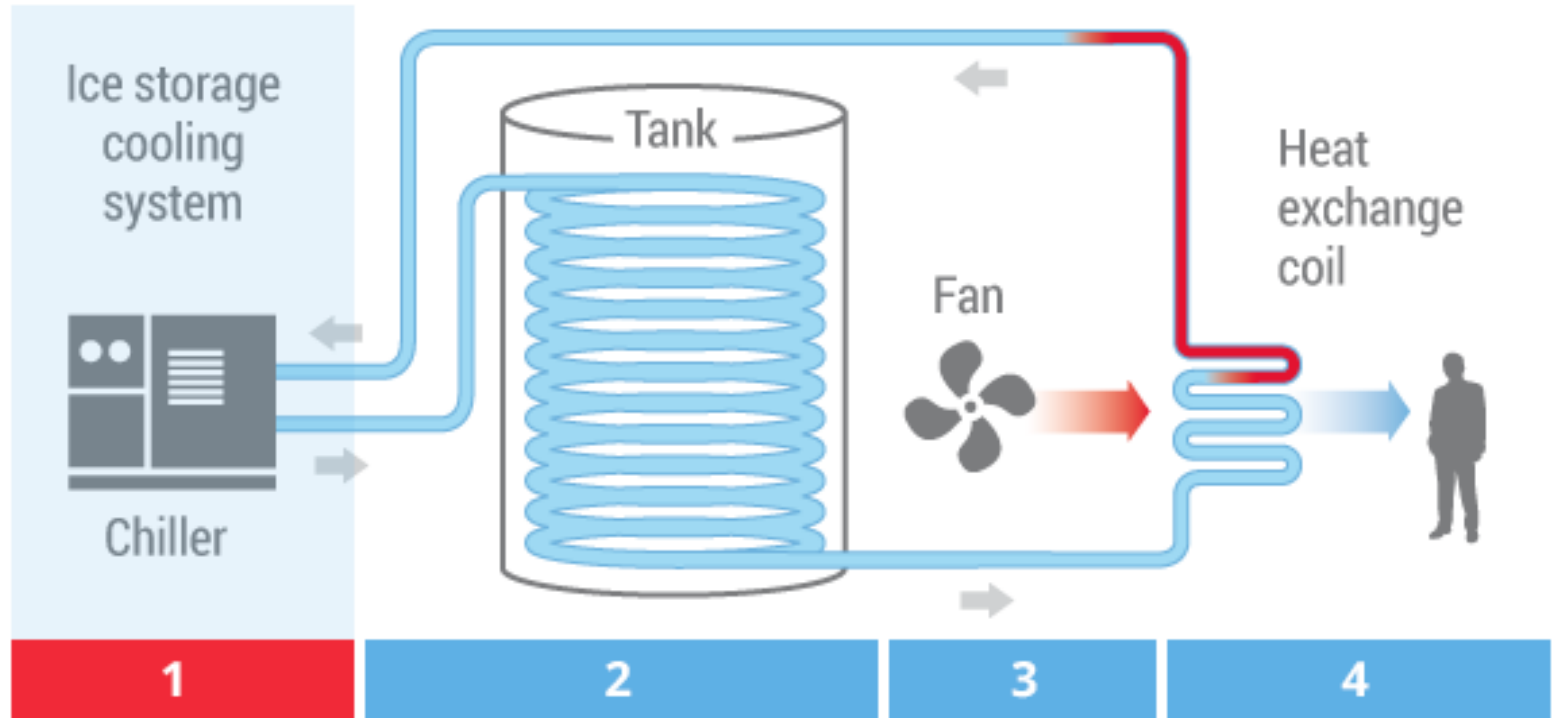


ENERGY MANAGEMENT

STORAGE SYSTEMS

- ❑ There are **two general types** of storage systems, ones that **shut the chiller down** during on-peak times and run completely off the storage system during that time are known as **“full storage systems”**.
- ❑ Those designed to have the **chiller run during the on-peak period** supplementing the storage system are known as **“partial storage systems”**.
- ❑ The full storage systems have a **higher first cost** since the chiller is off during peaking times and the cooling load must be satisfied by a **larger chiller** running fewer hours and a **larger storage system** storing the excess.
- ❑ The full storage systems do realize **greater savings** than the partial system since the chillers are **completely turned off** during **on-peak periods**.

ENERGY MANAGEMENT



Thermal Energy Storage System

ENERGY MANAGEMENT

STORAGE SYSTEMS

- ❑ *Full storage systems are often implemented in **retrofit projects** since **a large chiller system** may already be **in place**.*
- ❑ *A **partial storage system** provides attractive savings with **less initial cost and size** requirements.*
- ❑ ***New construction projects** will often implement a **partial storage system** so that the size of both the chiller and the storage system can be reduced.*
- ❑ *Figures 19.2 and 19.3 and Tables 19.2 and 19.3 demonstrate the chiller load required to satisfy the cooling needs of the office building presented in Figure 19.1 for the full and partial systems, respectively.*
- ❑ *Column 2 in these tables represents the building cooling load each hour, and column 3 represents the chiller output for each hour.*

