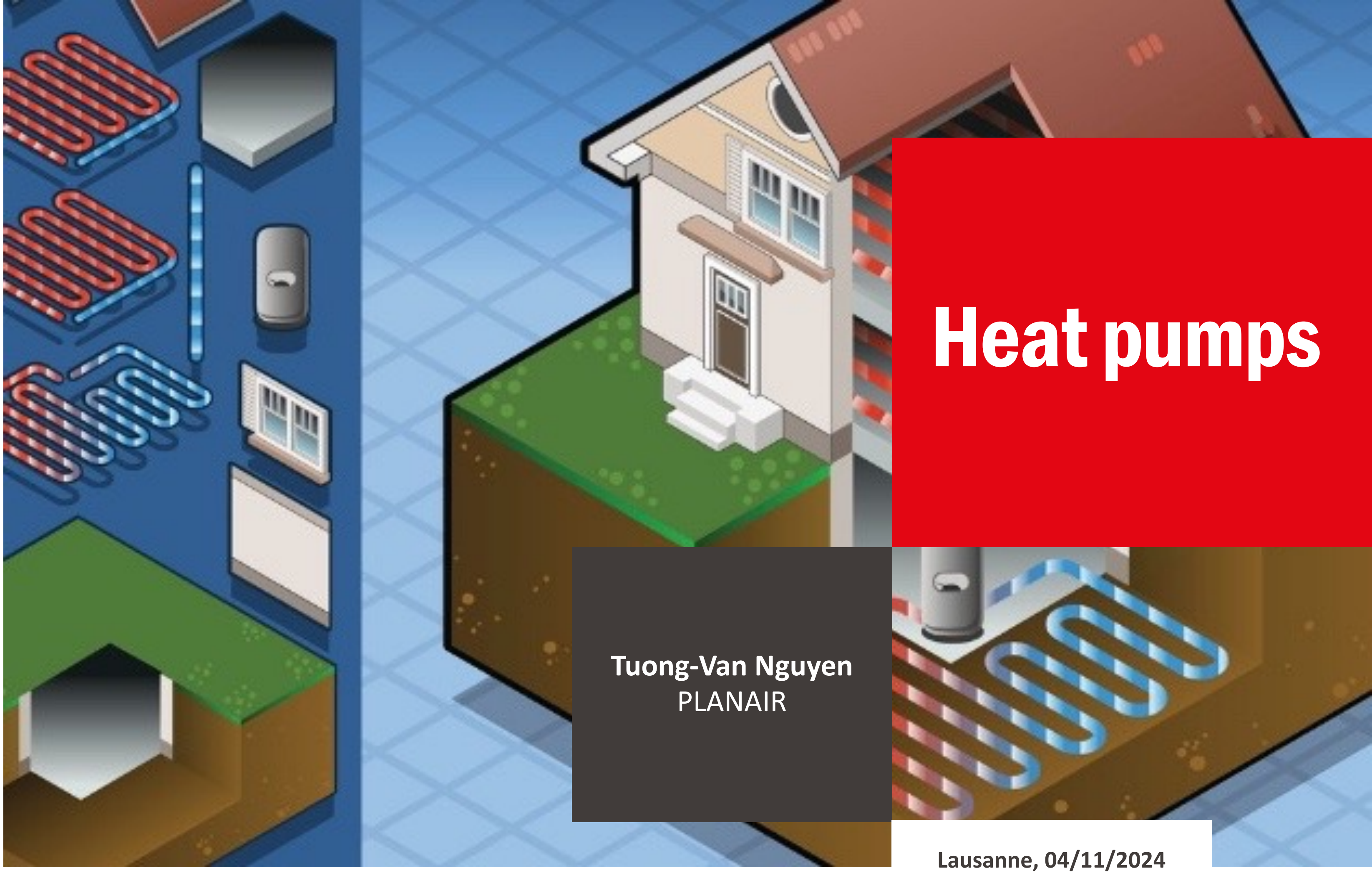
EPFL



Heat pumps

Tuong-Van Nguyen
PLANAIR

Lausanne, 04/11/2024

École
polytechnique
fédérale
de Lausanne

Goals

- ***Describe*** the working principle of a *heat pump*

- ***Calculate*** its coefficient of performance and second-law efficiency

- ***Select*** an appropriate working fluid

- ***Estimate*** the potential savings when implementing a heat pump

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

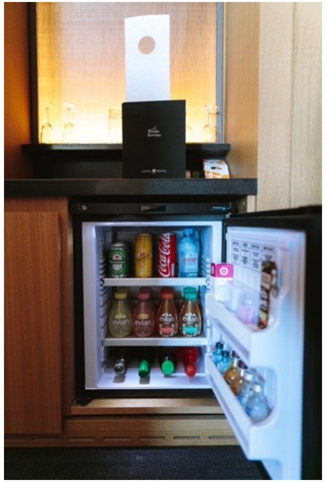
Introduction

Examples of applications

- **Fridge:** production of a **cooling effect**

HEAT
FROM THE
FRIDGE
CONTENT

ELECTRICITY



HEAT
TO THE
ENVIRONMENT

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Introduction

Examples of applications

- **Low-temperature heating:** space heating and hot water production

HEAT
TO THE
BUILDINGS

67°C

The **heat pump facility** of EPFL

ELECTRICITY

> 7°C

HEAT
FROM THE
GROUND/LAKES
& DATACENTER

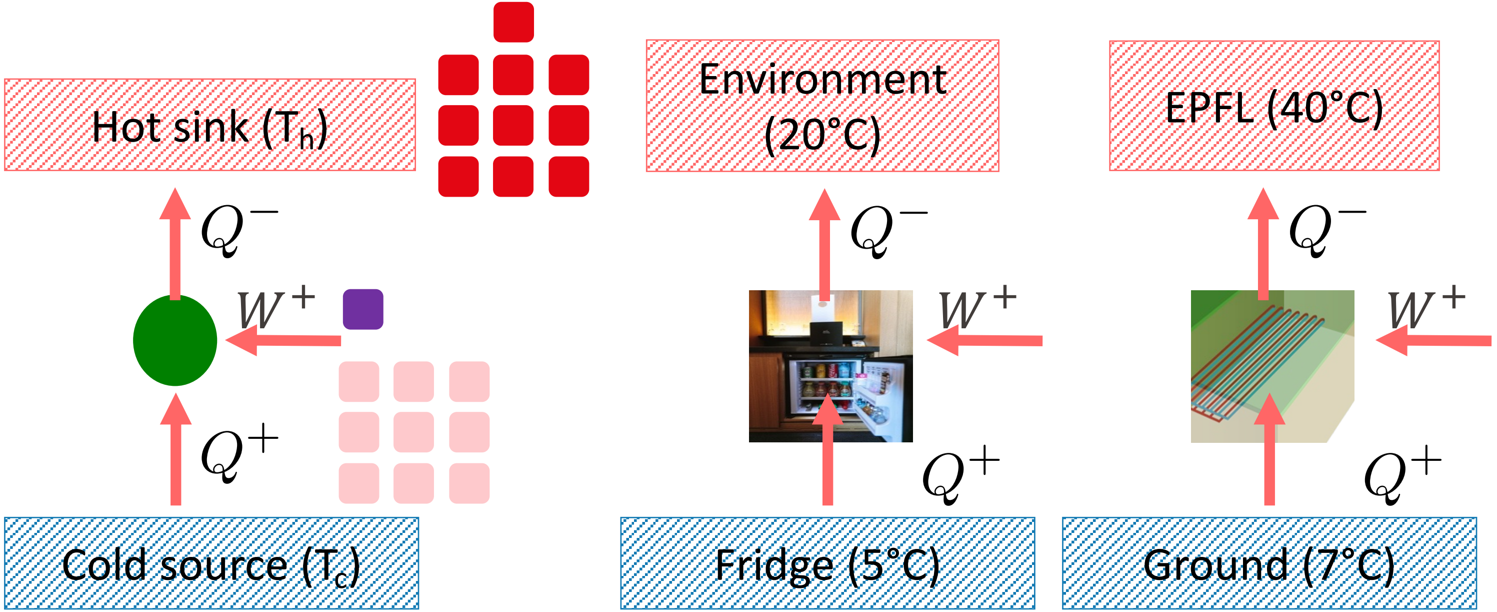
Source : https://actu.epfl.ch/news/une-centrale-de-chauffe-qui-cumule-les-energies--3/

