



**Carnegie Mellon University**

# Thermodynamics (Part II)

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# Learning objectives

1. Heat sources in a building
2. Use of Heat, Ventilation and Air-Conditioning (HVAC) system
3. Anthropogenic heat in a city

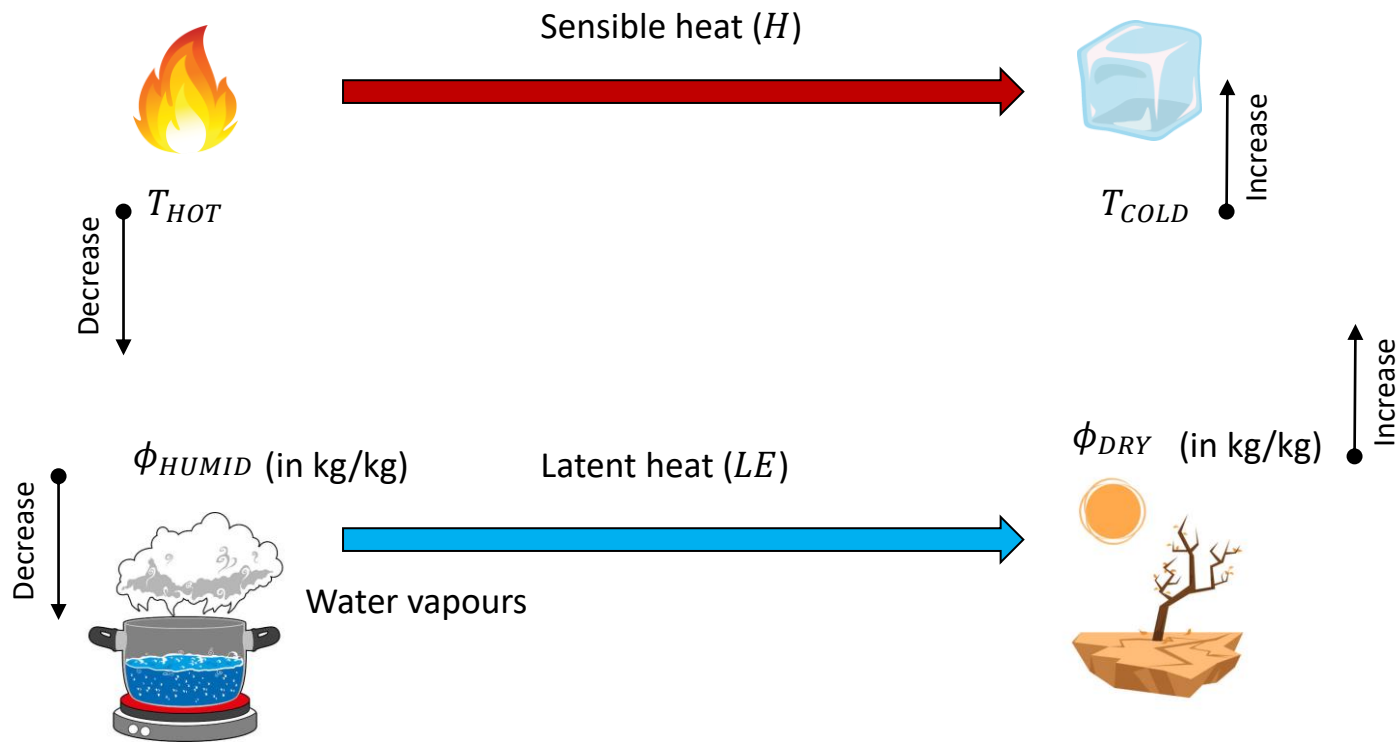
# References

Hens H. S. L., "**Building Physics -- Heat, Air and Moisture: Fundamentals and Engineering Methods with Examples and Exercises**". 2nd Edition. Newark: Ernst Sohn, (2008).

