Imperial College London

6th International Conference on Smart Energy Systems
6-7 October 2020
#SESAAU2020

A Pathway Towards the Heat-Autonomous City

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Presented by Peter North

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Context

- Climate change is currently the world's most pressing challenge.
- Having addressed this, there will remain the need to live within the means of one planet; our current rate of resource consumption is unsustainable.
- Policy is moving us towards a more circular economy approach in terms of the materials we use.
- We can adopt the same approach to energy: mass and energy are different forms of the same thing.
- The use of gas in heat-only boilers for space heating is typically around 81% energy efficient and 13% exergy efficient.
- With building space heating currently amongst the largest single energy consumer alongside transport and electricity generation, the low exergy efficiency practice of using gas in boilers is a gross waste of resource.

Illustration

- Gases, such as natural gas, hydrogen and biomethanes, burn at a flame temperatures just below 2000°C.
- In contrast, building space heating demand is around 21°C.
- These temperature levels are an indication of energy ‘quality’: gas, a ‘high quality’ energy resource, space heating a ‘low quality’ energy demand.
- A wider application of the second law of thermodynamics and use of exergy efficiency by policy-makers could help eliminate the wasteful practice of using high quality energy resources for low quality energy applications.

Solution

- Cities have enough waste and local renewable heat to meet their annual heat demand; this includes heat rejected from building cooling, the subject of this research.
- The role of heat networks is one of an energy carrier, connecting low temperature heat sources to demands.
- Heat pumps, powered by zero-carbon electricity, deployed at consumer's premises ensure the heat network supply temperature meets the consumer's system requirements.
- Cheap field sensors, actuators and IoT, combined with evermore powerful, cost-effective computing, and the rise of artificial intelligence and predictive process control techniques provide for optimised system operation to achieve specific objectives.

Could Cities Become Heat-Autonomous?

- The objective of this research is to understand the potential for minimising the consumption of primary energy resource used in building space heating in cities.
- Heat networks are repurposed to provide hot and cold energy sinks that:
  - Allow heat rejected from building cooling systems to be transferred to heat nearby buildings augmented by building-level heat pumps;
  - Provide energy sources for the chiller condensers and heat pump evaporators that maximise their coefficient of performance (efficiency); this contrasts with the traditional use of ambient air.
- Advanced process control strategies optimise the operation of this complex process against the defined objective.
- Research outputs to inform future policy to create a better market for exergy efficient building space heating solutions.