ENERGY MANAGEMENT

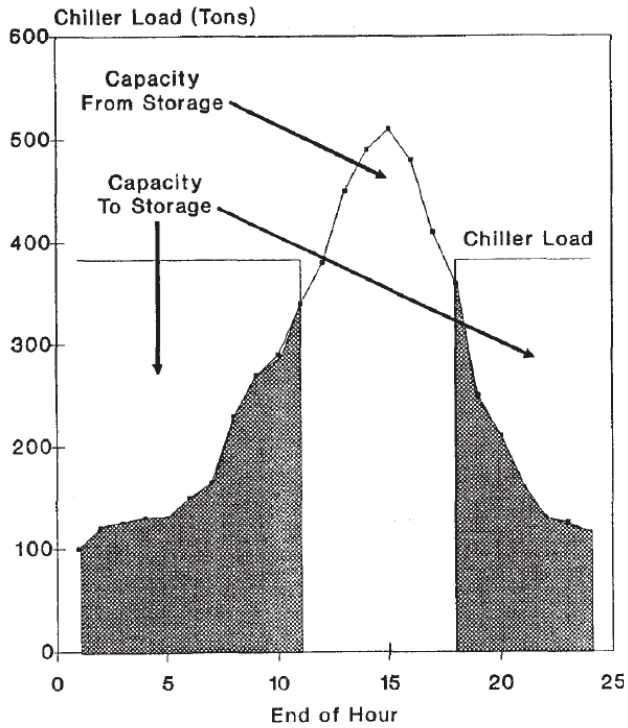


Figure 19.2 Full storage chiller consumption profile.

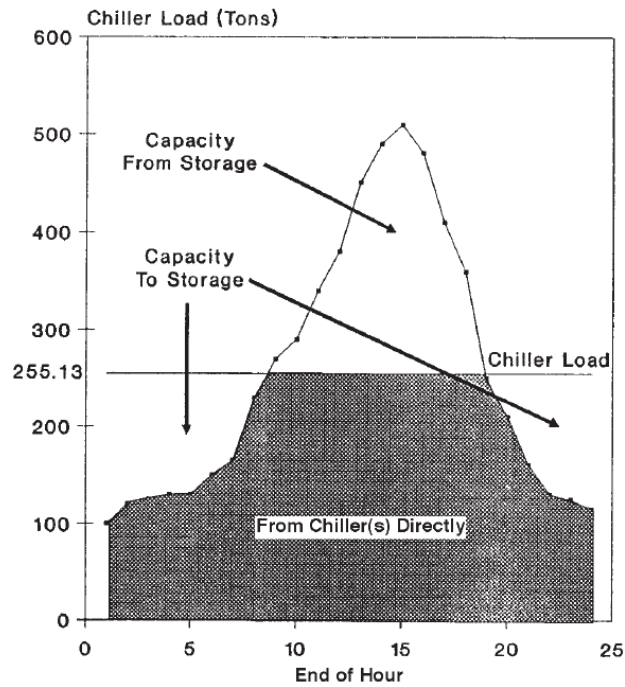


Figure 19.3 Partial storage chiller consumption profile.

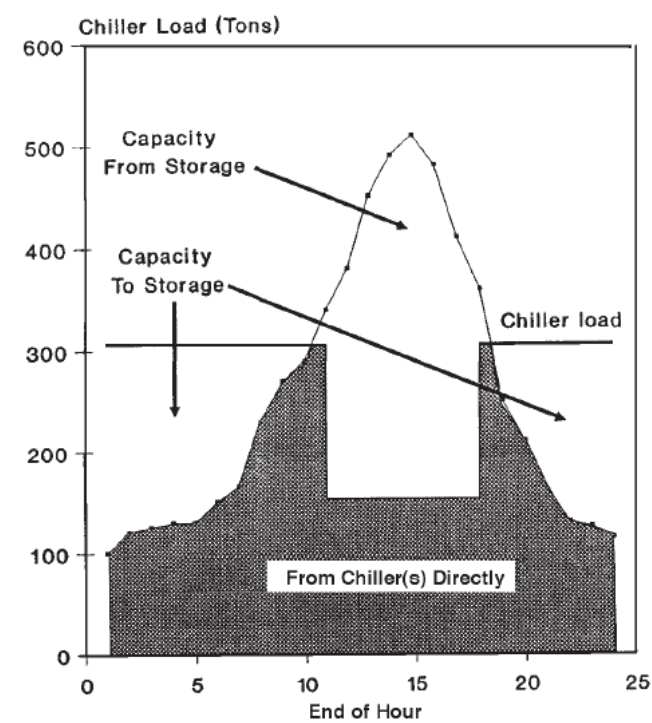


Figure 19.4 Optional partial storage chiller profile.

Table 19.8 System performance comparison.

PERFORMANCE PARAMETERS	SYSTEM			
	Conventional No Storage	Partial Storage	Full Storage	Optional Partial
Overall Peak Demand (Tons)	510	255.13	383	306
On-Peak, Peak Demand (Tons)	510	255.13	0	153
On-Peak Chiller Consumption (Ton-Hrs)	3,420	2,041	0	1,225
Required Storage Capacity ¹ (Ton-Hrs)	—	1,379	3,420	2,195
MAXIMUM STORAGE OUTPUT ¹ (Tons)	—	255	510	357

ENERGY MANAGEMENT

Table 19.1 Example chiller consumption profile

Table 19.2 Full storage chiller consumption profile.

Table 19.3 Partial storage chiller consumption profile.

