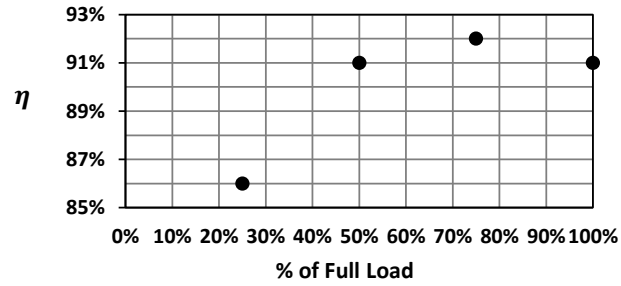
Problems

1. A 3-phase induction motor drives a centrifugal pump. This equipment operates 8760 hours/year. The motor has the following performance ratings:

synchronous speed = 1800 rpm
rated speed = 1760 rpm
rated output = 20 hp (14.9 kW)
efficiency curve = see figure



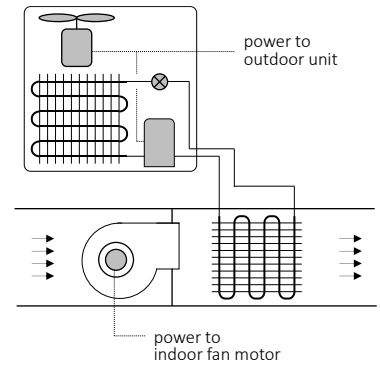
During an energy audit, a tachometer measurement indicates that the motor shaft speed is 1770 rpm. Based on the provided information, estimate the following quantities:

a) Load on the motor (% of full-load).
b) Shaft power being delivered by the motor (hp).
c) Torque being delivered by the motor (ft-lb).
d) Electric input power to the motor (W).

2. An air-conditioning unit provide cooling to a zone in a building. The outdoor condenser unit provides heat rejection. It includes the compressor and the condenser fan. The indoor fan moves air from the conditioned zone, across the cooling coil, and then back to the conditioned zone. The indoor fan and its directly-coupled motor are located within the air-stream.

At a particular moment, the operating conditions are:

- The cooling coil provides cooling rate 20 kW with the outdoor unit using electric power of 5.43 kW.
- The indoor-fan provides flow = 1600 L/s and pressure-rise = 750 Pa, operating at fan efficiency = 55% and motor efficiency = 85%.



Estimate the following:

a) Shaft power required by the indoor fan (W).
b) Electric power input to the indoor fan motor (W).
c) Rate of heat generation (i.e. losses) of the indoor-fan motor (W).
d) Cooling COP of the air-conditioner unit (i.e. outdoor unit).
e) Electrical energy (kWh) required to run the equipment at these conditions for 20 hours.

3. A centrifugal fan is being installed in a particular duct system. When driven at 1150 rpm, the fan requires shaft power = 5,976 W (~8.0 hp). The fan laws may be applied to estimate the change in required power with speed. A particular 6-pole induction motor is to be directly-coupled to the fan. The motor characteristics are:
Synchronous speed = 1200 rpm; Rated speed = 1150 rpm; Rated power =7,460 W (10.0 hp).

a) Provide calculations to verify that the operating speed of the fan + motor will be approximately 1159 rpm when the fan and motor are coupled.
b) Estimate the electric power consumption of the motor (W) when it drives the fan at 1159 rpm assuming that it operates with motor-efficiency = 90% at that condition.

4. Consider a centrifugal fan connected to a duct system in an HVAC installation. The intended air flow is 6,000 L/s. The fan is driven by a belt-drive and motor. The efficiency of the motor is approximately constant at 91%, and the combined-efficiency of the drive and motor is approximately constant at 87%. After the fan is initially installed, it is operated at fan-shaft speed ≈ 1150 rpm. The measured air flow is 6,400 L/s and pressure difference (fan inlet to outlet) is 720 Pa. Further, it is determined that $\eta_{fan} \approx 60\%$ at this condition.

Estimate the following:
a) Input power to the motor (W) at the initial operating condition (6,400 L/s).
b) Rate of heat dissipation by the motor (W) at the initial operating condition.
c) Efficiency (%) of the "transmission" (i.e. belt-drive).

Apply the fan-laws for shaft-speed changes and estimate the following:
d) Fan-shaft rotational speed (rpm) required to achieve the intended air flow.
e) Required fan-shaft power (W) at the new rotational speed.

5. An HVAC zone is heated by a rooftop unit. Consider the following situation and apply a simplified "sensible fluid heating/cooling" approach to the analysis with $\rho \cdot c_p = 1.23\ J/L \cdot ℃$ and $\Delta h = c_p \cdot \Delta T$. (That is, the moisture in the air can be ignored—a psychrometric analysis is not needed.) Also, ignore changes in air density, so $\dot{m} = \rho \dot{V}$.

The RTU fan provides supply air flow = 500 L/s. The mixing dampers provide a supply air mix of 20% outdoor air and 80% recirculated air. The net heat loss from the space is 5 kW. Air leakage across the building envelope is negligible. The outdoor air temperature is -10°C, and the conditioned space is 21°C. Heating effects (i.e. heat gain) caused to the operation of the fan and motor can be neglected.

For the condition described, estimate the following:

- Mixed air temperature (T_m, °C) in the RTU.
- Average rate of heat (kW) to be provided by the heating coil to main steady conditions for this system.
- Supply air temperature (T_s, °C) if the heating rate calculated in b) was provided by the coil.
- For a reasonably long period under these conditions: the average on-time fraction (%) for the heating coil if it operates on-off and its heat output rate is 15 kW (when on).