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Energy-Efficient HVAC Systems for Health Care Facilities

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A modern hospital is like a 5- star hotel, in fact it offers much more by way of encompassing a wider spectrum of human needs. While a hotel caters to the physical needs such as shelter, food, recreation and other amenities, a modern hospital goes far beyond that in catering to the medical and psychological needs, supplemented by physical needs.

From an engineering perspective, a hospital requires all the building utilities and engineering services that a hotel requires, and in addition requires medical gases, expensive, environment-sensitive medical equipment and specifically engineered facilities for the optimum functioning of various medical departments.

For the HVAC engineer, a hospital offers the challenge to design and build a suitable system that will be adequate (but not over-designed and hence expensive), economical (both in capital and operating costs), easily maintainable (with minimum downtime) and use 'state-of-theart' technology available in HVAC systems and equipment.

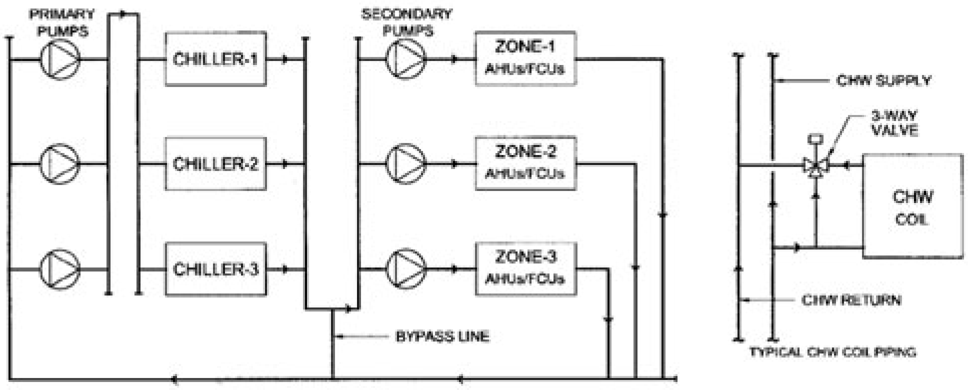

Figure 1 : Constant flow primary-secondary system

Click to view clear picture

Just like a 5-star hotel, a modern hospital consumes a lot of energy, and both have 'zonal' air conditioning loads. This article addresses three areas where a good HVAC system can be designed to reduce the energy consumption :

1. Variable chilled water flow
2. Pre-cooling of outside air
3. Gas fired vapour absorption chillers.

Table 1 : Zonal loads in a hospital and hotel

	Round-the-clock (24 hrs)	**Day-time (12 hrs.)**	**Variable (6-18 hrs.)**
Hospital	Patient rooms ICUs Casualty dept.	OPD Consulting rooms Clinical labs.	Operating rooms
Hotel	Lobby & Front Office, Guest rooms Coffee shop	Back-of-house Shopping arcade	Specialty - restaurants Banquet rooms

Variable Chilled Water Flow

Take a look at the concept of zonal loads, which is elaborated in **Table 1** and it will be obvious that, it makes good design sense to consider splitting the air conditioning system into two or more zones. It is the chilled water (CHW) which is the 'life-blood' of a central plant HVAC system, hence the CHW system needs to be zoned. This necessitates having primary (circulating CHW through the chillers) and secondary (circulating CHW through the air handling units - AHUs and fan coil units FCUs) loops in the system. The schematic diagram - **Figure 1**, is self explanatory.

How do we reduce energy consumption with this primarysecondary CHW system ? Consider the situation when one or more secondary zones is not in operation; let's take the zone serving the OPD (which would normally be closed from, say, 8.00 p.m. to 8.00 a.m.). The secondary pump serving this zone should be switched off to save on pumping energy and heat loss (gain) through this piping network. With a conventional single zone system, CHW would be unnecessarily circulated through all the AHUs and FCUs, even when there is no cooling requirement in some areas.

Having seen the merits of a primary-secondary system, let us now discuss how even more energy could be saved with the concept of variable flow. The thermal load of any system will never be constant through the day nor through the year (except in industrial cooling applications). So why circulate a constant flow of CHW, only to bypass the excess flow (when the load is below design, which occurs most of the time anyway) via the 3-way valve?