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

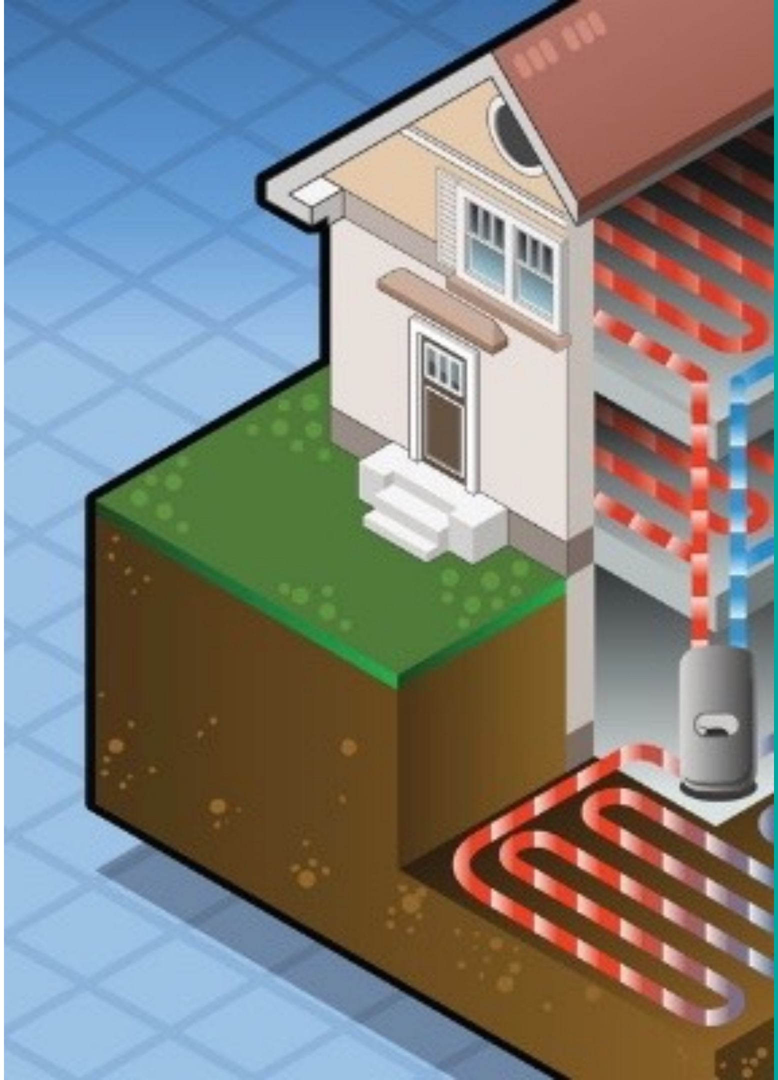
Introduction

General concept

- **A heat pump :** device that consumes electricity and low-temperature heat to produce high-temperature heat



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch



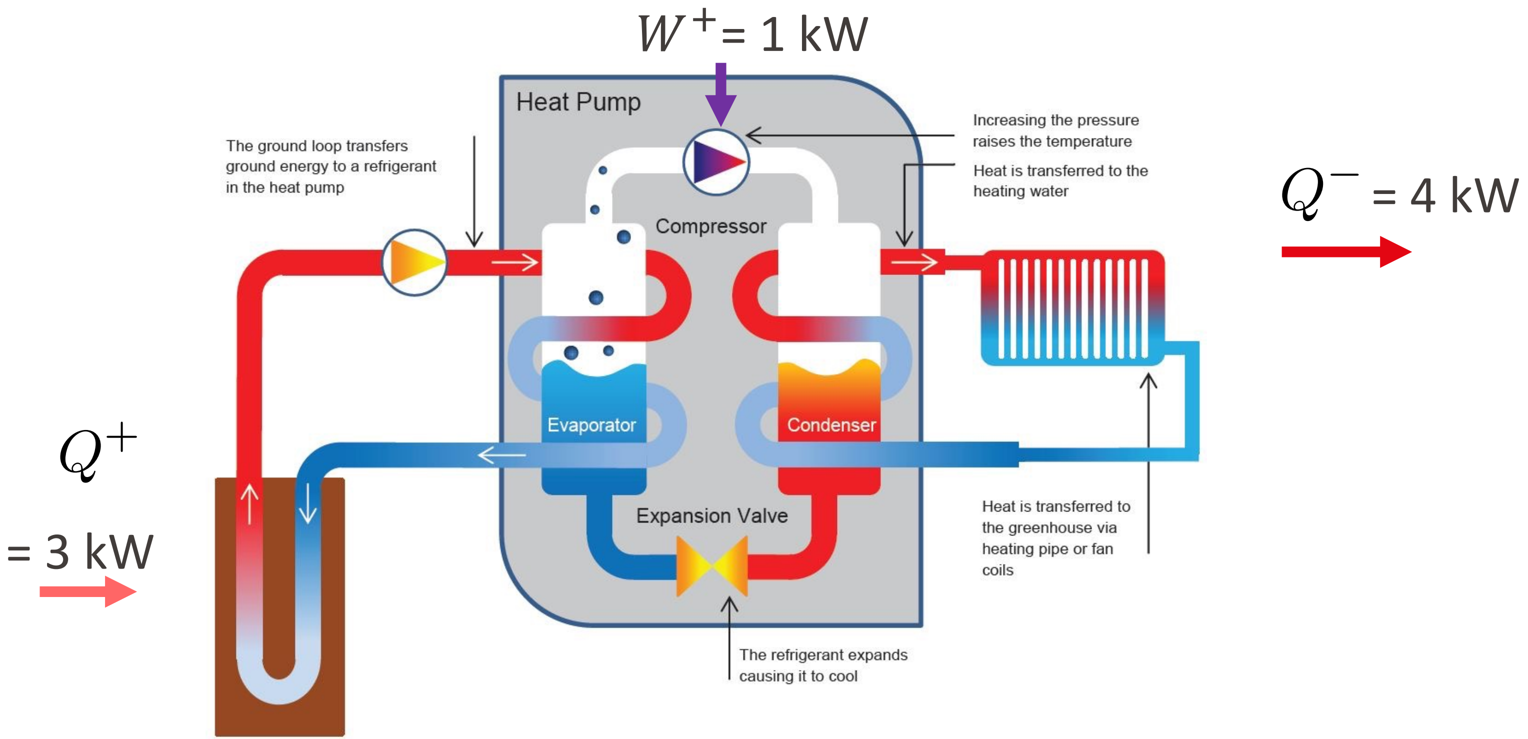
Principle

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Principle

How does a heat pump work?

