AC 2011-2072: USING TRAVEL AND THE INTERNET TO DEVELOP AND FORMULATE ENHANCED HOMEWORK ASSIGNMENTS

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Using Travel and the Internet to Develop and Formulate Enhanced Homework Assignments

Introduction

One student criticism of homework and project exercises in engineering courses is the lack of connection that the projects have with the "real world." The author has taught a required course in thermal systems design in Mechanical Engineering at Mississippi State University for many years and has endeavored to make assignments as realistic and credible as possible. Over the last decade the realism has been enhanced by developing homework exercises from engineering "examples" observed on trips. This paper will delineate in detail the process of evolving assignments based on an engineering system observed on a trip. For example, during a trip to Toronto, a tour-bus guide mentioned that Toronto used cold (4^{o}C) lake water from the bottom of Lake Ontario as a cooling medium for much of downtown Toronto. Few additional details and no quantitative information were available from the guide. However, a Google search revealed a number of hits with significant quantitative details of the chilled water system installed in Toronto. With these details, a design-oriented homework problem was developed. The web sites on the Toronto Deep Lake Water Cooling system contained not only information, but color schematics and system diagrams. Graphics available on the web sites enhance the professional appearance of problem statements and sharpen the interests of students.

Procedure

At some level most cities/states/regions are cognizant of any noteworthy infrastructure developments and feature at least some mention of them in "chamber-of-commerce-like" literature or in tour-guide narrations. Once a likely and interesting engineering system has been identified, the following procedure can be used to develop one or more engineering exercises or problems:

1. Ask a tour guide or consult printed information for
   - -the official name
   - -additional information

2. Ascertain whether or not the system has the potential to be useful as an engineering education example

3. Using a search engine, such as Google, find out the number of hits as an indicator of the availability of additional information

4. Review promising web sites for details
   - -quantitative information

-pictures
-graphics
-schematics
-other details

5. Consider, based on the results of item 4, what kind of problems/exercises might be formulated for the information acquired
   -design
   -analysis
   -extension/modification
   -validation

6. Work problems from item 5

7. Based on the results of items 5 and 6 seek additional information, if needed, about the system

8. Complete formulation, solution, and assign exercise

9. Assess student interest and performance on exercise

10. If results of item 9 are positive, formulate additional exercises based on system modifications, changes in system operation, and/or system optimization.

Some examples illustrating the aforementioned procedure are appropriate. Although such a procedure could be used independently of visiting a site, engineering accomplishments of note are often part of the local tourist information.

Examples

Example 1: Toronto Deep Lake Water Cooling System

A tour guide mentioned that many of the high-rise buildings in the downtown area of Toronto used cold water from the depths of Lake Ontario for cooling in the summer. The guide has little information, including the actual name, beyond that, but the system seemed to offer a good possibility for an engineering education example. A Google search using “Toronto chilled water system” produced a number of hits, many of which contained useful information including the official name, Toronto Deep Lake Water Cooling System. Useful web sites are included as References 1-8. Quantitative information and illustrations were obtained from these web site—indeed many of the web sites contain the same information with or without attribution.

The city of Toronto uses cold water (4 ^{o}C) from deep within Lake Ontario as a chilled water source for a large district cooling system. The "deep lake water cooling" serves more than 50 high-rise buildings in a high density area of downtown Toronto with a combined cooling capability of 75,000 tons at a chilled water flow rate of 100 million gallons/day. System illustrations are provided in Figure 1.