Chiller Consumption Profile		
End of Hour	Chiller Load (Tons)	Rate
1	100	Reg
2	120	Reg
3	125	Reg
4	130	Reg
5	130	Reg
6	153	Reg
7	165	Reg
8	230	Reg
9	270	Reg
10	290	Reg
11	340	On-Peak
12	380	On-Peak
13	450	On-Peak
14	490	On-Peak
15	510	On-Peak
16	480	On-Peak
17	410	On-Peak
18	360	On-Peak
19	250	Reg
20	210	Reg
21	160	Reg
22	130	Reg
23	125	Reg
24	115	Reg
Daily Total	6123 Ton-Hrs	
Daily Avg.	255.13 Tons	
Peak Total	3420 Ton-Hrs	
Peak Demand	510 Tons	

Chiller Consumption Profile—Full Storage System				
	1	2	3	4
End of Hour (Tons)	Cooling Load (Tons)	Chiller Load ²	Rate	
1	100	382.69	Reg	
2	120	382.69	Reg	
3	125	382.69	Reg	
4	130	382.69	Reg	
5	130	382.69	Reg	
6	153	382.69	Reg	
7	165	382.69	Reg	
8	230	382.69	Reg	
9	270	382.69	Reg	
10	290	382.69	Reg	
11	340	0	On-Peak	
12	380	0	On-Peak	
13	450	0	On-Peak	
14	490	0	On-Peak	
15	510	0	On-Peak	
16	480	0	On-Peak	
17	410	0	On-Peak	
18	360	0	On-Peak	
19	250	382.69	Reg	
20	210	382.69	Reg	
21	160	382.69	Reg	
22	130	382.69	Reg	
23	125	382.69	Reg	
24	115	382.69	Reg	
Daily Total (Ton-Hrs)		6123	6123	
Daily Avg (Tons):		255.13 ¹	255.13	
Peak Total (Ton-Hrs)		3420 ³	0 ⁴	
Peak Demand (Tons)		510 ³	0 ⁴	

Chiller Consumption Profile Partial Storage System				
	1	2	3	4
Hour of Day	Cooling Load (Tons)	Chiller Load (Tons) ¹	Rate	
1	100	255.13	Reg	
2	120	255.13	Reg	
3	125	255.13	Reg	
4	130	255.13	Reg	
5	130	255.13	Reg	
6	153	255.13	Reg	
7	165	255.13	Reg	
8	230	255.13	Reg	
8	270	255.13	Reg	
10	290	255.13	Reg	
11	340	255.13	On-Peak	
12	380	255.13	On-Peak	
13	450	255.13	On-Peak	
14	490	255.13	On-Peak	
15	510	255.13	On-Peak	
16	480	255.13	On-Peak	
17	410	255.13	On-Peak	
18	360	255.13	On-Peak	
19	250	255.13	Reg	
20	210	255.13	Reg	
21	160	255.13	Reg	
22	130	255.13	Reg	
23	125	255.13	Reg	
24	115	255.13	Reg	
Daily Total (Ton-Hrs)		6123	6123	
Daily Avg (Tons):		255.13	255.13	
Peak Total (Ton-Hrs):		3420 ²	2041 ³	
Peak Demand (Tons):		510 ²	255.13 ³	

ENERGY MANAGEMENT

STORAGE SYSTEMS

- ❑ The **full storage system** has been designed so that the total daily chiller load is produced during **the off peak hours**.
- ❑ This eliminates the need to run the chillers during the **on-peak hours**, saving the increased rates for demand charges during this period and as well as any future penalties due to ratchet clauses.
- ❑ The **partial storage system** produces **255.13 tons per hour** during the entire day, **storing excess capacity** for use when the building demand **exceeds** the chiller production.
- ❑ This provides the ability to control the chiller load, limit the peak chiller demand to **255.13 kW**, and still take **advantage** of the **off peak rates** for a portion of the on-peak chiller load.

ENERGY MANAGEMENT

STORAGE SYSTEMS

- ❑ There are **several methods** currently in use to store cold in thermal energy storage systems.
- ❑ These are **water, ice, and phase change materials**.
- ❑ The water systems simply store **chilled water** for use during on-peak periods.
- ❑ Ice systems **produce ice** that can be used to cool the actual chilling water, utilizing the **high latent heat of fusion**.
- ❑ Phase change materials are those materials that exhibit properties, **melting points** for example, that lend themselves to thermal energy storage.
- ❑ Figure 19.5a represents the configuration of the cooling system with either a **water or phase change material** thermal storage system and Figure 19.5b represents a general configuration of a TES utilizing **ice** as the storage medium