- In this example, the HP consumes 1 kW of power, takes 3 kW of heat from the environment, and produces 4 kW of heat

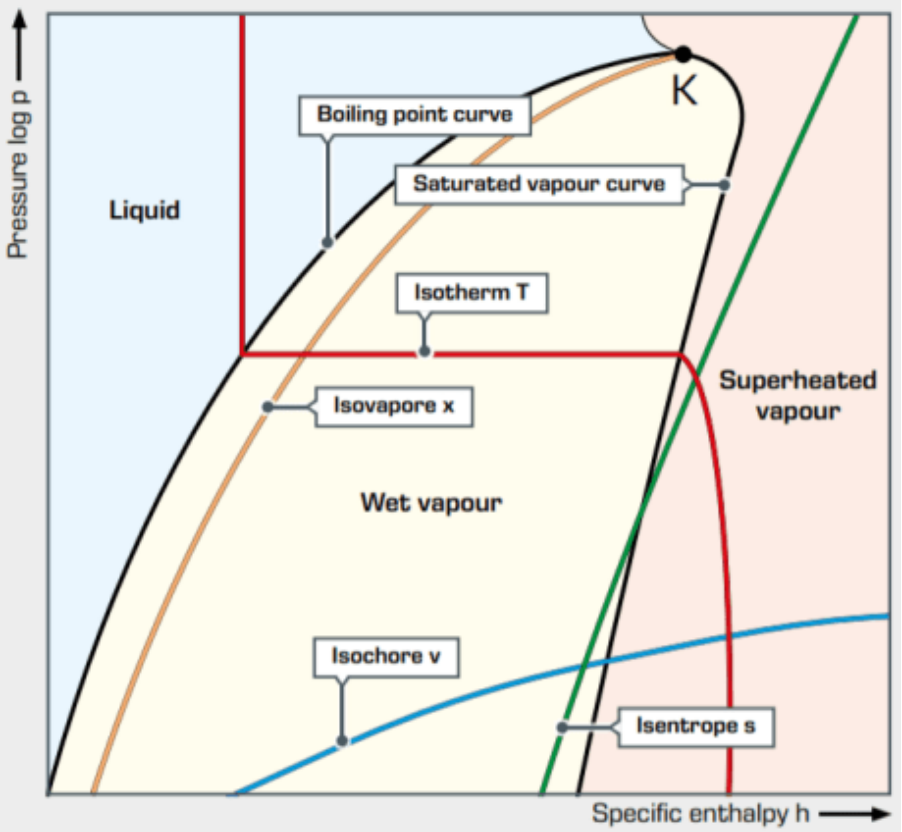


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Principle

pressure-enthalpy diagram (basics)

- Commonly used for heat pump design
- Horizontal lines in the liquid-vapour region = constant temperatures

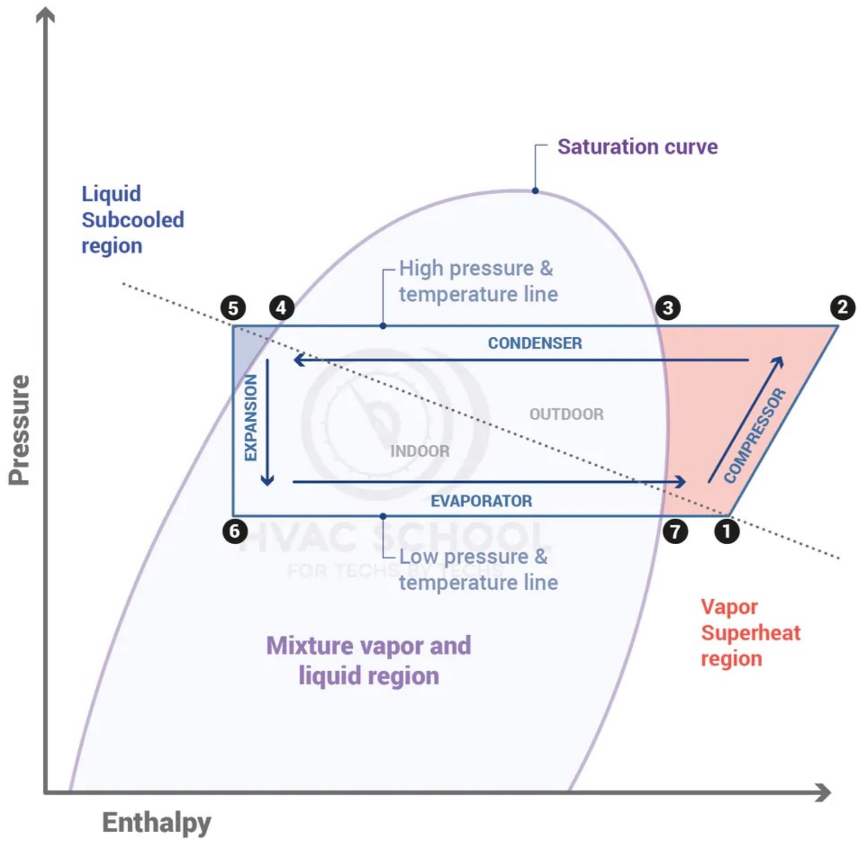


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Principle

pressure-enthalpy diagram (hp)

- 1 – 2 : refrigerant compression => pressure increase
- 2 – 5 : refrigerant condensation and cooling => heat is given
- 5 – 6 : expansion => pressure reduction
- 6 – 1 : heating and evaporation => heat is taken

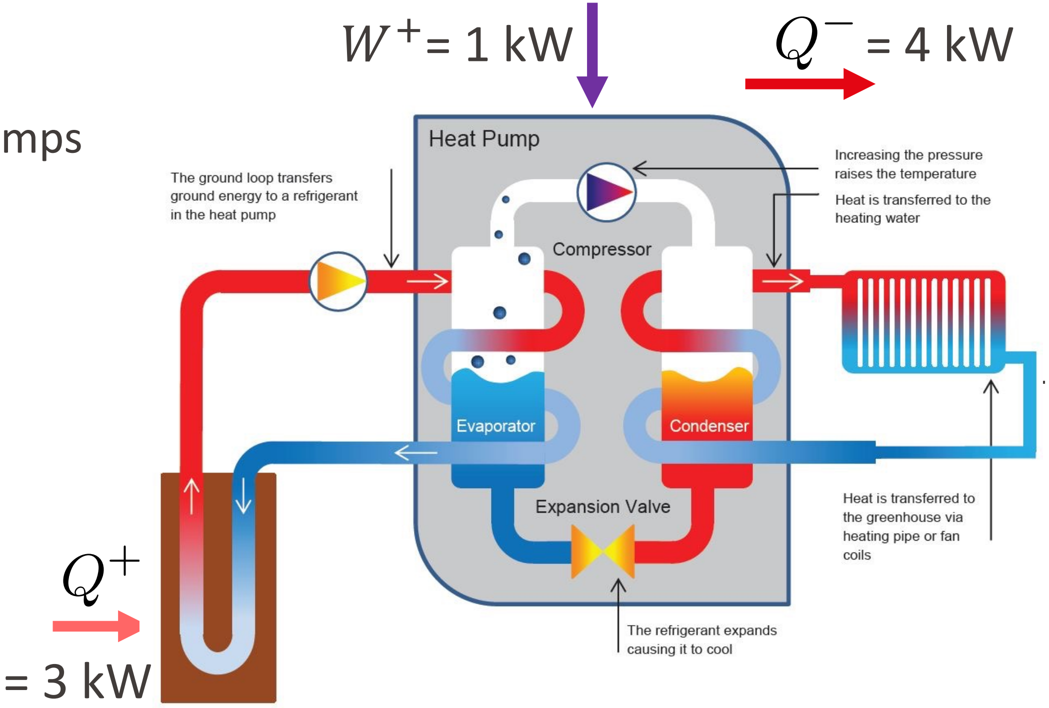


Principle

How performant is it ?

