University of Nebraska Lincoln
Nebraska Center for Energy Sciences Research

Energy Cost Optimization for a Large-scale Hybrid Cooling Plant with Multiple Energy Sources under Complex Electricity Cost Structure

Sponsors and Supporting Organizations

- Nebraska Center for Energy Science Research
- Nebraska Utility Corporation
- Lincoln Electric System (LES)

Researchers

Research Assistant: Yin Guo
PI: Dr. Jeonghan Ko
Industrial & Management Systems Eng., UNL

Participating UNL Units

- Industrial & Management Systems Eng.
- Construction Management
- Facility Management & Planning

Motivation

High cooling energy cost due to the lack of

- Systematic integration of a central cooling system
- Proper cost-optimized operation strategy

Objective

To develop a novel cost optimization model to plan the operation under multiple energy sources under complex non-linear electricity cost structure and unpredictable cooling demand.

Approach for Cost-effective Operation

Step 1: Build the cooling plant energy efficiency model

Step 2: Evaluate the cost function terms

Step 3: Forecast the cooling load in the planning horizon

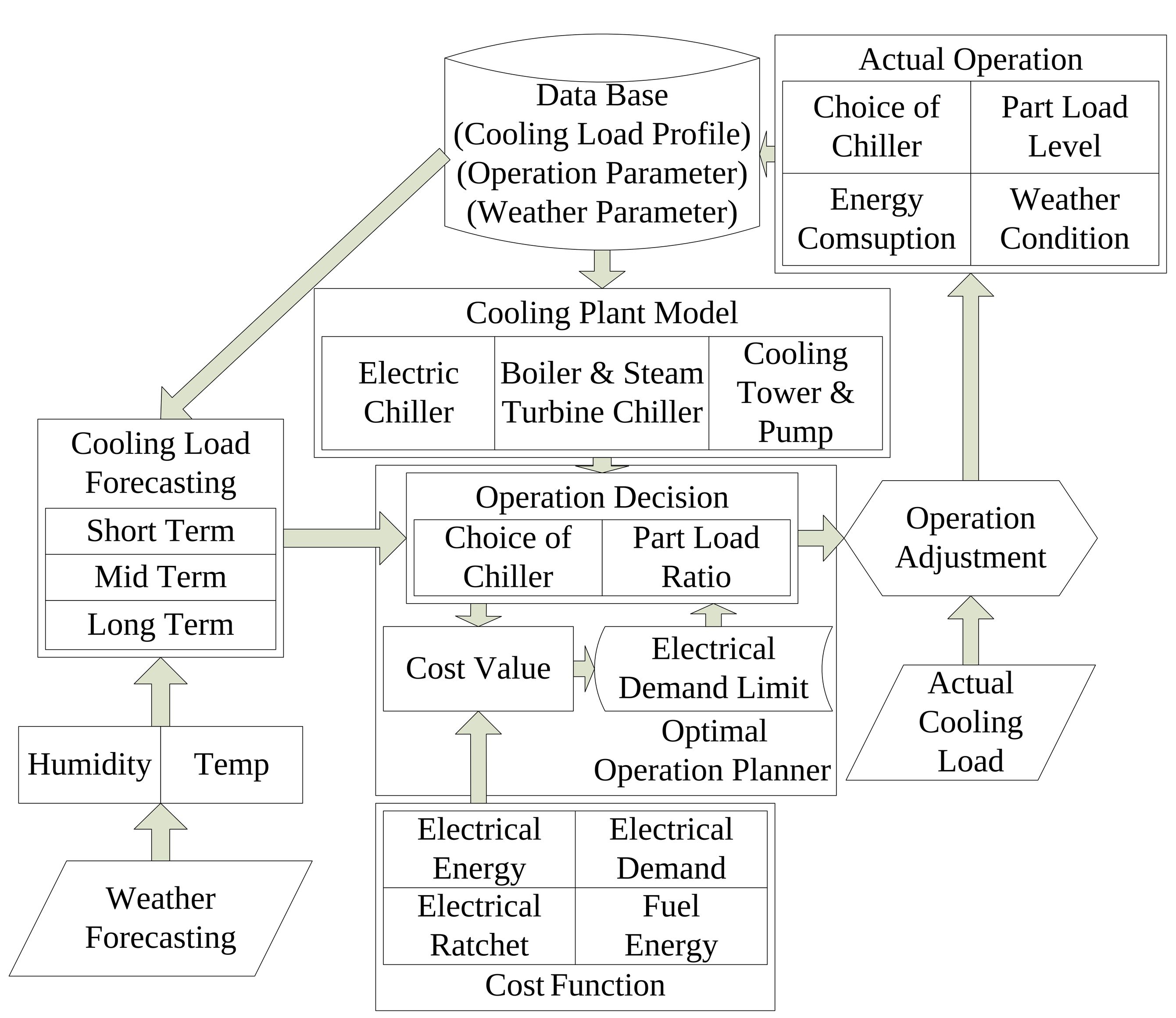
Step 4: Determine decision variables of

- Part load ratio of each chiller
- Pumps and cooling towers
- Electrical demand limit

to meet the cooling demand from buildings

Step 5: Adjust the generated operation schedule according to the actual cooling load

Step 6: Record the actual operation parameters for future references



Abstract

The cooling energy cost could be a significant portion of the total energy cost for a large organization or building complex during summer. A hybrid system or thermal energy storage system is usually applied to reduce the energy cost. However, without the proper integration and operation, the advantage of such systems could be limited. This research develops a general energy cost optimization methodology and mathematical model of a hybrid cooling system under a complex non-linear electricity cost structure. The energy cost evaluation reflects complex real cost structure including electrical energy cost, electrical demand cost, electrical ratchet cost, fuel cost, and electrical