ENERGY MANAGEMENT

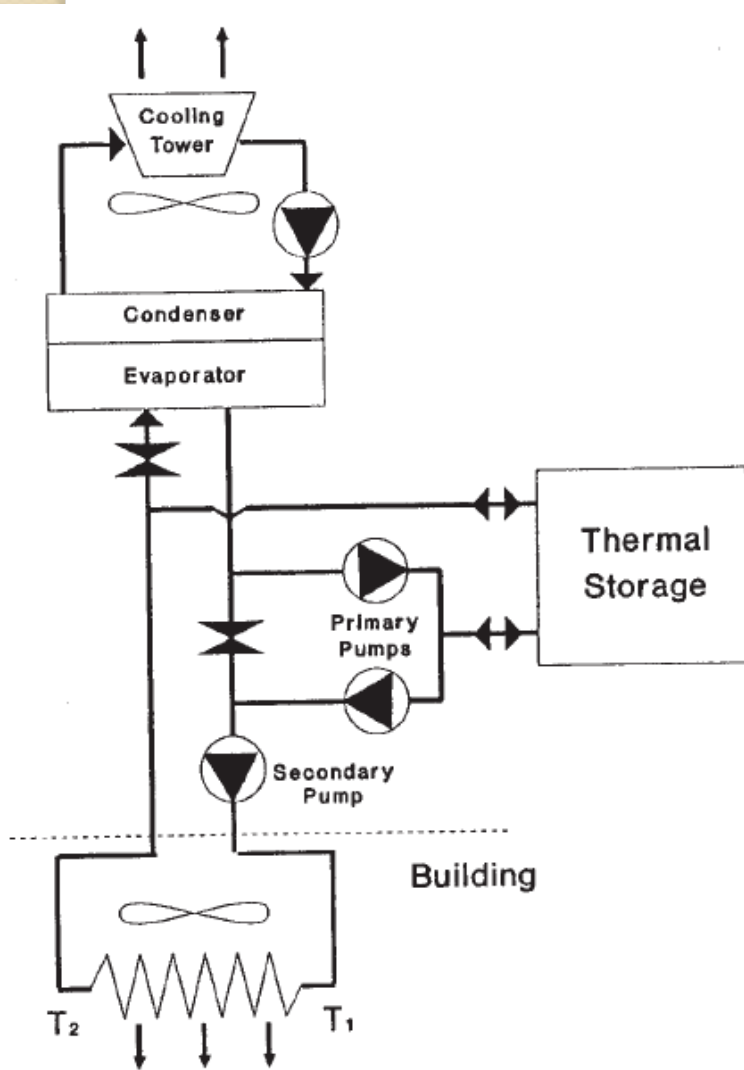


Figure 19.5a Water & eutectic storage system configuration.

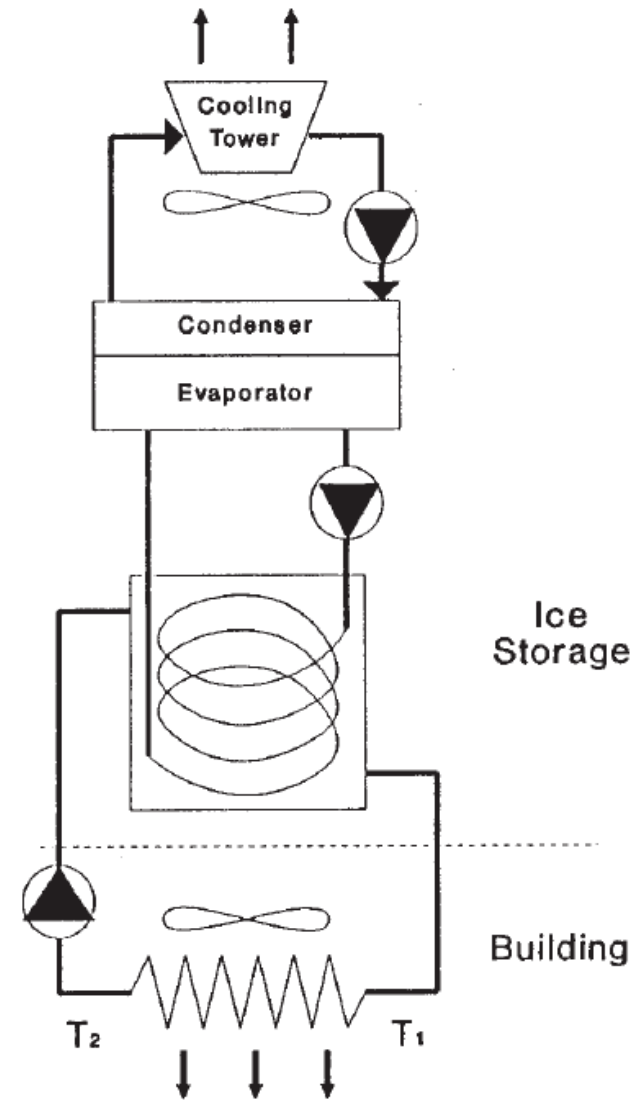


Figure 19.5b Ice storage system configuration.

ENERGY MANAGEMENT

- ❑ Chilled water storage is simply a method of storing chilled water generated **during off-peak periods** in a **large tank**.
- ❑ One factor to this popularity is the **ease** to which these water tanks can be **interfaced** with the **existing HVAC system**.
- ❑ The chillers are not required to produce chilled water **any colder than presently used** in the system so **the system efficiency** is not **sacrificed**.
- ❑ The chiller system **draws warmer water** from one end of the system and this is replaced with **chilled water** in the other.
- ❑ During the off-peak charge cycle, the **temperature** of the water in the storage will **decline** until the **output temperature** of the chiller system is **approached or reached**.
- ❑ This chilled water is then **withdrawn** during the **on-peak discharge cycle**, **supplementing or replacing** the chiller(s) output.

ENERGY MANAGEMENT

The advantages of using water as the thermal storage medium are:

1. **Retrofitting** the storage system with the existing HVAC system is **very easy**
2. Water systems utilize **normal evaporator** temperatures
3. With proper design, the water tanks have **good thermal storage efficiencies**
4. **Full thermal stratification** maintains chilled water temperature differential, maintaining chiller loading and efficiencies
5. Water systems have **lower auxiliary energy consumption** than both ice and phase change materials since the water has unrestricted flow through the storage system.