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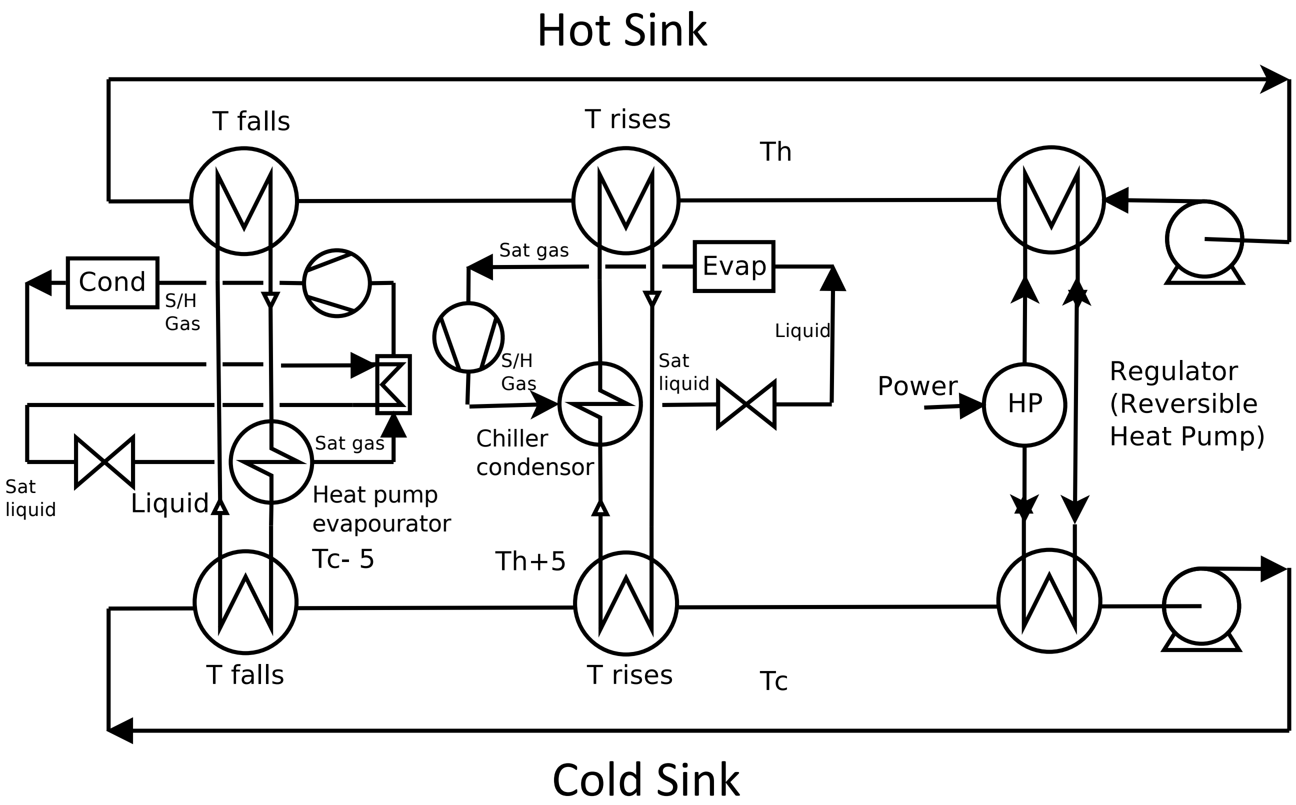

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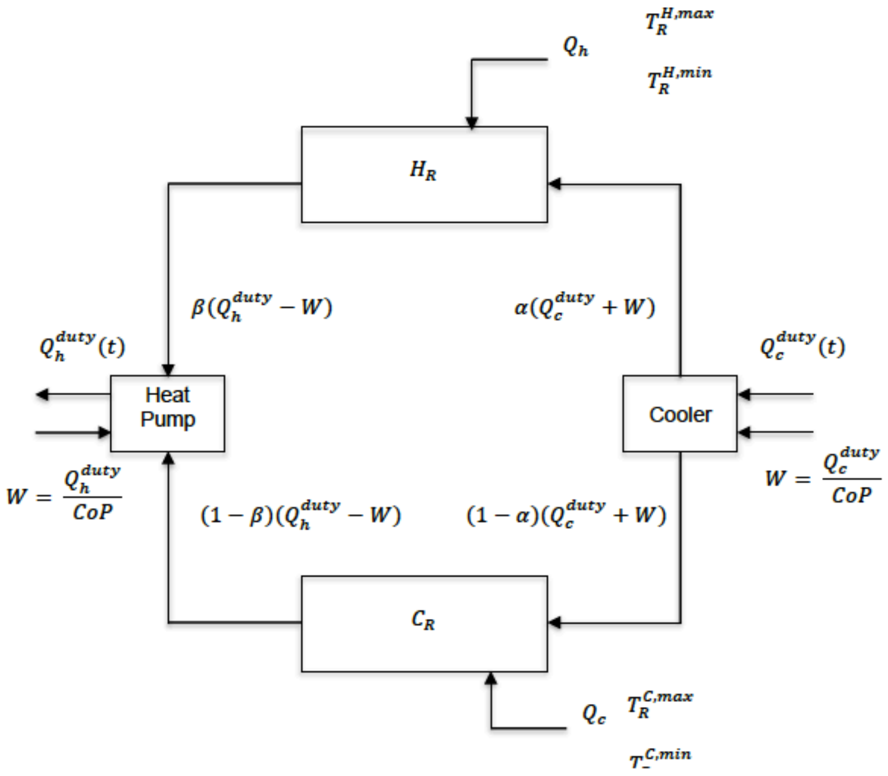