- **Coefficients of performance =** energy efficiencies for heat pumps
- $\mathbf{COP_{heating}} = \frac{Q^-}{W^+} = \frac{4}{1} = 4$
- $\mathbf{COP_{cooling}} = \frac{Q^+}{W^+} = \frac{3}{1} = 3$

COP are always greater than 1



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Principle

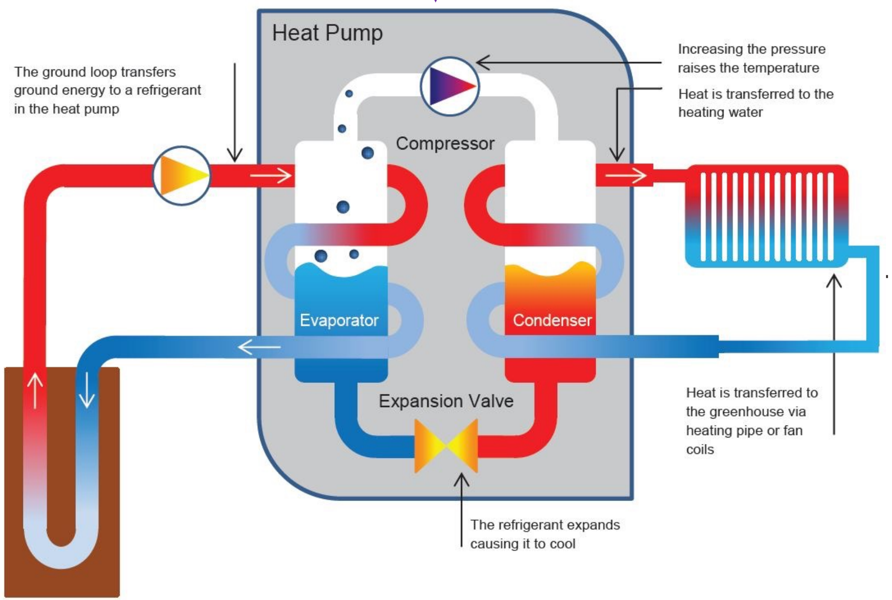
How performant can it be?

- **Carnot COP (ideal case) and 2nd law efficiency**
- $COP_{Carnot} = \frac{Q^-}{W^+_{min}} = \frac{T_h}{T_h - T_c}$
- $\varepsilon = \frac{COP}{COP_{Carnot}}$

Water circuit temperature = 40°C

W^+ = 1 kW

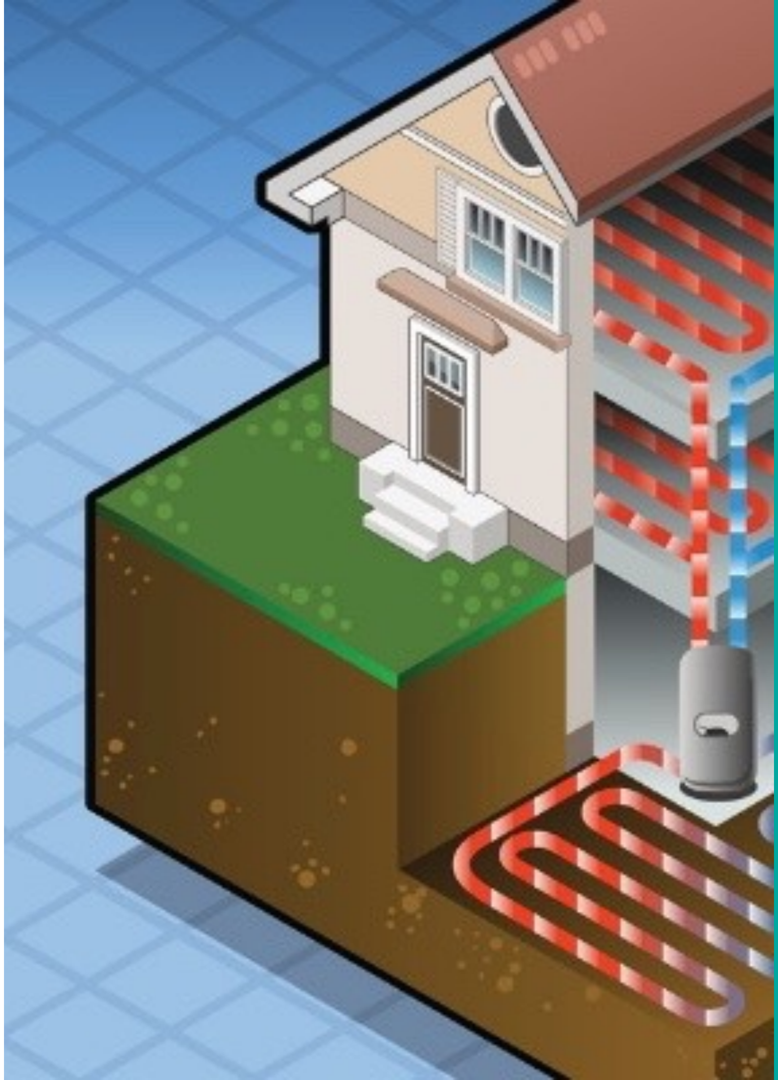
Q^- = 4 kW



Q^+ = 3 kW

Ground average temperature = 7°C

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch



Sizing

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Sizing

Heat pumps vs. boilers

- Sizing procedure

1

- Estimate the **heat** needs of the house / industrial site (kWh of heat per year) based on the current consumption of oil or gas

2

- Estimate the electricity needs of the heat pump (assuming a coefficient of performance COP, typically 3), in kWh per year

3

- As heating is necessary only during a certain period (heating hours, typically about 2000 hours), determine the size of the heat pump, in kW

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

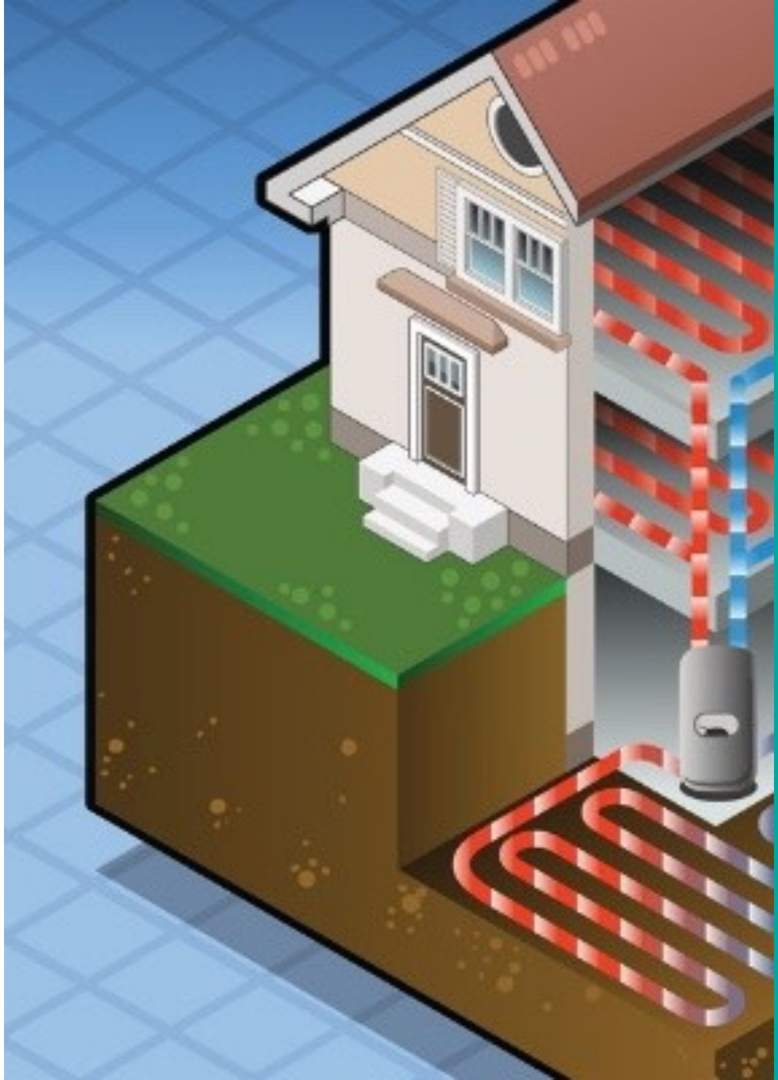
GROUP QUESTION (2 ppl., 10 mins)

A typical Swiss family living in an old building needs, per year, 4’000 kWh electricity and 18’000 kWh heat. It uses a gas boiler for heating with **90% efficiency** that runs **2’000 hours per year**. The heating takes place at **35°C** and the outdoor conditions are **7°C** on average.