ENERGY MANAGEMENT

Ice Storage

- ❑ *Ice storage utilizes water's **high latent heat of fusion** to store cooling energy.*
- ❑ *One pound of ice stores **144 Btu's of cooling energy** while chilled water only contains **one Btu per pound per °F**.*
- ❑ *This **reduces** the required **storage volume** approximately **75%** if ice systems are used rather than water.*
- ❑ *Ice storage systems **form ice** with the chiller system **during off-peak periods** and this ice is **used to generate chilled water** during **on-peak periods**.*
- ❑ *There are **two main methods** in use to utilize ice for on-peak cooling i.e., **Static and Dynamic methods**.*

ENERGY MANAGEMENT

Static Method

- ❑ *The first is considered a static system in which **serpentine expansion coils** are fitted within a insulated tank of cooling water.*
- ❑ *During the charging cycle, the **cooling water forms ice** around the **direct expansion coil** as the cold gases pass through it (see Figure 19.5b).*
- ❑ *The **thickness of the ice** varies with the **ice building time** (charge time) and **heat transfer area**.*
- ❑ *During the **discharge cycle**, the **cooling water** contained in the tank is used to **cool the building**.*
- ❑ *The **warmer water** returned from the building is **circulated** through the tank, **melting the ice**, and **using its latent heat of fusion for cooling**.*

ENERGY MANAGEMENT

Dynamic Method

- ❑ *The second major category of thermal energy storage systems utilizing ice can be considered a **dynamic system**.*
- ❑ *This system has also been labelled a **plate ice maker** or **ice harvester**.*
- ❑ *During the charging cycle the cooling water is **pumped over evaporator “plates”** where **ice** is actually **produced**.*
- ❑ *These **thin sheets of ice** are **fed** into the cooling water tank, **dropping** the temperature.*
- ❑ *During **on-peak periods**, this **chilled water** is **circulated** through the building for **cooling**.*
- ❑ *This technology is considered **dynamic** due to the **fact** that the **ice is removed** from the **evaporator** rather than simply **remaining** on it.*

ENERGY MANAGEMENT

The advantages of using ice as the thermal storage medium are:

- ❑ **Retrofitting** the storage system with the existing HVAC chilled water system is **feasible**
- ❑ Ice systems require **less space** than that required by the water systems
- ❑ Ice systems have higher storage but **lower refrigeration efficiencies** than those of water
- ❑ Ice systems are available in **packaged units**, due to smaller size requirements

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Phase Change Materials

- ❑ *The benefit of capturing latent heat of fusion while maintaining evaporating temperatures of existing chiller systems can be realized with the use of **phase change materials**.*
- ❑ *There are materials that have **melting points higher than** that of water that have been successfully used in thermal energy storage systems.*
- ❑ *Several of these materials fall into the general category called “**eutectic salts**” and are salt hydrates which are mixtures of inorganic salts and water.*
- ❑ *Some eutectic salts have melting (solidifying) points of **47° F**, providing the opportunity for a **direct retrofit** using the existing chiller system since this is at or above the existing evaporator temperatures.*

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- ❑ *In a thermal storage system, these salts are placed in **plastic containers**, which are **immersed** within an insulated chilled water tank.*
- ❑ *During the charging cycle, the **chilled water flows** through the gaps between the containers, **freezing the salts** within them.*
- ❑ *During the on-peak discharge, the **warmer building return water** circulates through the tank, **melting the salts** and utilizing the latent heat of fusion to cool the building.*
- ❑ *These salt solutions have latent heat of fusion around **40 Btu/lb**.*
- ❑ *This additional latent heat reduces the storage volume **by 66%** of that required for an equivalent capacity water storage system.*
- ❑ *Another obvious benefit of using eutectic salts is that the **efficiency of the chillers is not sacrificed**, as stated earlier, since the phase change occurs around normal evaporator suction temperatures.*

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The advantages of using eutectic salts as the thermal storage medium are that they:

1. Can **utilize the existing** chiller system for generating storage due to evaporator temperature similarity,
 2. **Require less space** than that required by the water systems
 3. Have **higher storage** and equivalent refrigeration efficiencies to those of water
- ❑ The **auxiliary energy consumption** of the eutectic salt systems and ice systems are **higher** than chilled water systems since the chilled water must be pumped through the array of eutectic blocks or ice system coils.
 - ❑ The chilled water systems had an average auxiliary energy use of **0.43 kWh/Ton-Hr** compared to the phase change systems (eutectic and ice) average auxiliary energy use of **0.56 kWh/Ton-Hr**.

ENERGY MANAGEMENT

Table 19.9 Complete system comparison.

Performance Parameters	SYSTEM			
	Conventional No Storage	Partial Storage	Full Storage	Optional Partial
CHILLER				
SIZE (# and Tons)	1 @ 600	1 @ 300	1 @ 450	2 @ 175
COST(\$)	180,000	90,000	135,000	105,000
WATER STORAGE				
Capacity (Ton-Hrs)	—	1,715	4,104	2,634
Volume (cubic feet)	—	27,484	65,769	42,212
Volume (gallons)	—	205,635	492,086	315,827
Cost per Ton-Hr (\$)	—	200	135	165
Storage cost (\$)	—	343,000	554,040	434,610
ICE STORAGE				
Capacity (Ton-Hrs)	—	2,144	5,130	3,293
# and size (Ton-Hrs)	—	2 @ 1,080	4 @ 1,440	3 @ 1,220
Ice volume (cubic feet)	—	2,859	6,840	4,391
Cost per Ton-Hr (\$)	—	150	150	150
Storage cost (\$) ¹	—	324,000	864,000	549,000
EUTECTIC STORAGE				
Capacity (Ton-Hrs)	—	1,715	4,104	2,634
Eutectic vol (cubic feet)	—	8,232	19,699	12,643
Cost per Ton-Hr (\$)	—	250	200	230
Storage cost (\$)	—	428,750	820,000	605,820

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Table 19.13 Available demand management incentives.