Heat Transfer Equations

Hot Sink

$$M^H C_p \frac{dT^H}{dt} = Q_h - \beta(Q_h^{duty} - W) + \alpha(Q_c^{duty} + W)$$

Cold Sink

$$M^C C_p \frac{dT^C}{dt} = -Q_c - (1-\beta)(Q_h^{duty} - W) + (1-\alpha)(Q_c^{duty} + W)$$

Differential Equations

Hot Sink Temperature

$$\frac{dT}{dt} = \frac{Q_h - \beta(Q_h^{duty} - w) + \alpha(Q_c^{duty} + w)}{M^H C_p}$$

Cold Sink Temperature

$$\frac{dT}{dt} = \frac{-Q_c - (1-\beta)(Q_h^{duty} - w) + (1-\alpha)(Q_c^{duty} + w)}{M^C C_p}$$

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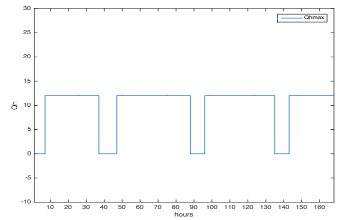
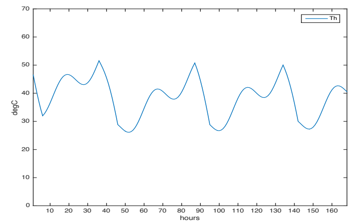
Control strategies modelled in Matlab/Simulink

Objective: set and maintain the hot and cold sink temperature set points

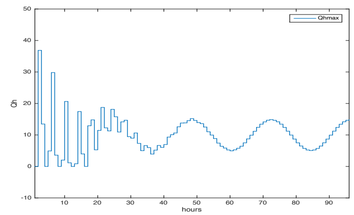
Balancing Heat Pump Operation | **Sink Temperature**

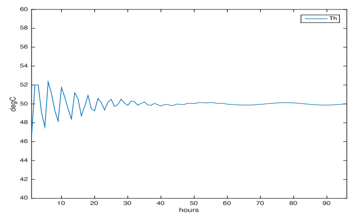
1. Discrete control (on/off)





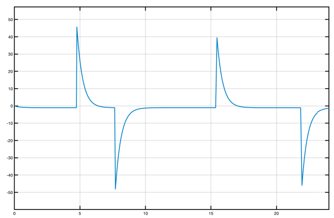
2. PID control (proportional – integral - derivative)

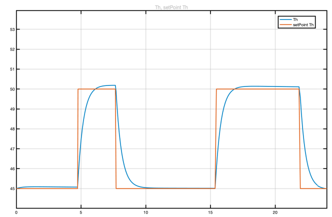




3. PRBC (predictive rule-based control)

   Rule- based control is one of the simplest forms of artificial intelligence. Used in conjunction with the PID controller, a matrix of prevailing operating conditions is used to anticipate a new sink temperature set point for the next time interval, dT/dt, using IF, THEN statements, e.g., if T_h = high, and Q_h high, then T_h = low) .