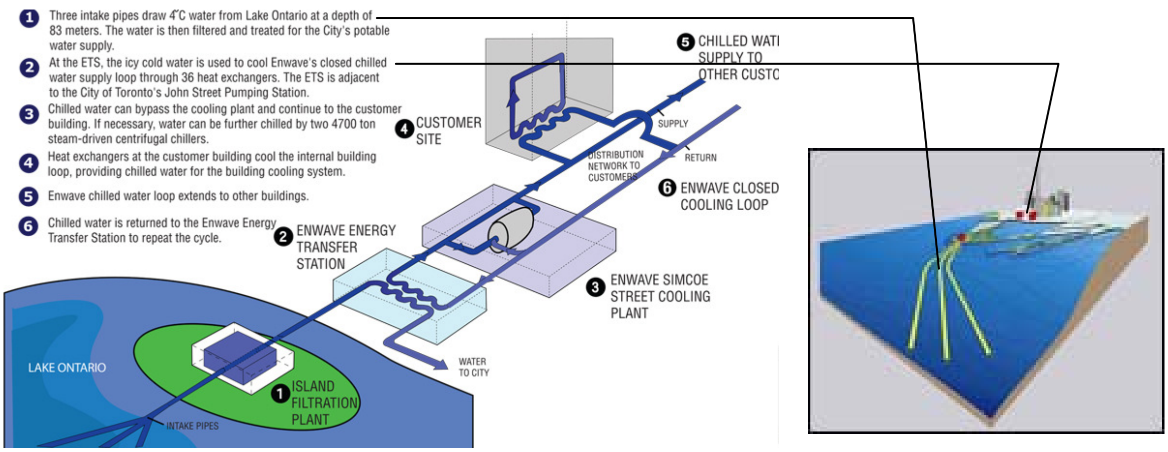

Figure 1. Deep Lake Water Cooling System Schematic [1, 2].

The five primary system components as well as additional information is provided in the figure. Three 5.6-km, 1.6-m diameter intake pipes draw water from a lake depth of 83 m to an island filtration plant (station 1 in Figure 1). The intake pipes are made of high-density polyethylene (HDPE). A single concrete pipe connects the filtration plant with the Enwave Energy Transfer Station at the John Street Pumping Station (station 2 in Figure 1). An unusual feature is that the 3.7-km long, 3.48-m diameter concrete pipe does not contain a pump but uses an elevation difference to gravity feed the filtered lake water to the transfer station (station 2). In 2004 United States dollars the system cost was $170 million. The heat exchangers (station 3 in the figure) use the lake water to cool water in a self-contained circulation system, which flows through buildings in downtown Toronto. About 30 million square feet of building space is cooled by the system for an energy expenditure of about 10 percent of conventional vapor compression cooling—a savings of 85 million kWh of electricity and 79,000 metric tons of CO_2. After passing through the heat exchangers, much of the lake water is used as potable water for the city.

At the energy transfer station the lake water at 4.7 ^{o}C is heated to 12.5 ^{o}C as it exchanges energy with the circulating chilled water in the closed loop that is cooled from 13.1 ^{o}C to 5 ^{o}C. The heat exchanger bank at the John Street Plant has a maximum duty of 40,600 tons (487 million Btu/hr) and contains a bank of 36 heat exchangers. Consider the following problem statement devised for the Toronto Deep Lake Water Cooling system:

If the 3.7-km long concrete pipe does not contain a pump but uses an elevation difference of 2 m to gravity feed the filtered lake water to the transfer station, The energy cost of electricity is $0.05/kWh, and the demand charge is $9.00/kW with initial pipe costs are $\$10^7 \cdot (D/m)^{1.75}$ where D is the pipe diameter in meters *with pump costs of* $\$2000 \cdot (Power/hp)^{0.5}$*, find the following:*

- *(a) The system uses an existing pipe from the filtration plant (station 1) to the John Street Pumping Station (station 2). Estimate the pipe diameter for the conditions stated.*
- *(b) As a function of pipe diameter, compute the power required for one of the three supply pipes (Lake Ontario to the filtration station). Based on the rule of thumbs, estimate the pipe diameter. Based on the "knee" in the power required versus pipe diameter, select the pipe diameter.*
- (c) *If the system is used 2000 hours/year over a 5-month period determine based on economics (other than first cost) the pipe diameter. Explain why the results of parts (b) and (c) differ.*

The Toronto system provided a homework exercise in meaningful series piping design by taking quantitative information from the web and "reverse" working assigned problems to ensure rational results. The steps were thus: (1) discovering the Toronto Deep Lake Water Cooling System, (2) gathering and evaluating information on the system from the web, (3) reverse working several problems to ensure credible results, and (4) assigning a selected problem.