energy consumption from other facilities. The optimization model is constructed as a mixed integer nonlinear program. To reduce high computational intensity, a dual-stage solution method is used by exploiting a variable of electrical demand limit as a 1st stage constraint. This reduced computation allows real time implementation of the model for practical purposes. The case study of the central cooling system in an academic institution shows a possible energy saving of $144,000 by the optimized operation of August 2010. An approximate yearly saving in energy cost of $150,000 could be achievable.

Non-linear Characteristics of the Model

- Non-linear energy efficiency plant model

$$E_i^{EC} = E_i^{EC,D}\left(a_{0,i} + a_{1,i}PLR_i + a_{2,i}PLR_i^2\right)$$

- Non-linear cost structures

$$C_K^{DM} = \begin{cases} c_K^{DM,W} P_K^W + c_K^{DM,PR,L} \dfrac{P_K^{PR}}{P_K^{PR}+P_K^{SC}}\left(P_K^{PR}+P_K^{SC}-P_K^W\right) + c_K^{DM,SC,L} \dfrac{P_K^{SC}}{P_K^{PR}+P_K^{SC}}\left(P_K^{PR}+P_K^{SC}-P_K^W\right) & P_K^{PR}+P_K^{SC}-P_K^W > R_K \\ c_K^{DM,W} P_K^W + c_K^{DM,PR,L} \dfrac{P_K^{PR}}{P_K^{PR}+P_K^{SC}} R_K + c_K^{DM,SC,L} \dfrac{P_K^{SC}}{P_K^{PR}+P_K^{SC}} R_K & P_K^{PR}+P_K^{SC}-P_K^W \le R_K \end{cases}$$

Mathematical Model

Mixed Integer Non-linear Program with integer decision variable of part load ratio of chillers (x), on-off decision variable of steam turbine chiller (u), and decision variable of peak electrical demand limit (y)

$$z = \min_{u,x,y} C_K^{Total} = \min_{u,x,y} C_K^{EG} + C_K^{DM} + C_K^{FC} + C_K^{F} + C_K^{DR}$$

s.t.

$$\sum_{i=1}^{N} Q_i^{EC,D} x_{t,i} + \sum_{i=1}^{M} Q_i^{TC,D} x_{t,i} \ge d_t \quad \forall t$$

$$P_t^{SC} \le y_K \quad \forall t$$

$$r_{K-1} \le y_K$$

$$\alpha\left(P^{PR} + y_K - P_K^W\right) \ge R_{K-1}$$

Case Study Results

- Based on cooling load profile: August 2010.
- Comparison
  - Simulated cost-optimized operation
  - Actual past operation based on operator experiences
- Optimized operation characteristics
  - Shifting more cooling load from electric chillers to a natural-gas based steam-turbine chiller to lower the peak electrical demand
  - A significant saving of $141,000 in demand ratchet punitive cost