Performance Parameters	System			
	Conventional No Storage	Partial Storage	Full Storage	Optional Partial
Actual On-Peak Demand ¹ (kW)	510	255	0	153
On-Peak Demand Shifted ² (kW)		255	510	357
Utility Subsidy ³ (\$)		51,000	102,000	71,400

¹Yearly design peak demand from Table 19.8.

²Demand shifted from design day on-peak period. For partial: $510 \text{ kW} - 255 \text{ kW} = 255 \text{ kW}$.

³Based upon \$200/kW shifted from design day on-peak period. For partial: $255 \text{ kW} * \$200/\text{kW} = \$51,000$.

ENERGY MANAGEMENT

Economic Analysis

- ❑ *Capital investment decisions* arise in many circumstances. The circumstances range from evaluating business opportunities to personal retirement planning.
- ❑ Regardless of circumstances, the basic criterion for evaluating any investment decision is that the **revenues** (savings) generated by the investment must be **greater than** the **costs incurred**.
- ❑ The **number of years** over which the revenues accumulate and the **comparative importance** of future dollars (revenues or costs) relative to present dollars are important factors in making sound **investment decisions**.
- ❑ This consideration of costs over the **entire life cycle** of the investments gives rise to the name **life cycle cost analysis**.
- ❑ Life cycle cost analysis methods can be applied to virtually any public or private business sector **investment decision**.

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Economic Analysis

*Energy related decisions provide excellent **examples** for the application of Life cycle cost analysis. Such decisions include:*

- 1. Evaluation of **alternative building designs** which have different initial costs, operating and maintenance costs, and perhaps **different lives**.*
- 2. Evaluation of **investments** to improve the thermal performance of an existing building (wall or roof insulation, window glazing),*
- 3. Evaluation of **alternative** heating, ventilating, or air conditioning systems.*

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Capital Investment Characteristics

- ❑ *When companies spend money, the outlay of cash can be broadly categorized into one of **two classifications**; **expenses or capital investments**.*
- ❑ *Expenses are generally those cash expenditures that are **routine**, ongoing, and necessary for the ordinary operation of the business.*
- ❑ *Capital investments, on the other hand, are generally more **strategic** and have **long term effects**.*
- ❑ ***Decisions** made regarding capital investments are usually made at **higher levels** within the organizational hierarchy and carry with them additional tax consequences as compared to expenses.*

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Capital Investment Cost Categories

In almost every case, the **costs** which occur over the life of a capital investment can be classified into one of the following categories:

1. *Initial Cost,*
 2. *Annual Expenses and Revenues,*
 3. *Periodic Replacement or Maintenance,*
 4. *Salvage Value.*
- ❑ *As a simplifying assumption, the cash flows which occur during a year are generally **summed** and regarded as a **single end-of-year cash flow**.*
 - ❑ *Initial costs include all costs associated with preparing the **investment** for service. This includes **purchase cost** as well as installation and preparation costs.*
 - ❑ *Initial costs are usually **nonrecurring** during the life of an investment.*

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- ❑ Annual expenses and revenues are the **recurring costs** and benefits generated throughout the life of the investment.
- ❑ **Periodic replacement** and maintenance costs are similar to annual expenses and revenues except that they do not (or are not expected to) occur annually.
- ❑ The salvage (or residual) value of an investment is the revenue (or expense) attributed to **disposing** of the investment at the end of its useful life.

Cash Flow Diagrams

- ❑ A **convenient way** to display the revenues (savings) and costs associated with an investment is a cash flow diagram.
- ❑ By using a cash flow diagram, the **timing** of the cash flows are more apparent and the chances of properly applying **time value of money** concepts are increased.
- ❑ With practice, **different cash flow patterns** can be recognized.

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◦ **Cash Flow Diagrams Cont'd**

- ❑ *It is usually advantageous to determine the **time frame** over which the cash flows occur first.*
- ❑ *This establishes the **horizontal scale** of the cash flow diagram. This scale is divided into **time periods** which are frequently, but not always, **years**.*
- ❑ *Receipts and disbursements are then **located** on the time scale in accordance with the problem specifications.*
- ❑ *Individual outlays or receipts are **indicated** by drawing vertical lines appropriately placed along the time scale.*
- ❑ ***Upward** directed lines indicate **cash inflow** (revenues or savings) while **downward** directed lines indicate **cash outflow** (costs)*

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- ❑ *Figure 4.2 illustrates a cash flow diagram.*
- ❑ *The cash flows depicted represent an **economic evaluation** of whether to choose a baseboard heating and window air conditioning system or a heat pump for a ranger's house in a national park.*

The differential costs associated with the decision are:

- 1. The heat pump costs (cash outflow) \$1500 more than the baseboard system,*
- 2. The heat pump saves (cash inflow) \$380 annually in electricity costs,*
- 3. The heat pump has a \$50 higher annual maintenance costs (cash outflow),*
- 4. The heat pump has a \$150 higher salvage value (cash inflow) at the end of 15 years,*
- 5. The heat pump requires \$200 more in replacement maintenance (cash outflow) at the end of year 8.*