Example 2: Foyers Pumped Hydro Facility

On a visit to Loch Ness in Scotland, a tour guide pointed out an "electrical generating facility" on Loch Ness that did not have a dam but used pumps. The tour guide had little additional information (or understanding), but a search of the web yielded information on pumped hydro in Scotland. Scotland has a number of pumped hydro facilities, one situated on Loch Ness. Figures 2 and 3 present information about the Foyers Pumped Hydro Facility (FPHF) between Lochs Ness and Mhore in Scotland. FPHF is composed of an upper reservoir (Loch Mhore), a lower reservoir (Loch Ness), a turbine/generator, a motor/pump, and associated valves and controls. The overall strategy is to pump from the lower reservoir to the upper reservoir during periods of light electrical demand (typically nights) and cheap base-loaded rates and to generate electricity by flow from the upper reservoir to the lower reservoir during periods of high system demand (typically days and evenings) and premium electrical rates. Pumped hydro facilities can be rapidly brought online when demand peaks and can be rapidly shutdown when demand lessens. As with the Toronto Deep Lake Water Cooling system, the web is a useful source of information and illustrations for the Foyer Pumped Hydro Facility. References 9-13 are primary sources of information about Foyers, and information and illustrations from these web sites were used in the problem development. Miller et al. [13] is of historical interest as it presents details about the initial engineering of the pumped-hydro system.

Useful web sites for the Foyers station include:

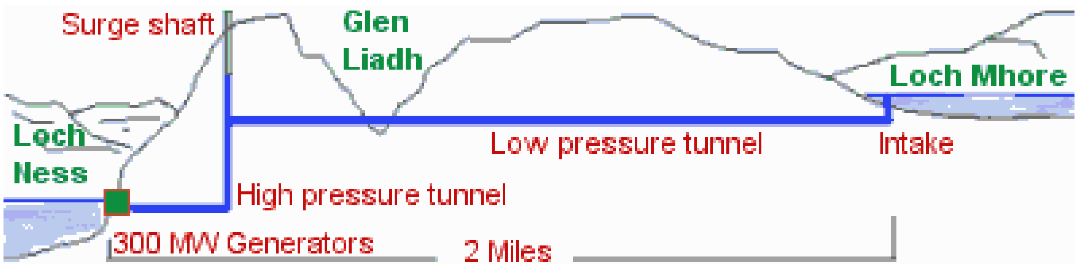

Figure 2. Schematic of FPHF [9, 10].

Figure 3. Loch Ness Near the FPHF [12].

In the FPHF water travels though a near horizontal low-pressure tunnel (see Figure 2) 9000 ft in length, joining a vertical high pressure shaft and tunnel, with a surge shaft above. The high pressure shaft is 370-ft deep and feeds into a horizontal tunnel 385-ft long, which then divides into two smaller tunnels, each serving one turbine, 1034-ft long sloping down to the turbines. The single tunnels are 24 ft in diameter, and the two smaller tunnels are 16 ft in diameter. The average elevation difference between the lochs is 587 ft, and the nominal flow rate is 7000 cfs. The FPHF output is stated to be 305 MW.

This is a relatively simple system, but a consistent analysis is thought provoking. If a few rational assumptions (pumping and generating efficiency) are considered, the facility generating output can be calculated and compared to the stated. With £ 0.06/kWh as an off-period energy cost and £ 0.15/kWh as an on-peak cost, some economics can be considered. Consider the problem statement.

Analyze the FPHF by considering the following:

- *(a) For the given characteristics, find the power that can be generated. How does this compare with the stated power generation of 305 MW?*
- *(b) What is the yearly revenue for 6 hours/day generating if energy can be sold for £ 0.15/kWh and the generating efficiency is 0.92?*
- *(c) If the total gallons pumped per day is the same as the total that passes through the generator per day, what is the pumping power required for 18 hours/day pumping if the pumping efficiency is 0.89?*
- *(d) What is the yearly cost of pumping if the base-load electric rate is £ 0.06/kWh?*
- *(e) What is the net revenue per year for this operating scenario?*
- *(f) Comment on the feasibility of the proposed system.*

The results indicate a power generation of 302 MW that compares well with the actual value. The economics also demonstrate a significant yearly difference between the sold kWh and purchased kWh (for pumping).