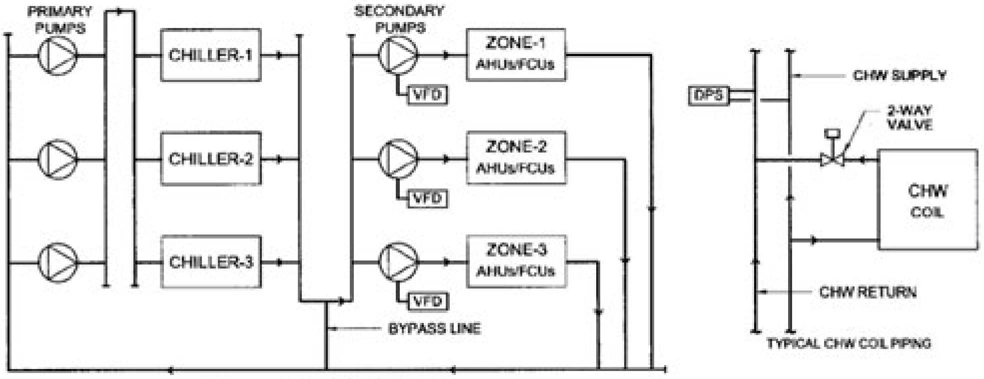

Figure 2 : Variable flow primary-secondary system

Click to view clear picture

Hence the concept of variable flow comes in, i.e. circulate only as much CHW as demanded by each CHW coil, by replacing the 3-way valve with a 2-way valve, and incorporating a Variable Frequency Drive (VFD) for each secondary pump-see **Figure 2**.

It would be appropriate at this jucture to introduce the 'pump laws' which simply stated tell us that for centrifugal pumps "flow is directly proportional to speed, head is directly proportional to the square of speed, and the brake power is directly proportional to the cube of speed.

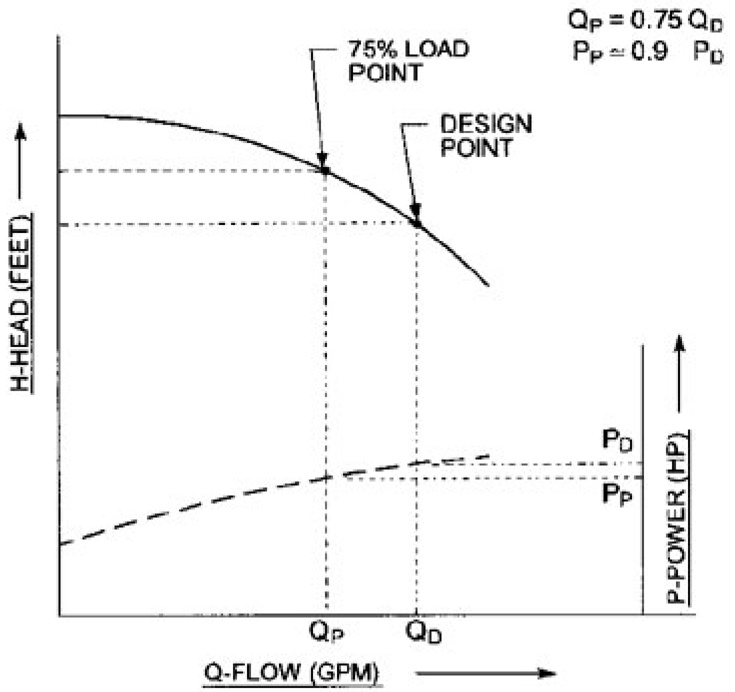

Figure 3 : Constant speed centrifugal pump

Without a VFD, the constant speed pump would ‘ride up’ it’s speed curve as the load reduces i.e. flow reduces, resulting in low reduction in power consumption, see **Figure 3**. However with the VFD, when the 2-way valve closes on reducing load, the Differential Pressure Sensor (DPS), will signal the VFD to reduce pump speed to precisely cater to the system flow requirement (no more, no less), resulting in very high reduction in power consumption. See **Figure 4**.