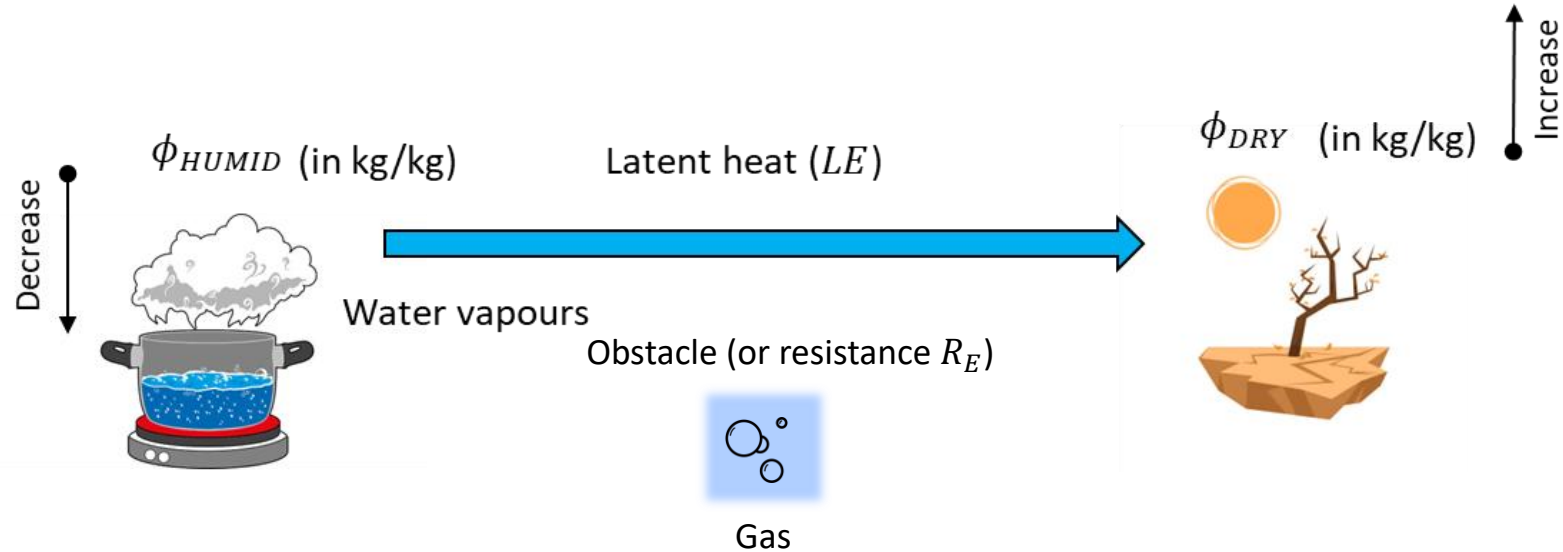
Enteria, Napoleon, Matteos Santamouris, and Ursula Eicker, eds. "**Urban Heat Island (UHI) Mitigation : Hot and Humid Regions**". 1st ed. 2021. Gateway East, Singapore: Springer, (2021).

**What are the important sources of heat in a building?**

# Sensible versus latent heat



# Latent heat transfer



$$LE = L \cdot \frac{\phi_{HUMID} - \phi_{DRY}}{R_E} = L \cdot A \cdot \left( \frac{h}{Le \cdot c_p} \right) \cdot (\phi_{HUMID} - \phi_{DRY})$$

# Sources of sensible and latent heat in a building

Interior surfaces



Occupants



Artificial light



Electric equipment



HVAC system

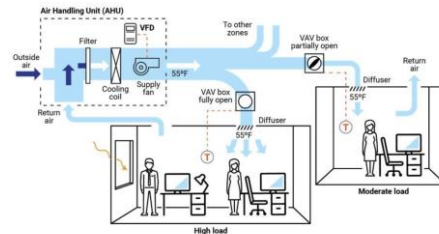
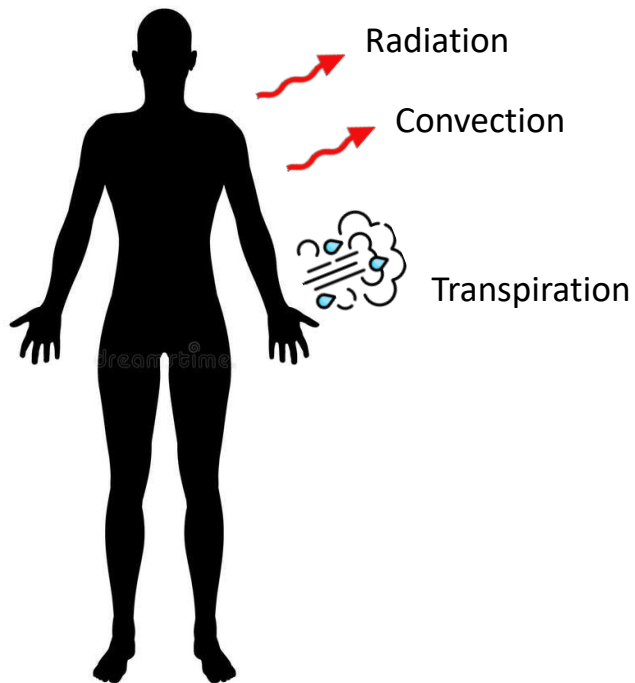


Figure 1. Typical VAV-based HVAC distribution system.