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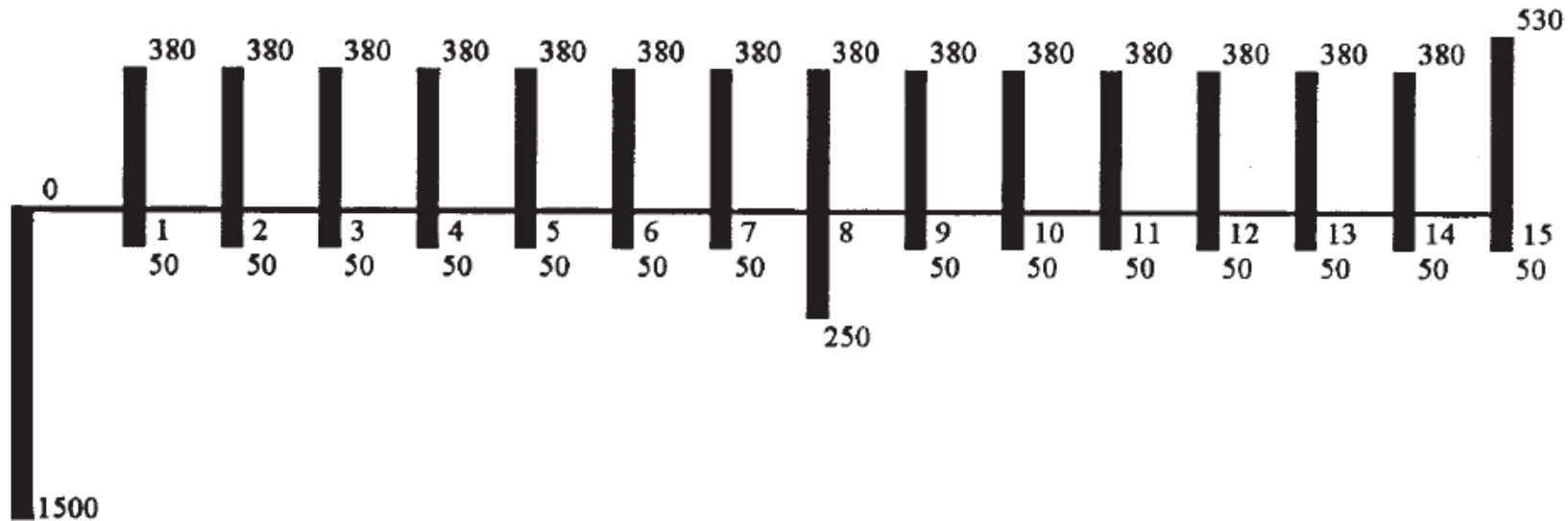


Figure 4.2. Heat pump and baseboard system differential life cycle costs

During the analysis phase, it is useful to show the **Minimum Attractive Rate of Return** (an interest rate used to account for the time value of money within the problem) on the cash flow diagram, although this has been omitted in Figure 4.2.

- ❑ The requirements for a good cash flow diagram are **completeness, accuracy, and legibility**.
- ❑ The measure of a successful diagram is that someone else can **understand** the problem fully from it.

ENERGY MANAGEMENT

ECONOMIC ANALYSIS

- ❑ *The general scenario for economic analysis is that a set of **investment alternatives** are available and a decision must be made regarding which ones to accept and which ones to reject.*
- ❑ *If the analysis is **deterministic**, then an assumption is made that cash flow amounts, cash flow timing, and MARR are known with certainty.*

The accept or reject judgment can be made using either the PW, AW, IRR measure of worth.

PW Decision Rule: *If Present worth $PW \geq 0$, then the project is attractive.*

AW Decision Rule: *If Annual Worth ≥ 0 , then the project is attractive.*

IRR Decision Rule: *If Internal Rate of Return is unique and $IRR \geq \text{Minimum Attractive Rate of Return}$, then the project is attractive.*

ENERGY MANAGEMENT

Example 17

Consider the set of four investment projects whose cash flow diagrams are illustrated in Figure 4.9. If MARR is 12%/yr and the analysis is unconstrained, which projects should be accepted?

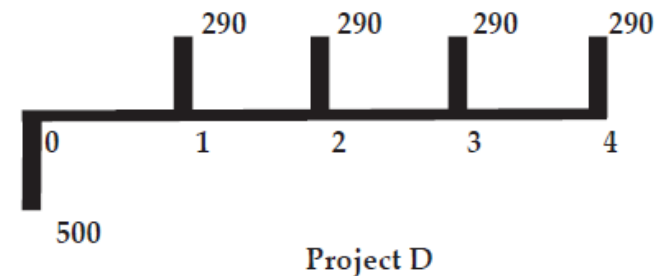
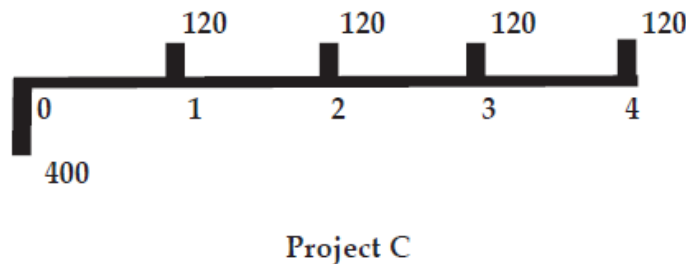
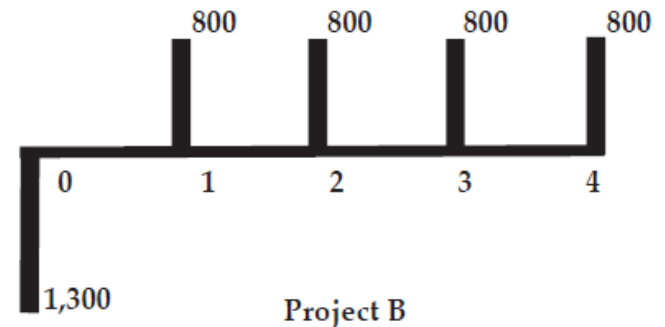
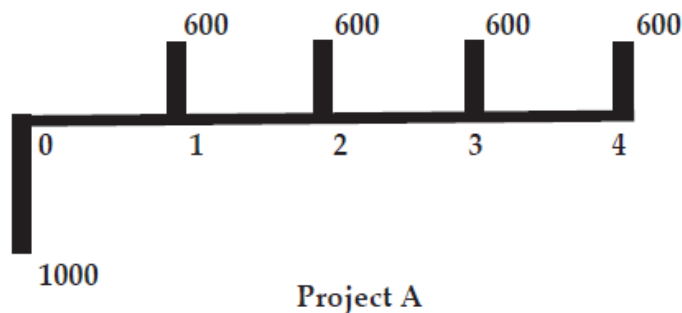