- *What are the actual **heating** needs of the house?*

- *If a heat pump with a COP of 3 could be integrated, what would be the **additional electricity consumption**, and how much does that represent in comparison to the house current demands?*
- *Which **size** of the heat pump is necessary (2000 hours heating)?*
- *What’s the **maximum (Carnot) efficiency** of this heat pump?*

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch



Types

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

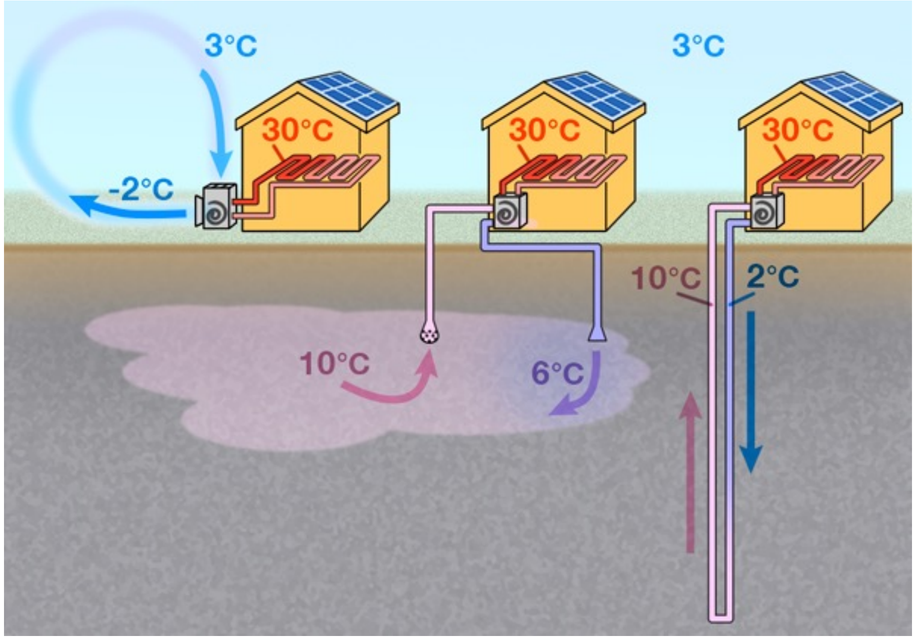
EPFL

Types of heat pumps

How are they named?

- Heat pumps are named based on **where they take heat** and **where they discharge it**.

- **Air/water** heat pumps = take heat from ambient **air**, and discharge it into water of a heating system

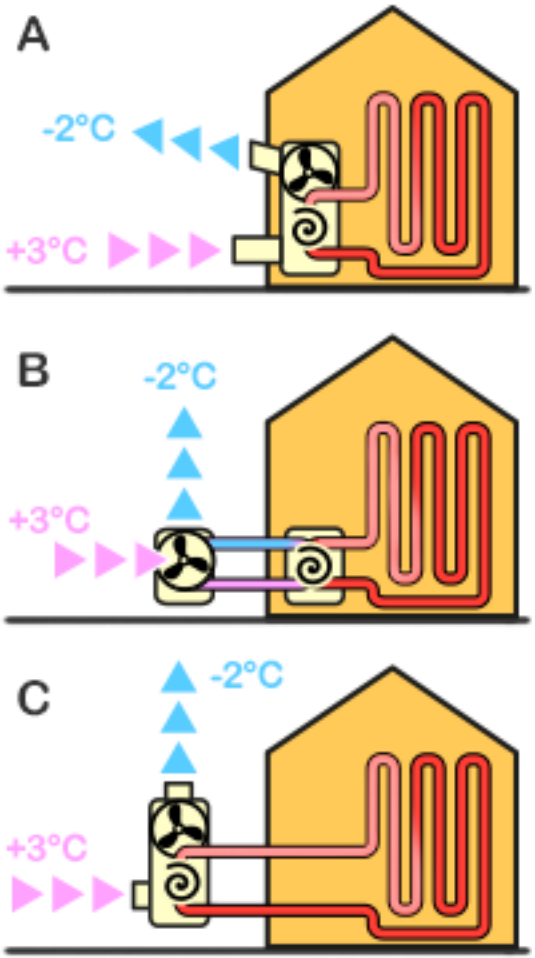


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Air-based heat pumps

The common, but inefficient type

- Air-based heat pumps : usually noisy, poorly efficient in winter
- **Air/air heat pumps =** poorly efficient, not recommended for houses or offices
- **Air/water heat pumps** = most common type today

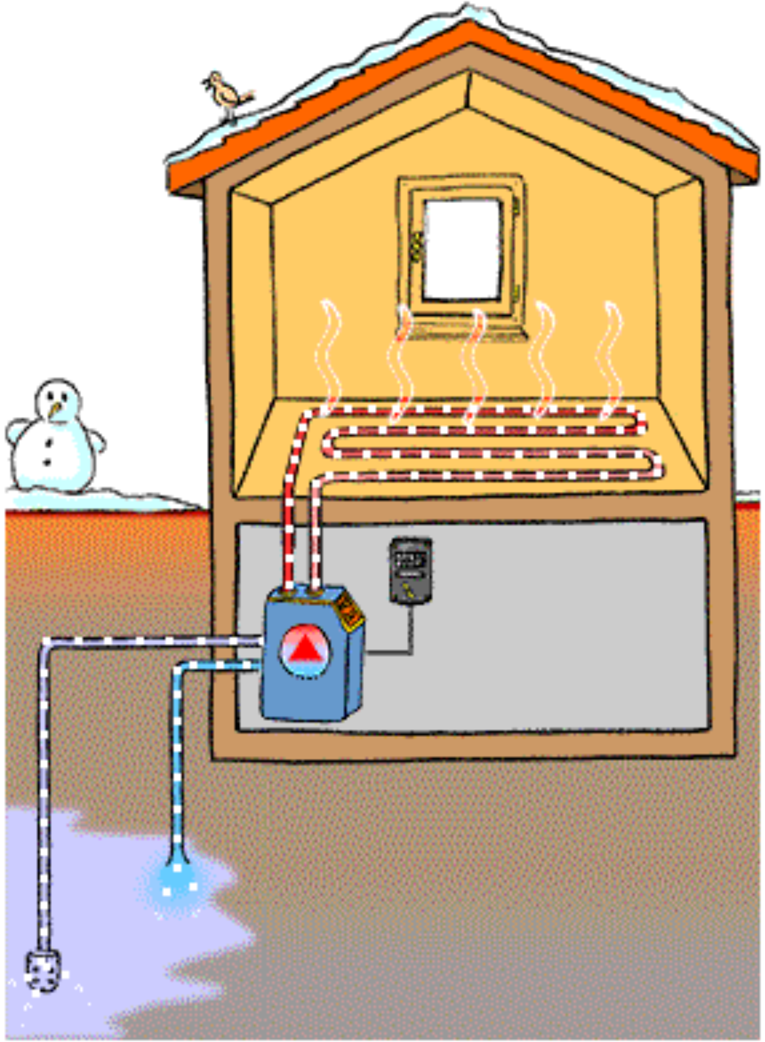


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Water-based heat pumps

The new standard

- **Water**-based heat pumps : less noisy, but require an open source of water (rivers, lakes…)
- **Water/water heat pumps** = more efficient than air heat pumps, but require specific state authorizations
- Example of EPFL