# Occupants

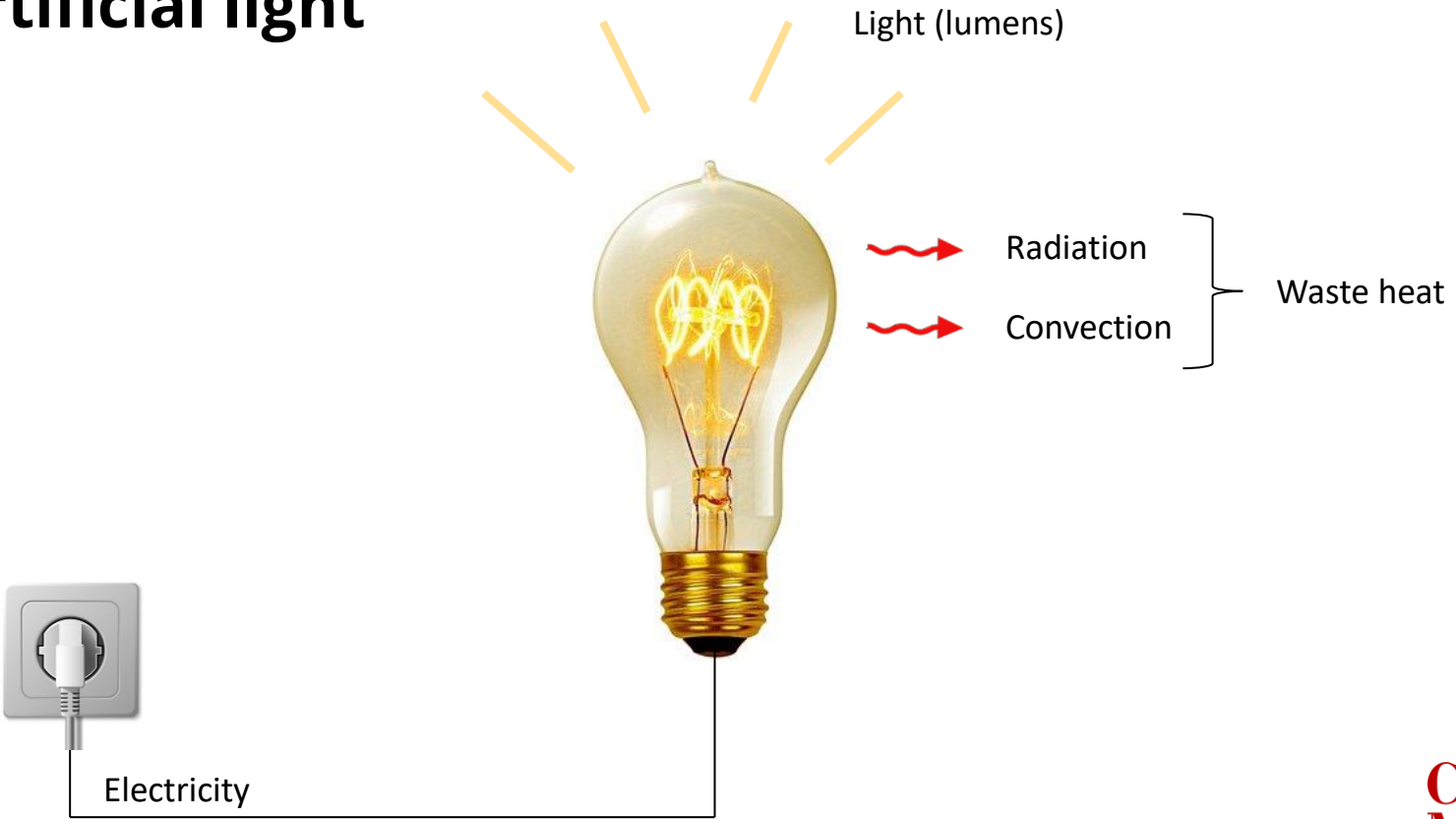


Activity





# Artificial light



# Electric equipment

Computer

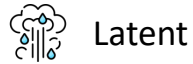


→ Sensible

Kitchen



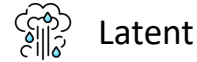
→ Sensible