Example 3: Fire Department of New York Fireboat Three-Forty-Three

On a tour around Manhattan Island including the Fire Department of New York's Marine Company 1, the guide pointed out the then-newly-commissioned Fireboat Three-Forty-Three. The guide also, surprisingly, discussed some quantitative information concerning capabilities of the "343." Google was again used to find additional information and pictures of the fireboat. Fireboat Three-Forty-Three was named for the 343 FDNY members killed on 9/11. Figures 4 and 5 show the "343" and the primary fire nozzle (monitor). The monitor is capable of a flow rate 17,000 gpm (sea water) with a range (throw) of 700 ft. References 14-19 are web sites that contain useful information and illustrations.

Figure 4. Fireboat Three-Forty-Three [14, 15, 19].

Figure 5. Fireboat Three-Forty-Three Primary Monitor (Nozzle) [14, 15, 19].

The four engines on the "343" produce approximately 8,000 horsepower. The boat, able to pump 50,000 gpm on four engines as a pumping station and 20,000 gpm on two engines as a firefighting vessel, has 12,500-gpm fire pumps and 11 fire monitors (nozzles), one 17,000 gpm, six 6,000 gpm and four 2,000 gpm.

Figure 6 illustrates the piping typical for the fire monitors of a fireboat. The “343’ is 140-ft long and has a draft of nine feet.

Figure 6. Cutaway Showing Piping for a Typical Fireboat [17].

Of the three examples in this paper, the web sites for the “343” contained less quantitative information than the web sites for the first two examples. As a result, the flexibility to formulate problems is more restricted and involves making more assumptions. A problem formulated and assigned for Fireboat 343 is:

(a) *Estimate the monitor exit diameter for a flow rate of 17,000 gpm and a throw of 700 ft.*
(a) *What is the pump increase in head required for Part (a)? What is the power imparted to the fluid?*
(b) *How sensitive is the pump increase in head to the supply pipe diameter? What does this suggest about pipe diameter selection?*

Example 4: Central Supply, Distribution, Return/Regeneration Network Example

One of the largest classes of piping systems of interest to mechanical engineers is the “central supply-distribution-return/regeneration” network. As the name implies, in such a system there is a central supply from which fluid is distributed to a number of sites and then either used or collected and returned to the central site for regeneration and redistribution. A good example of a large system of this type is a central chiller system. Large airports present a good opportunity to devise a meaningful network problem using such a network. The FAA provides airport diagrams for many airports. The airport diagram for Orlando International Airport is provided in Figure 7. Airport diagrams are to scale and contain, in addition to aircraft operation information, representations of runways, taxiways, and terminal layouts. Distances on the airport diagram can be scaled to first order using the runway lengths that are specified.   Useful Web sites are included as References 20 and 21, although the FAA provides airport diagrams for all significant United States airports.

Since the “central supply/distribution/return” problem is a generic one and since the details can be quite long, the problem statement is included as Figure 8 and covers several pages. The contents of Figure 8 are shown in italics to distinguish the problem statement from the text narrative. Also, figures numbers in the problem statement are indicated with “E” in front of the number to keep the same distinction.   The problem statement in Figure 8 mandates using a Z-network arrangement as illustrated in *Figure E2* of the problem statement. *Figure E1*, extracted from the Orlando International Airport diagram, of the problem statement presents a larger-scale view of the terminal area. The actual physical piping layout is indicated in *Figure E1* of the problem statement included in this paper. In the actual assignment, no piping layout is shown since the students are expected to sketch in the piping layout as part of the solution. However, the actual piping layout in *Figure E1* of the problem statement possesses a one-to-one correspondence with Z-network of *Figure E2* of the problem statement. *Figure E2* simply makes visualizing the pipes and loops easier than using the layout in *Figure E1*.