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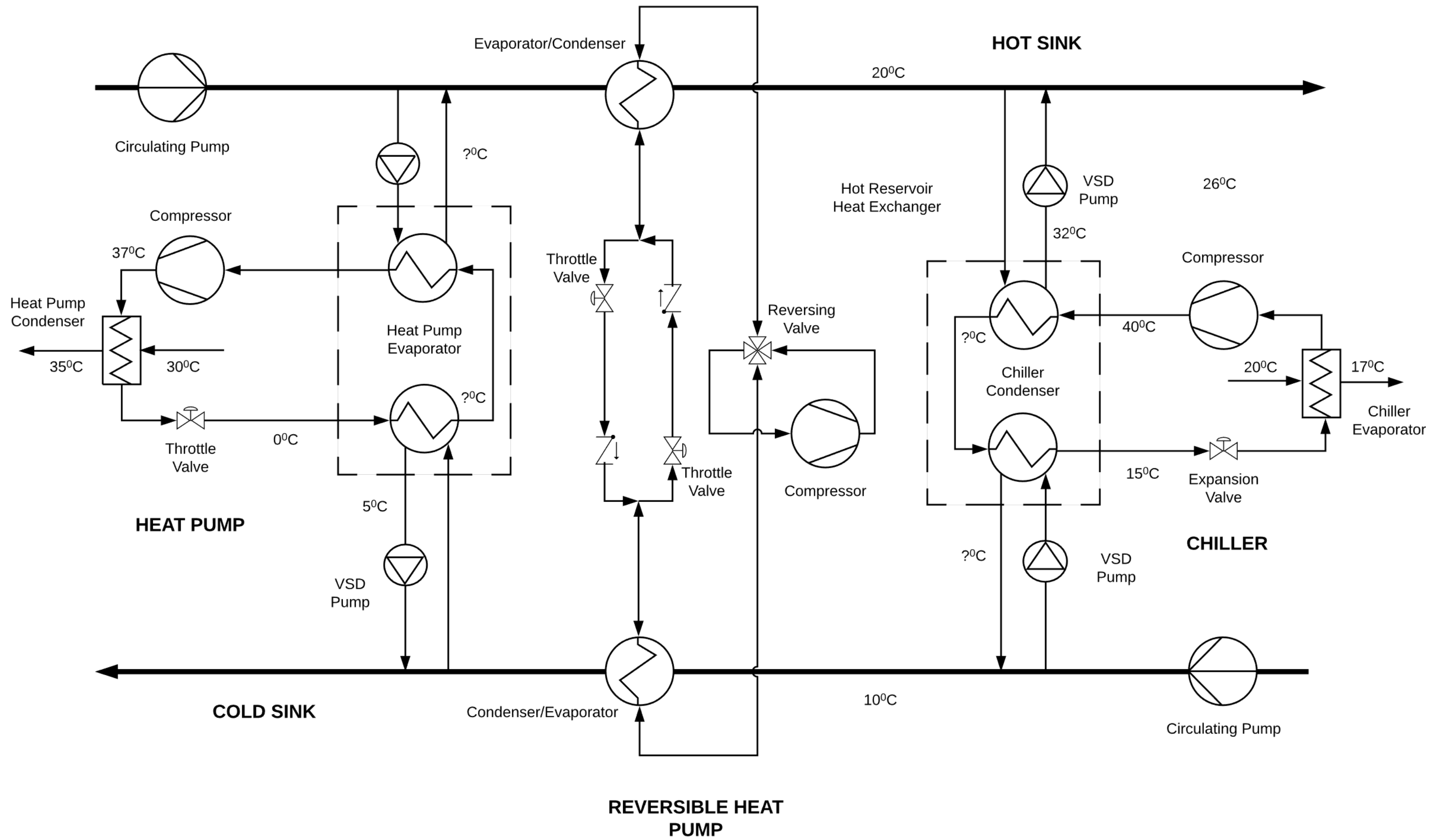

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Next Steps

Validation Model

1. Finalise ‘engineered’ model: NTU method for heat exchanger analysis, assess network dimensioning.
2. Implement typical annual building heating and cooling profiles.
3. Include heat pump/chiller performance characteristics.
4. Determine system seasonal limitations/constraints

Case Model

1. Identify case study area.
2. Establish cooling and heating demand data.
3. Implement model.
4. Optimise heat supply
5. Evaluate benefits.
6. Inform policy implications

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