Figure 4.9 Four investments projects

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Example 17 Cont'd

Using present worth as the measure of worth:

$$PWA = -1000 + 600 * (P|A, 12\%, 4) = -1000 + 600(3.0373) = \$822.38$$

⇒ Accept A

$$PWB = -1300 + 800 * (P|A, 12\%, 4) = -1300 + 800(3.0373) = \$1129.88$$

⇒ Accept B

$$PWC = -400 + 120 * (P|A, 12\%, 4) = -400 + 120(3.0373) = -\$35.52 \Rightarrow$$

Reject C

$$PWD = -500 + 290 * (P|A, 12\%, 4) = -500 + 290(3.0373) = \$380.83 \Rightarrow$$

Accept D

Therefore, Accept Projects A, B, and D and Reject Project C

The best option is Project B

Time Value of Money Factors—Discrete Compounding

$i = 12\%$

n	Single Sums		Uniform Series				Gradient Series	
	To Find F Given P (F P,i%,n)	To Find P Given F (P F,i%,n)	To Find F Given A (F A,i%,n)	To Find A Given F (A F,i%,n)	To Find P Given A (P A,i%,n)	To Find A Given P (A P,i%,n)	To Find P Given G (P G,i%,n)	To Find A Given G (A G,i%,n)
1	1.1200	0.8929	1.0000	1.0000	0.8929	1.1200	0.0000	0.0000
2	1.2544	0.7972	2.1200	0.4717	1.6901	0.5917	0.7972	0.4717
3	1.4049	0.7118	3.3744	0.2963	2.4018	0.4163	2.2208	0.9246
4	1.5735	0.6355	4.7793	0.2092	3.0373	0.3292	4.1273	1.3589
5	1.7623	0.5674	6.3528	0.1574	3.6048	0.2774	6.3970	1.7746
6	1.9738	0.5066	8.1152	0.1232	4.1114	0.2432	8.9302	2.1720
7	2.2107	0.4523	10.0890	0.0991	4.5638	0.2191	11.6443	2.5515
8	2.4760	0.4039	12.2997	0.0813	4.9676	0.2013	14.4714	2.9131
9	2.7731	0.3606	14.7757	0.0677	5.3282	0.1877	17.3563	3.2574
10	3.1058	0.3220	17.5487	0.0570	5.6502	0.1770	20.2541	3.5847
11	3.4785	0.2875	20.6546	0.0484	5.9377	0.1684	23.1288	3.8953
12	3.8960	0.2567	24.1331	0.0414	6.1944	0.1614	25.9523	4.1897
13	4.3635	0.2292	28.0291	0.0357	6.4235	0.1557	28.7024	4.4683
14	4.8871	0.2046	32.3926	0.0309	6.6282	0.1509	31.3624	4.7317
15	5.4736	0.1827	37.2797	0.0268	6.8109	0.1468	33.9202	4.9803
16	6.1304	0.1631	42.7533	0.0234	6.9740	0.1434	36.3670	5.2147
17	6.8660	0.1456	48.8837	0.0205	7.1196	0.1405	38.6973	5.4353
18	7.6900	0.1300	55.7497	0.0179	7.2497	0.1379	40.9080	5.6427
19	8.6128	0.1161	63.4397	0.0158	7.3658	0.1358	42.9979	5.8375
20	9.6463	0.1037	72.0524	0.0139	7.4694	0.1339	44.9676	6.0202
21	10.8038	0.0926	81.6987	0.0122	7.5620	0.1322	46.8188	6.1913
22	12.1003	0.0826	92.5026	0.0108	7.6446	0.1308	48.5543	6.3514
23	13.5523	0.0738	104.6029	9.560E-03	7.7184	0.1296	50.1776	6.5010
24	15.1786	0.0659	118.1552	8.463E-03	7.7843	0.1285	51.6929	6.6406
25	17.0001	0.0588	133.3339	7.500E-03	7.8431	0.1275	53.1046	6.7708
26	19.0401	0.0525	150.3339	6.652E-03	7.8957	0.1267	54.4177	6.8921
27	21.3249	0.0469	169.3740	5.904E-03	7.9426	0.1259	55.6369	7.0049
28	23.8839	0.0419	190.6989	5.244E-03	7.9844	0.1252	56.7674	7.1098
29	26.7499	0.0374	214.5828	4.660E-03	8.0218	0.1247	57.8141	7.2071
30	29.9599	0.0334	241.3327	4.144E-03	8.0552	0.1241	58.7821	7.2974