In addition to the assignment delineated in Figure 8, a good follow-on exercise is to select a suitable pump and to validate the pump selection. Options for pump selection include a single pump as well as a parallel arrangement (using pump different from the single option).

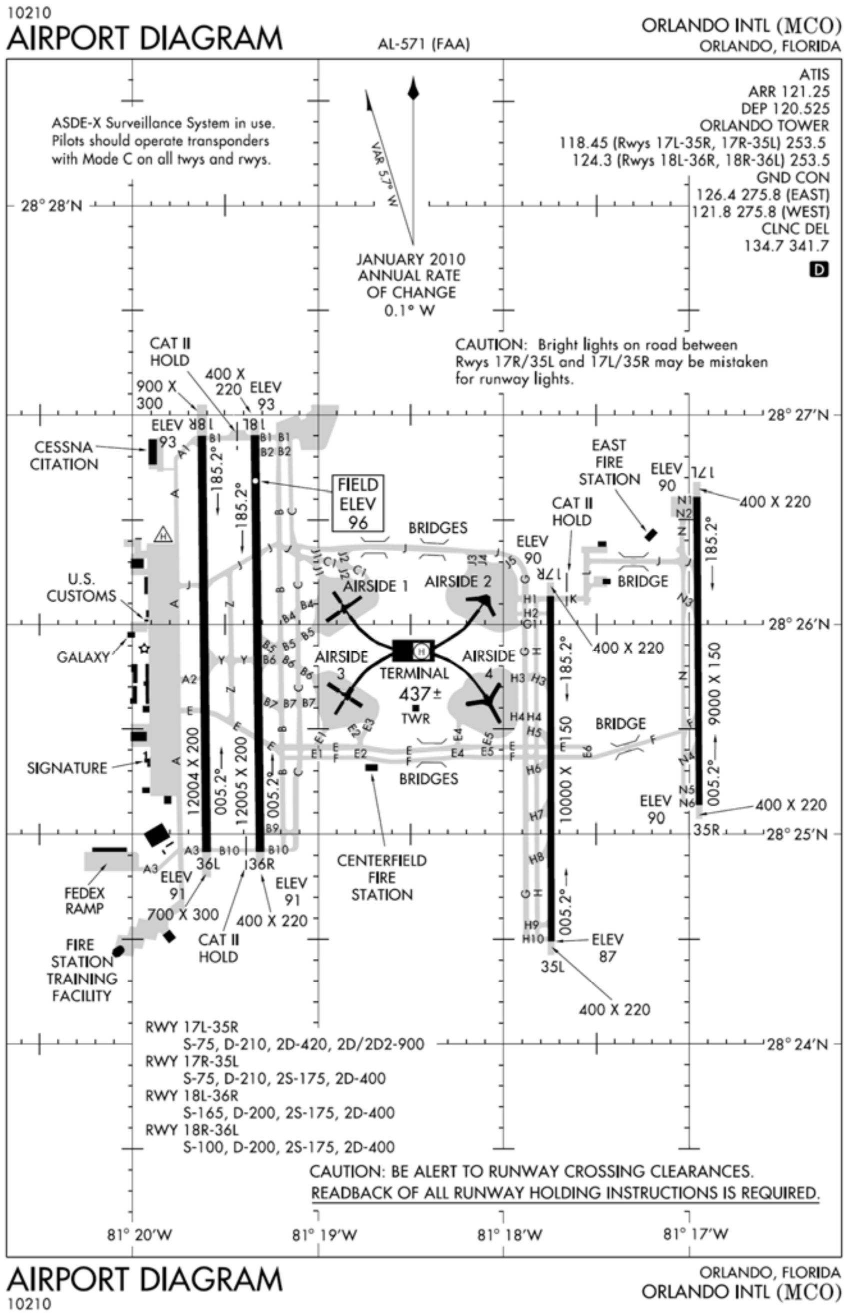

Figure 7. Orlando International Airport Diagram (FAA).