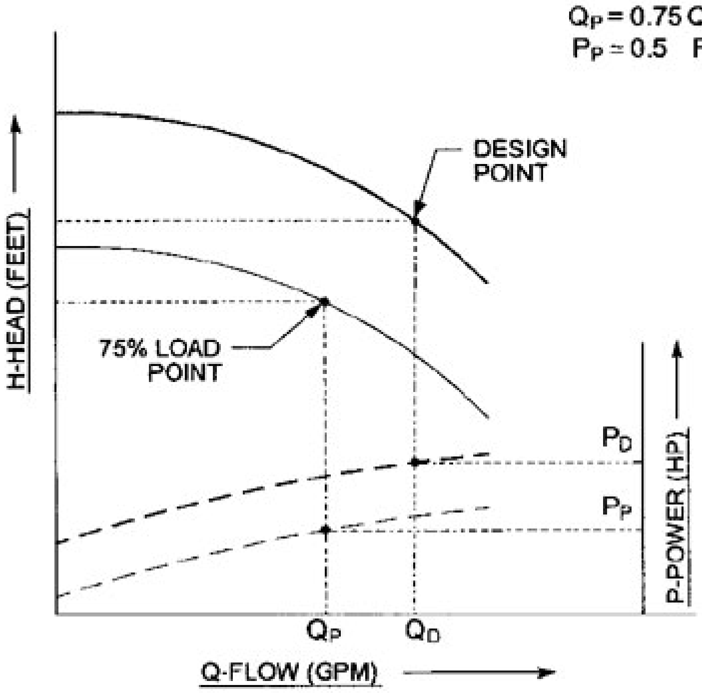

Figure 4 : Variable speed centrifugal pump

Hence it is easy to see the tremendous benefits vis-a-vis energy savings in opting for a variable flow secondary chilled water system.

Pre-cooling of Outside Air

Another method of conserving power is to reduce the energy consumed in cooling and dehumidfying outside air (OA). Introducing OA into an air conditioning system is a mandatory requirement, specific guidelines for which are given by ASHRAE. It serves three primary purposes – a) to dilute the CO_2 content of the air, b) to dilute body odours and c) to dilute the concentration of VOCs (volatile organic compounds) that are being continously released within all building interiors, be it from the paint on the surfaces, wall paper adhesives, furniture adhesives and polish, etc.

Further, OA plays an equally, if not more important role in a hospital i.e. to dilute and carry away airborne micro-organisms orginating within the hospital from patients and staff. The OA flow rate is high in terms of outside air changes / hour (OACH) in operating rooms (ORs). ASHRAE recommends minimum 5 OACH and minimum 25 total air changes per hour (TACH), or in case of 100% OA applications, minimum 15 ACH.

For a medium sized OR of 450 ft^2 with 11 ft false ceiling height, one ACH is approximately 80 cfm. Hence the OA required for this OR will range from 400 to 1200 cfm, depending on whether the OR is a re-circulating type or 100% OA type. The decision to choose from these two options, or an economical compromise in between, lies with the hospital consultant, the surgeon and HVAC consultant.

Having established the OA cfm, one should evaluate the merits of introducing a heat recovery wheel (HRW) to pre-cool and predehumidify the OA from the cool dehumidified exhaust air. It is necessary to have a direct exhaust system in an OR to ensure that the design TACH is maintained at all times.

Every 100 cfm OA introduced into the system adds 0.4 ton (in the case of an interior city like New Delhi) to 0.75 ton (in the case of a coastal city like Mumbai) to the system load. It is very easy to realise that OA is an expensive ingredient in an air conditioning system. Hence, a HRW plays a very useful role in reducing the OA cooling load and consequentially the power consumption of the system.

With 80% ‘effectiveness’ wheels which are commercially available, the OA heat load can be reduced by 70 - 80%. It is important to opt for an ‘enthalpy’ transfer wheel and not a sensible heat transfer wheel to derive maximum benefit. While the enthalpy wheel allows exchange of sensible and latent heat, the sensible transfer heat wheel allows exchange of sensible heat only.

An example which deals with energy saving by heat recovery wheel follows :

Take an OR of approximately 450 ft2, located in Mumbai with 60% OA. This OR will require 2000 cfm dehumidified air including 1200 cfm OA.

- Refrigeration load of 1200 cfm OA = 9 tons
- Effective refrigeration load of OA with 80% effectiveness enthalpy wheel = 1.8 tons
- Reduction in load = 7.2 tons

Assume a water cooled chilled water plant selected for 1.0 kW/ton (chiller, pumps and cooling tower). Based on 12 hours/day, 300 days/ year the energy savings will be :

7.2 x 1.0 x 12 x 300 x Rs. 5.00 / kW-hr = Rs. 1.3 lacs per year (per OR)

A HRW for the above application costs approximately Rs. 2.5 lacs and thus the heat recovery wheel pays for itself within two years.