Washing machine



→ Sensible



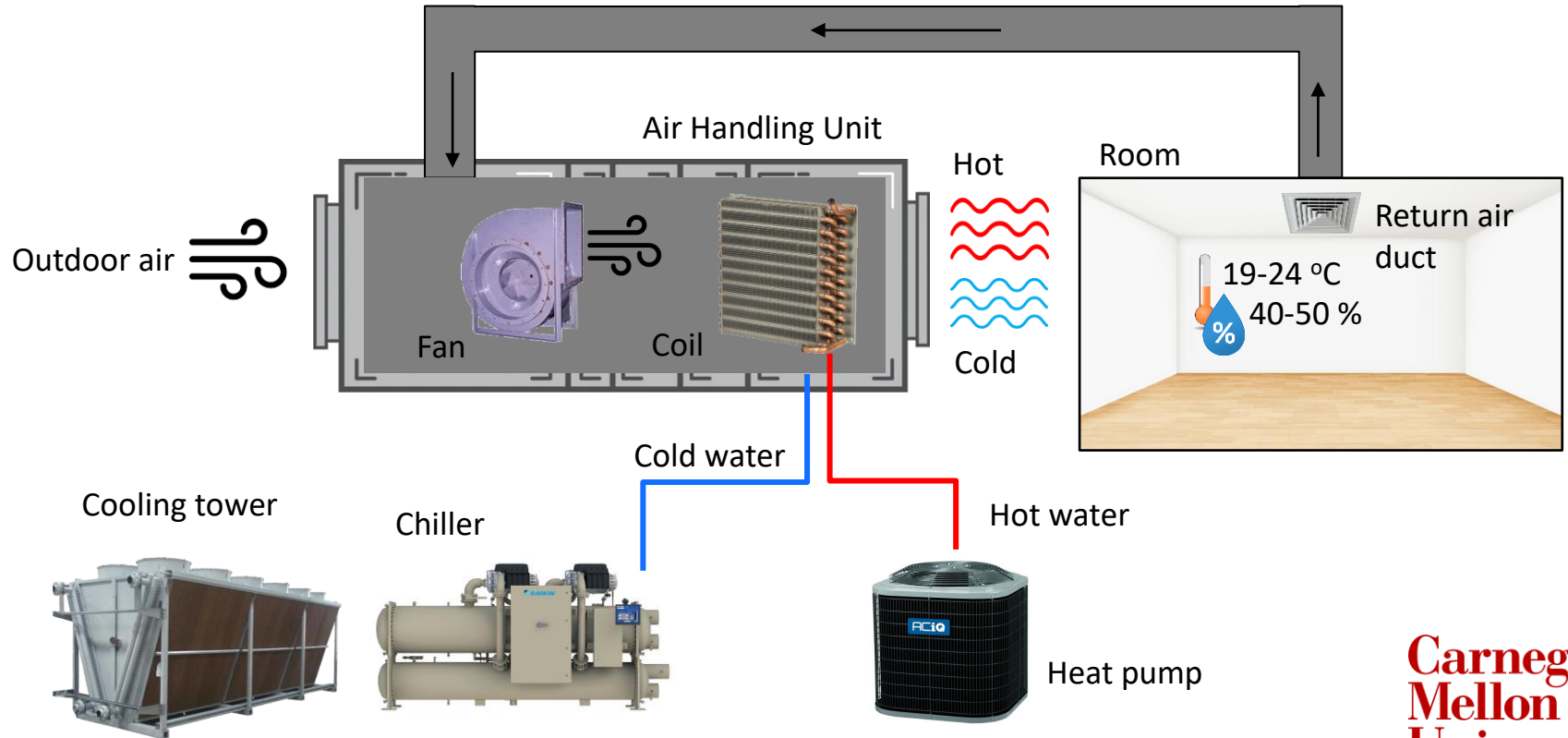
TV



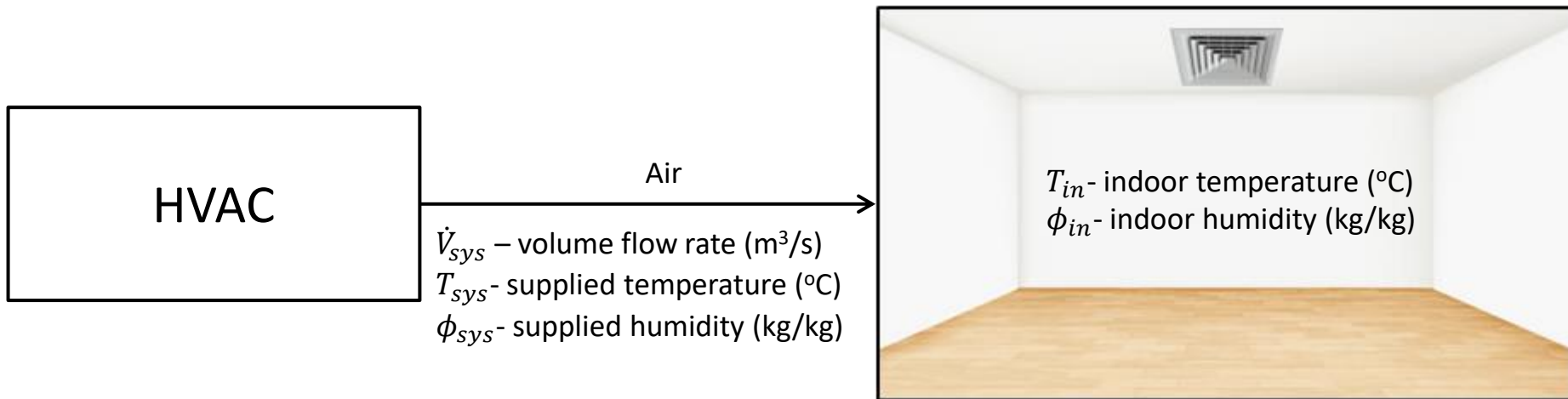
→ Sensible

# How does a HVAC system work in a building?

# Basic HVAC system

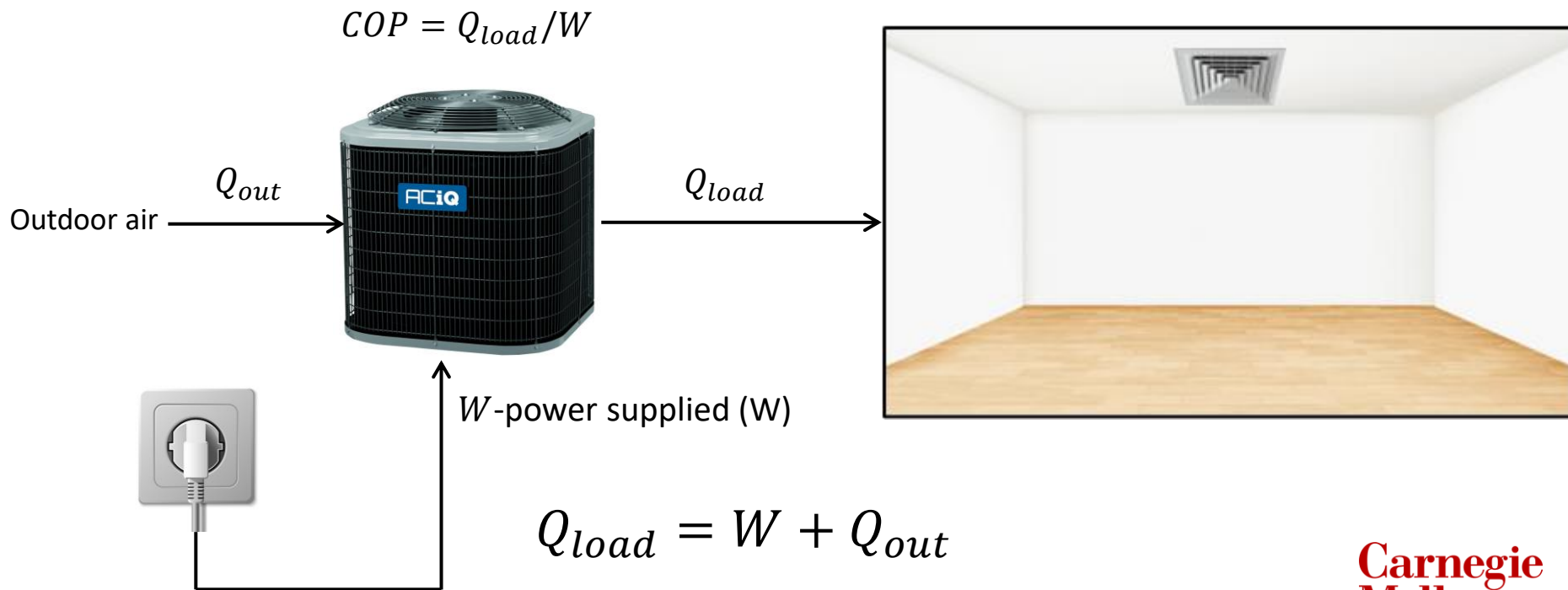