If cooling loads and head losses due to chillers and air handling units are estimated, a network problem involving the Orlando International Airport can be developed. The problem statement for such an assignment is provided in Figure 8.

ME 4333/6333 Energy Systems Design

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A central chiller system for the Orlando International Airport (MCO) is to be investigated. Layouts of the existing terminal arrangement are presented in Figure E1, an airport diagram considered to be accurate enough to scale for preliminary layout purposes. The system of interest is for the four outlying concourses, Concourses 1, 2, 3, and 4. The main terminal building is not to be included in the chilled fluid system. A central chiller facility is located in the open area at the top of the figure (see Figure E2). Chilled fluid lines from the central chiller are to be run through access tunnels located 20 ft below grade level. Dowtherm Q™, a commonly-employed heat transfer fluid, is to be used. Properties of Dowtherm Q are available on the web.

Cooling requirements are estimated as follows:

Concourse	tons(= 12,000 Btu/hr)	K
1	750	2.0
2	500	4.50
3	750	2.0
4	500	4.50
	500	4.50 (must be in parallel)

The head loss through the air handling units in each terminal is $K\,Q^2$ where Q is the flow rate in cubic feet per second (cfs) and the $K\,Q^2$ is in ft-lbf/lbm. The head loss in ft-lbf/lbm across the chiller is taken to be $0.05\,Q^2$, where Q is the total flow rate in cfs. The Dowtherm exits the chiller 25 F cooler that it enters. The lines are well insulated so that heat loss is minimized.

In addition, the following specifications must be met:

1. *Provide valves to isolate each concourse, the supply and return lines, and the pump.*
2. *Provide 100 ft of pipe in each mechanical room (one per concourse).*
3. *The access tunnels are 20 ft below the entrance to each concourse, and mechanical rooms are 20 ft above the surface.*
4. *Minimize tunnel length by placing lines in the same tunnel.*
5. *Use a "Z" network (see Figure E2).*
6. *Avoid pipe velocities in excess of 8 ft/s.*
7. *The two AHUs in Concourse 4 are to be placed in parallel.*

Include the converged Kirchoff or Hardy-Cross solutions, and make sure your logic is explained.

Accomplish a preliminary system design and provide:

1. *Layout of the network;*
   - (a) *actual physical layout (pipe numbers indicated)*
   - (b) *“Z” arrangement for Kirchoff or Hardy-Cross usage (pipe and loop numbers indicated);*

Figure 8. Supply, Distribution, Return/Regenerate Assignment.

2. *Lengths and sizes of all pipes required;*
3. *Number, size, and type of valves and fittings;*
4. *Increases in head and power delivered to the fluid for all required pumps;*
5. *List of materials (diameters, lengths, valves, ….) required.*