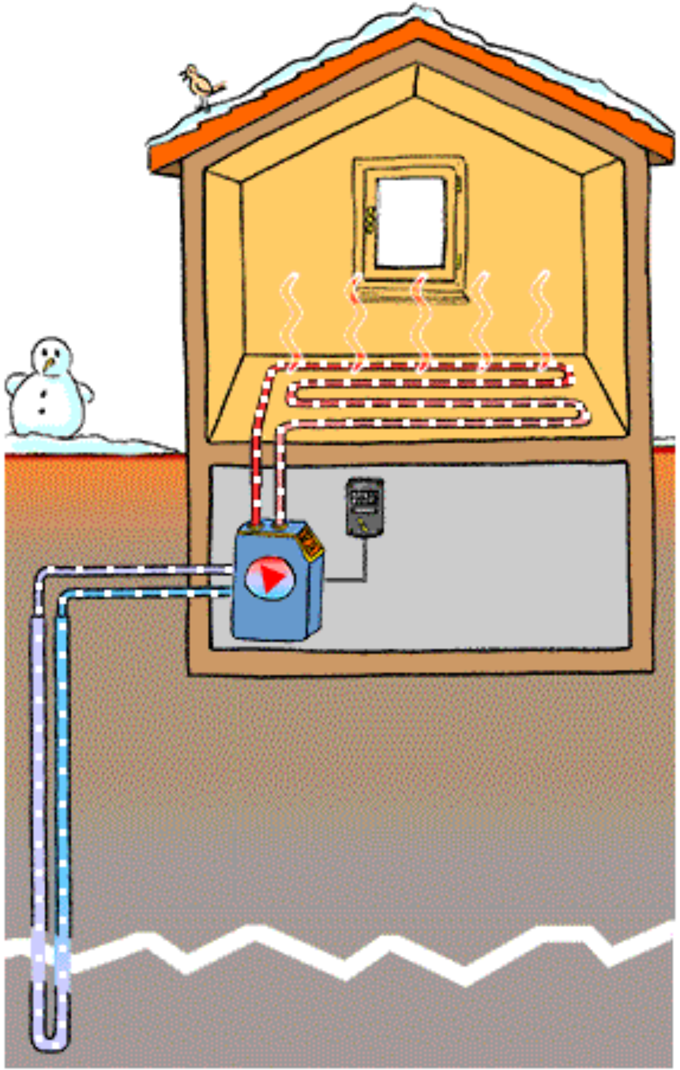


Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Water-based heat pumps

The most efficient, but expensive one

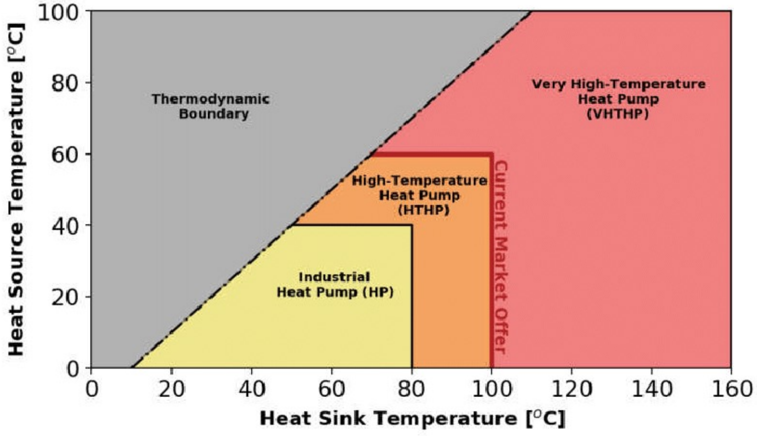
- **Ground**-based heat pumps : closed circuit of water, 50 to 200 m of depth
- **Geothermal heat pumps** = most efficient, but expensive, require space and authorisations



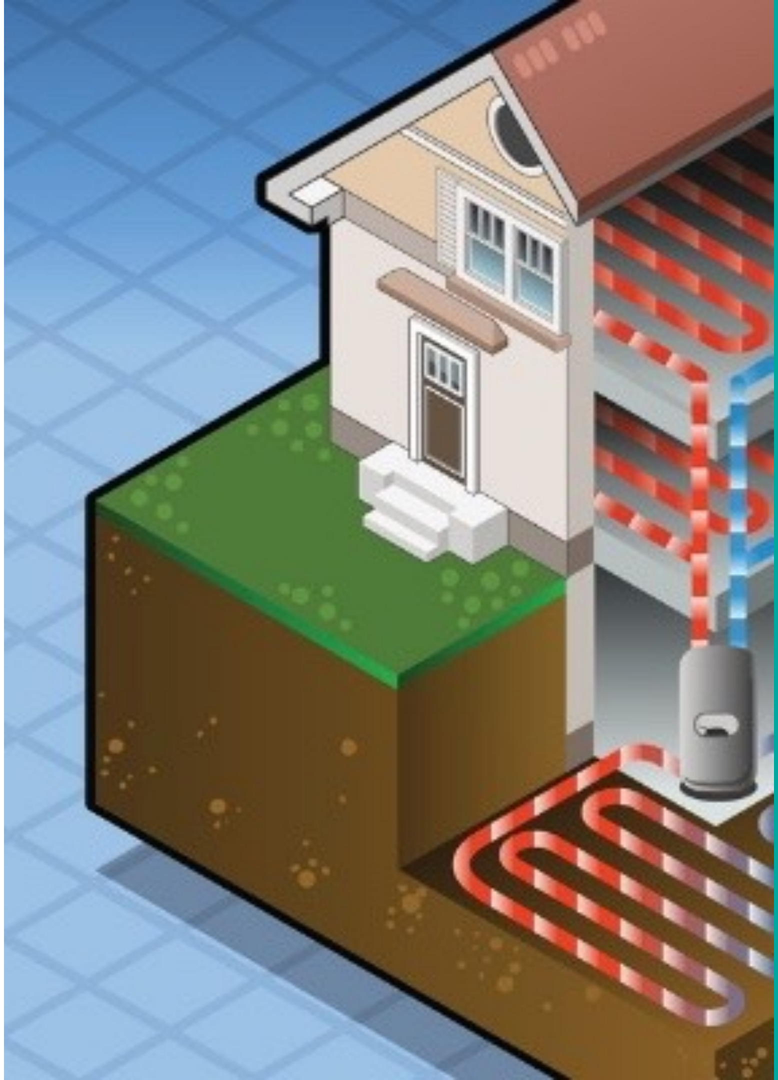
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Operating ranges

- Heat pumps can operate up to **100°C** for heat production (market limit)
- New heat pumps (research state) up to **160°C**
- **Can replace fossil sources for house heating, production of hot water, but not for industrial heating**



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch



Working fluids

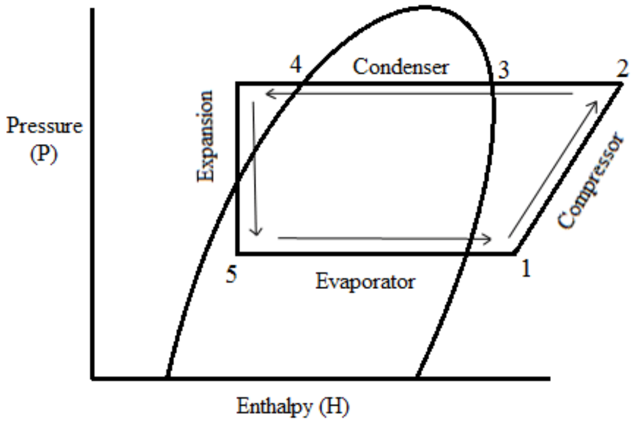
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