# Heating and cooling load

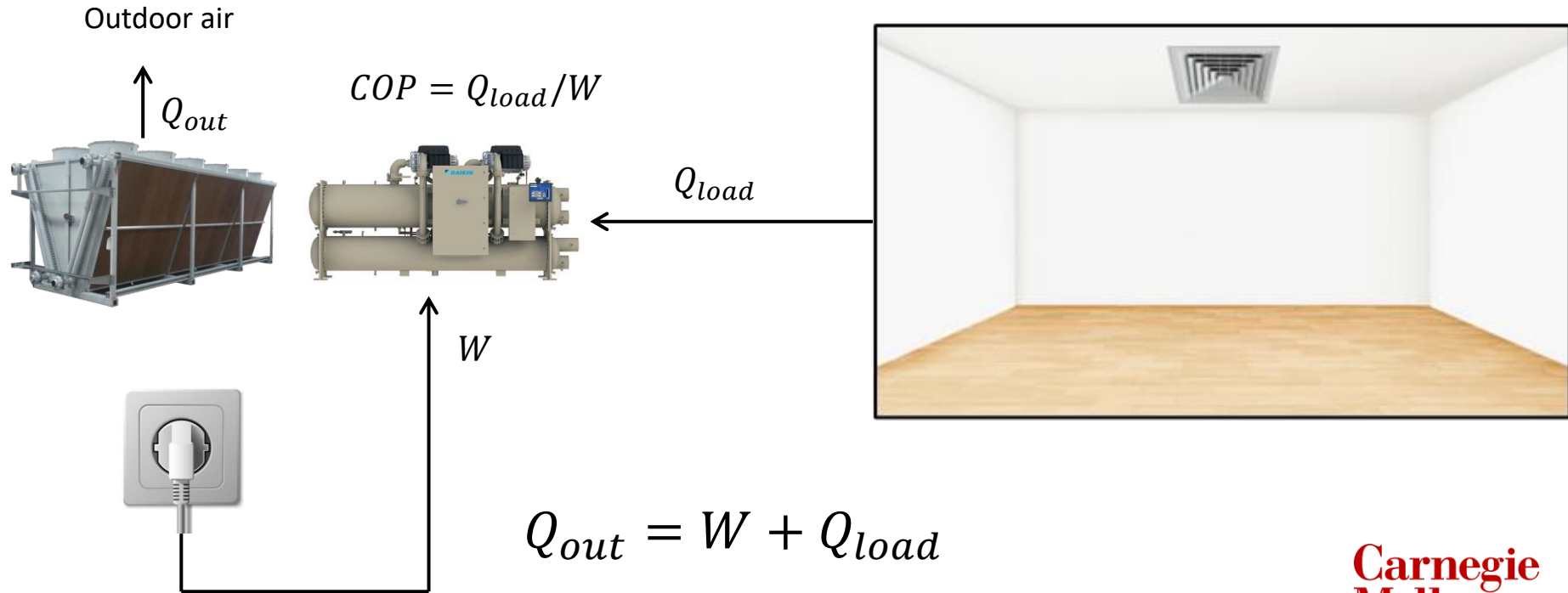


$$Q_{load} = \underbrace{\dot{V}_{sys} c_p \rho |T_{sys} - T_{in}|}_{\text{Sensible load}} + \underbrace{\dot{V}_{sys} L \rho |\phi_{sys} - \phi_{in}|}_{\text{Latent load}}$$

# Heat pump



# Chiller and cooling tower



**What are the main sources of anthropogenic heat in a city?**



# Waste heat releases

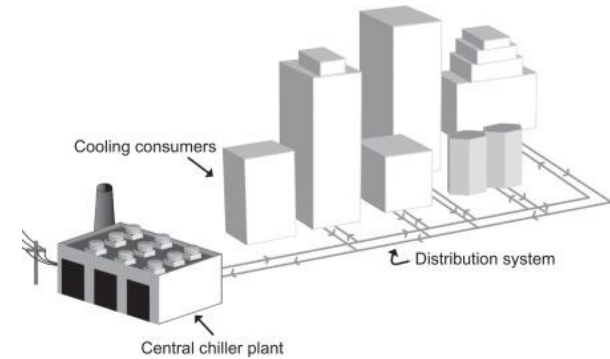
Individual split units



Rooftop chiller plant



District cooling plant



# Traffic