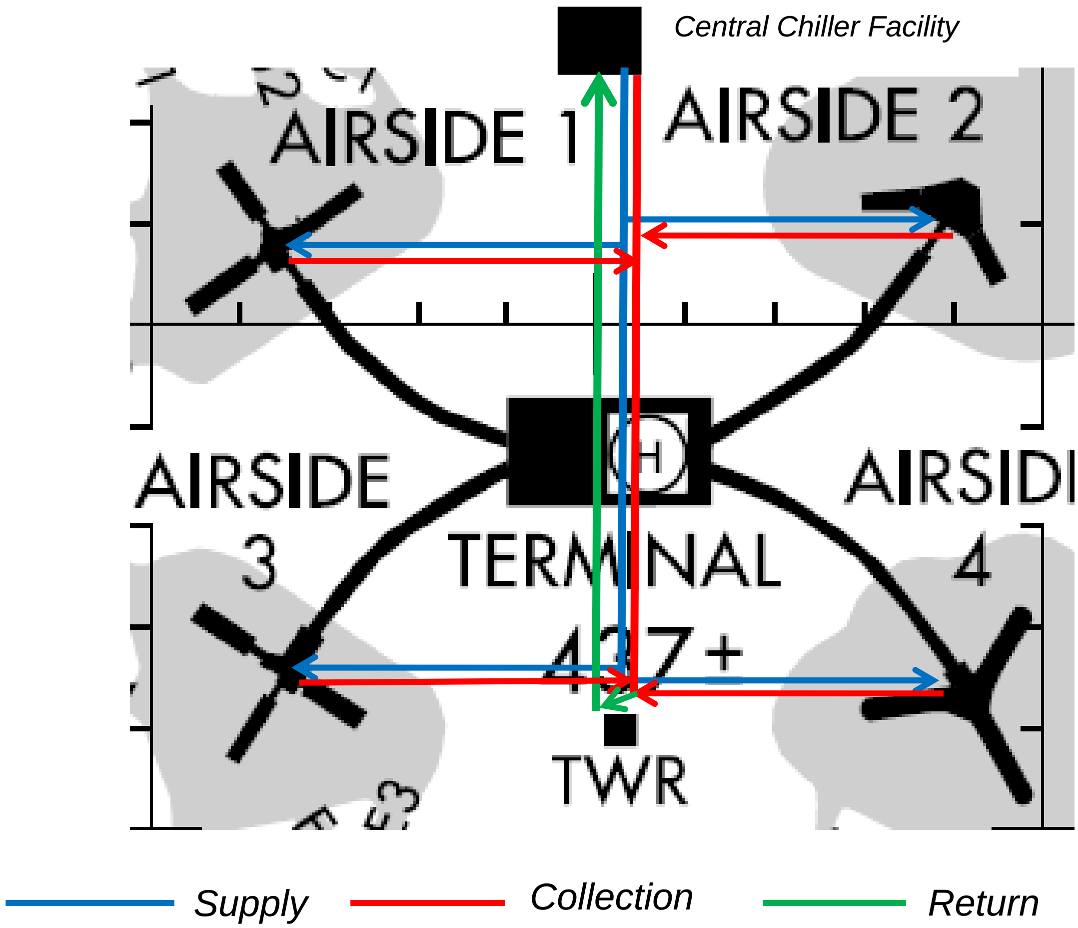

Figure E1. Scale Layout of Orlando International Airport Terminal Area (FAA).

Figure 8. Continued

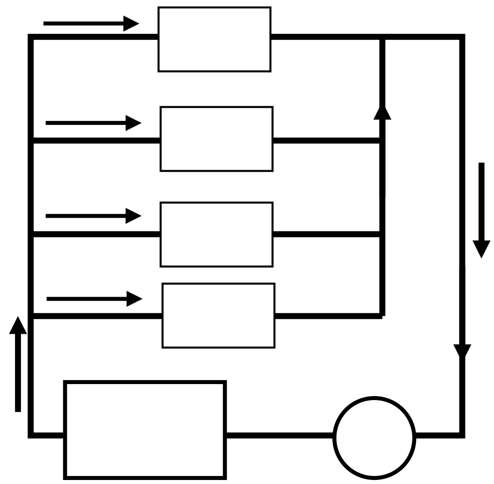

Figure E2. Z-layout schematic.

Figure 8. Concluded.

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Continuing Opportunities

Most engineering faculty travel a significant amount. Every trip provides opportunities to observe the local infrastructure and identify candidate systems for use in problem assignments. As in Example 4, many airports are candidates for network problems that can be structured about different systems. The key is to be on the look out for candidate examples.

Conclusions

Over the last decade, the author has developed many homework exercises based on systems observed during travel. The web is indispensible is obtaining quantitative and additional information, but keep in mind that the web sites have little quality control. For example, for the Toronto Deep Lake Water Cooling system, one web site stated that the supply pipe diameter was 0.6 m rather than 1.6 m. Careful cross-checking of web sites will lead to more consistent information.

Student response has been uniformly good. Most students appreciate the effort to devise homework exercises that are obviously not just “made up.” Indeed, every semester several students ask for additional information about assignments developed in the fashion explored in this paper. Many have visited the systems and are able to add person experiences. Overall, the technique discussed in this paper is a useful approach and a good addition to an engineering educator’s tool kit.

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