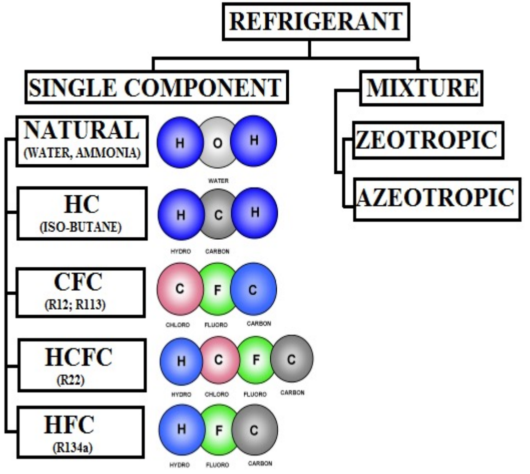
Refrigerant selection

Important properties

- **Thermo-physical properties**
  - Temperatures and conditions
  - Heat pump sizing (flowrate)
  - System performance (**COP**)

- **Economics and Environmental**
  - System and refrigerant costs
  - ODP, GWP (measure of the impact related to CO_2)
  - Flammability

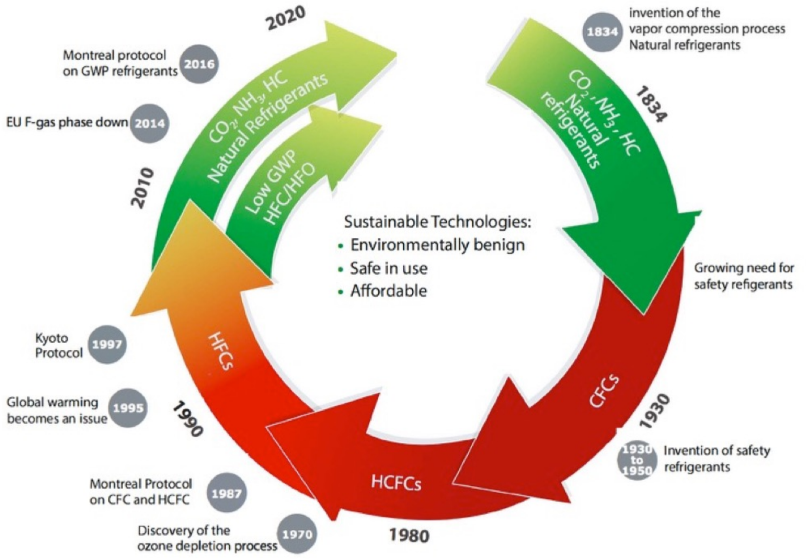




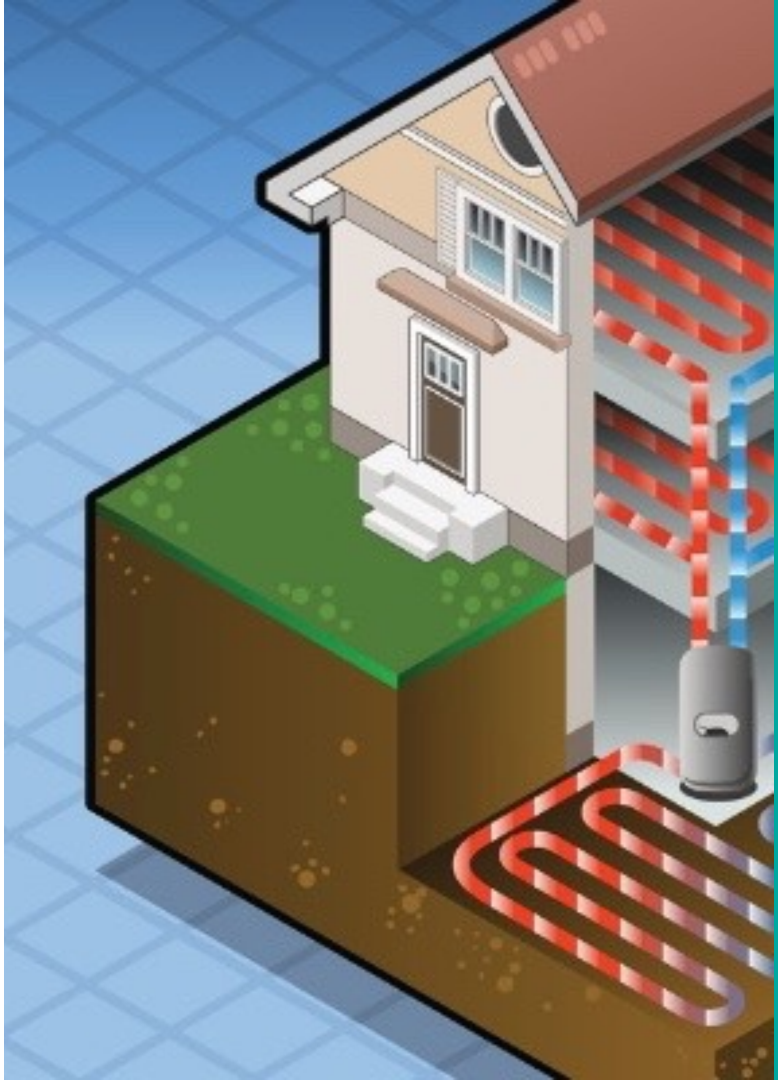
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Refrigerant selection
Historical development

- Synthetic fluids (CFCs, HCFCs, HFCs) = large environmental impacts
- CFCs and HCFCs banned (Montreal)
- High GWP HFCs banned in EU and CH (> 1500) – from 2030 (> 150)



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch



District heating

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

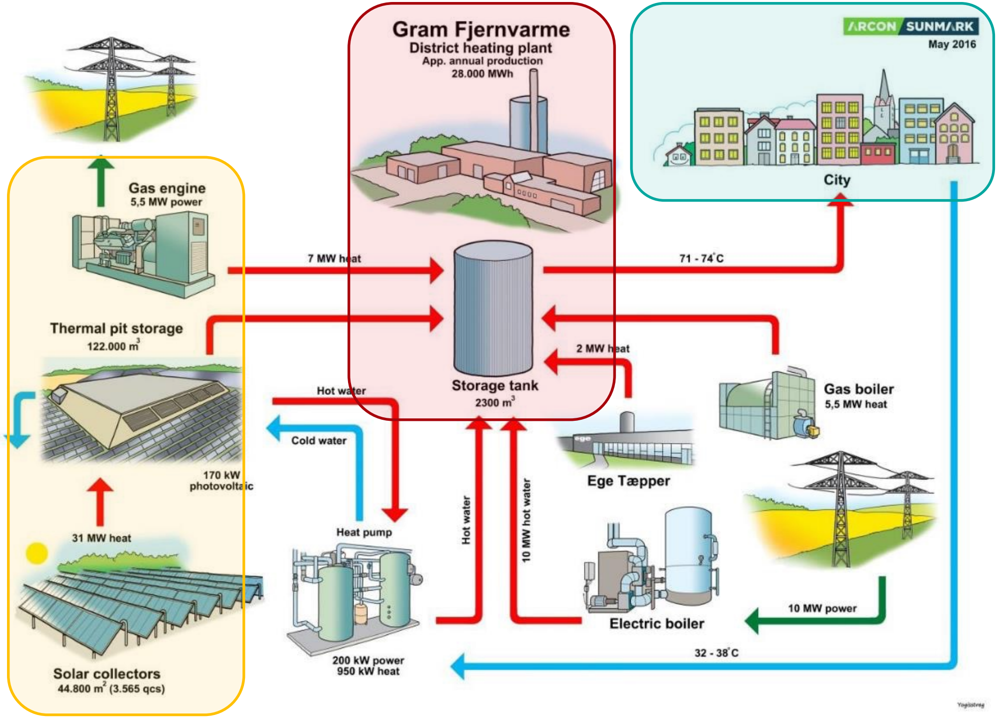
District heating

Generating/receiving heat and **transferring** it through heat carriers

(2) DH STORAGE + DISTRIBUTION

(3) CUSTOMERS

(1) HEAT GENERATORS



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

EPFL

District heating
- from 1800 to 2050

Temperature

Supply

< 200°C

< 100°C

90°C

4G = hot water

Return

< 80°C

< 70°C

< 45°C

50-70°C

25-30°C

1880 – 1930

1930 – 1980

1990 – 2010

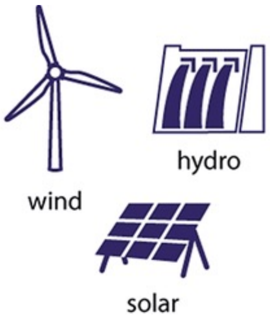
Development

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

District heating
- The future generations?