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Gas Fired Vapour Absorption Chillers

Finally let us get to the 'heart' of the plant. We have seen how energy consumption can be reduced in the chilled water circulating system and the outside air cooling and dehumidification system. Water chillers are the highest consumers of energy in an HVAC system, accounting for anything between 45% to 60% of the total energy consumed by the system.

An average sized hospital of say 200 beds, has approximately 175,000 ft^2 to 225,000 ft^2 of built-up area, with 150,000 ft^2 to 200,000 ft^2 of air conditioned area. The total cooling load will vary from 600 tons to 900 tons depending on the actual air conditioned area, the medical equipment installed and the ambient design conditions for the city.

Let us look at the scenario with a total cooling load of 750 tons. A designer would normally choose four chillers of 250 ton capacity each (three working plus one stand-by) or may be three chillers of 375 ton capacity each (two working plus one stand-by). For various reasons including a balanced loading on the electrical supply system (and standby diesel generator system), four chillers are preferred to three.

In the 200 ton to 300 ton capcity range, water cooled screw chillers are by far the best choice available today, (when considering electric - driven chillers), with a power consumption of around 0.65 to 0.7 ikW/ton depending on the ambient design wet bulb.

The annual energy bill for this 750 ton screw chiller system considering 60% average cooling load through the day and through the year, based on a H.T. (high tension i.e. 11 kV or 22 kV) consumer tariff of Rs. 4.50 per kWh works out to :

750 ton x 60% x 0.7 kW/ton x 8760 hrs/year x Rs. 4.50/kWh = Rs. 124.2 lacs per year

What is the possible alternative available ?

The answer lies in piped natural gas (PNG) i.e. use of gas-fired vapour absorption chillers or machines (VAM). Indigenously manufactured chillers are available from two companies. Imported chillers become economically attractive provided the owner can avail of either ‘EPCG’ benefits or ‘deemed export benefits.

Let us now look into the economics of a VAM system. The energy consumption of VAM is approximately 0.3 m^3/ton-hr. To make a fair analysis, one must not forget that since VAMs have a low COP compared with electric-driven chillers, the heat rejection is approximately 50% higher in terms of Btuh/ ton. Hence the cooling towers, condenser water pumps etc. are larger than in an electric-driven chiller system.

The electrical energy consumption of the VAM refrigerant pump and the additional electrical energy consumption of the cooling tower and condenser water pump is approximately 0.1 kW/ton

The annual energy bill for a 750 ton VAM system works out to :

- Gas
  750 tons x 60% x 0.3 m^3/ton–hr x 8760 hrs/year x Rs. 7.50 / m^3
  = Rs. 88.7 lacs per year
- Electricity
  750 tons x 60% x 0.1 kW/ton x 8760 hrs/year x Rs. 4.50/kWh
  = Rs. 17.7 lacs per year
- Total energy bill = Rs. 106.4 lacs/year

Compare this figure with the annual energy bill of an electric-driven chiller system i.e. Rs. 124.2 lacs per year. This indicates a saving of Rs. 17.8 lacs/ year, which amounts to a 14% reduction, which is definitely attractive.

How does the capital cost of VAMs compare with Screw Chillers ?

- 4 Screw Chillers of 250 ton each cost approximately Rs. 150 lacs.
- 4 VAMs of 250 ton each (including the incremental capital costs of the enhanced cooling water system) cost approximately Rs. 200 lacs.

Hence the pay-back for the VAMs is

$$\frac{200-150}{124.2-106.4} = 2.8$$

Therefore the VAM system pays for itself within three years.

Conclusion

Operating costs play an important role towards improving or reducing the financial viability of modern hospitals. Finally it is the patients who pay for the cost of services provided. We, as profesional engineers, must do our bit in designing, specifying, installing and maintaining energy efficient HVAC systems with a view towards minimising operating costs.

It is not enough to pay mere ‘lip-service’ to the looming energy crisis, by way of attending and contributing to discussions, seminars, technical papers etc. We, the body of HVAC engineers must all chip in by seriously encouraging the use of energy efficient HVAC systems in all spheres of our work.