- Another **paradigm** = integrating **electricity and heat** networks

Renewable electricity



Electricity

Heat pumps

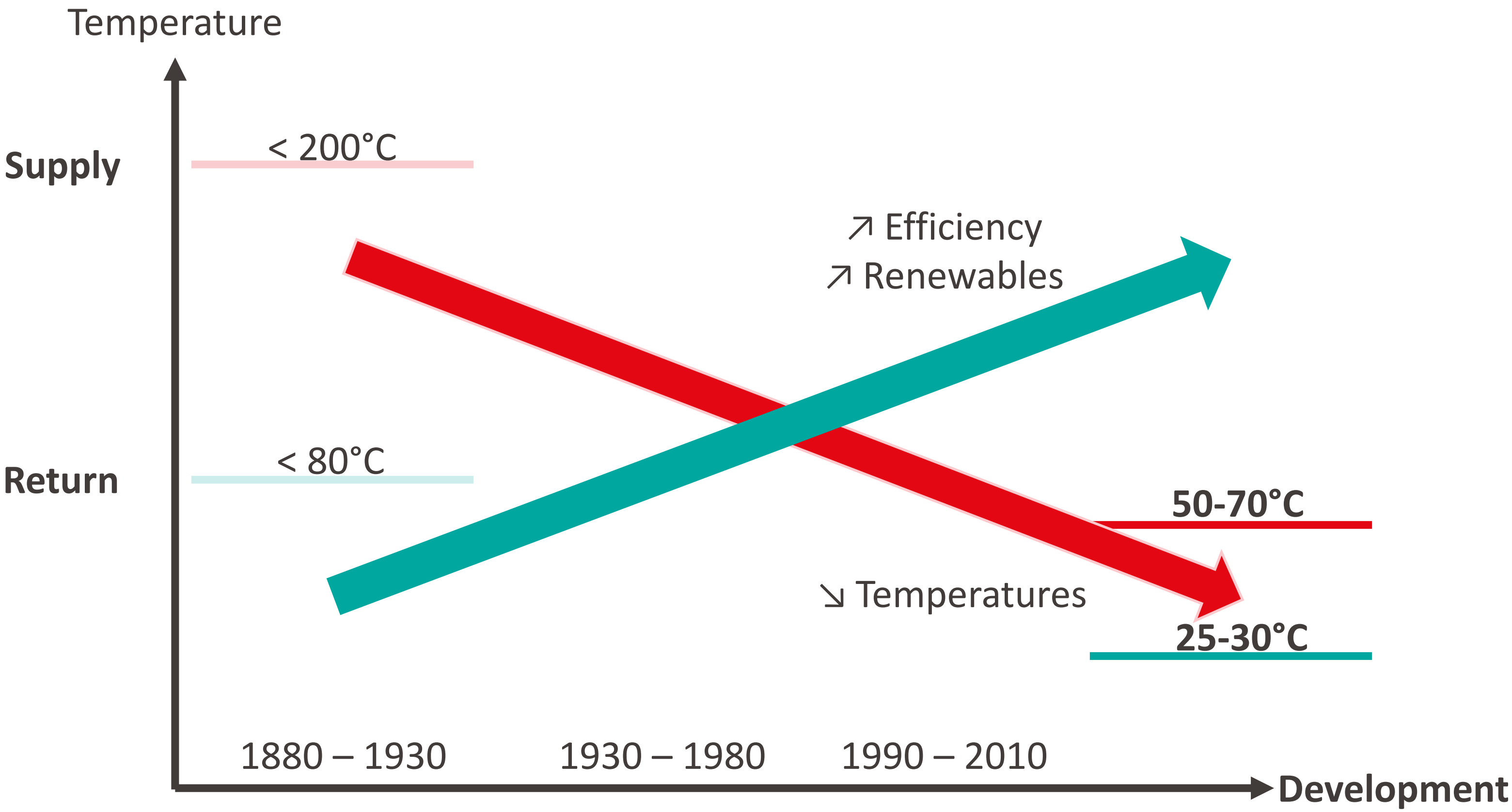
Low-temperature heat

Smart cities

- Waste + Geothermal heat

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

District heating
- the trend



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

District heating
- urban integration

An incinerator with a view: Copenhagen waste plant gets ski slope and picnic area

▲ A render of how the Amager Baake incinerator plant will look once completed next year. Illustration: BIG

The Amager Bakke plant - designed by celebrated architect Bjarke Ingels - boasts that it will provide social as well as environmental infrastructure near the centre of the city. Can industry become part of the urban fabric once again?

Stroll along Copenhagen's waterfront and the horizon is punctuated by the smokestacks from the power station at the tip of Amager island. Construction has just begun on a replacement that will run on fossil-fuel free biomass when it opens in 2020. Beside the power plant, the final touches are being put on the striking aluminium facade of

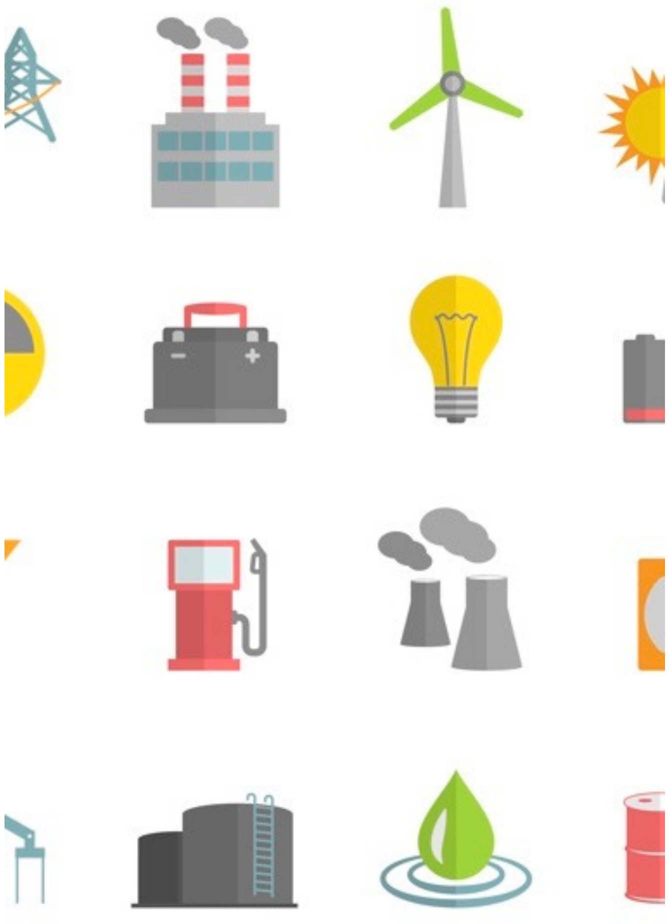
Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Take-home message

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Take-home message

- **Heat pumps**
  - “Reverse” heat engines
  - Substitute for boilers
  - Heating and Cooling
- **Refrigerant selection**
  - Thermodynamic properties
  - GWP, ODP and flammability
  - Compromises necessary
- **In the Energy System**
  - Path for heavier electrification?



Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Take-home message

- District heating = **decentralizing** heat production
- Towards lower temperatures, higher efficiencies, more renewables
- Very different situations from country to country (3/4G in Scandinavia, 2G in Eastern Europe, 1G in Paris/NYC)

Tuong-Van Nguyen – tuong-van.nguyen@epfl.ch

Questions?

Tuong-Van Nguyen