Czech Technical University in Prague
Faculty of Civil Engineering
Department of Microenvironmental and Building Services Engineering

BES1 – Heating systems

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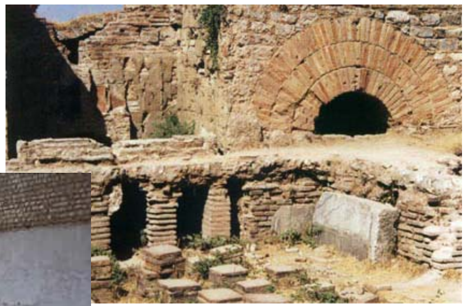
HISTORY

History 700 B.C. - 0

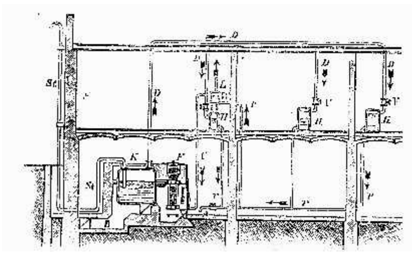
Hypocausta
Greece, Italy,
Turkey



Historie – medieval age

- Stoves, fireplaces

History 18-19.century steam



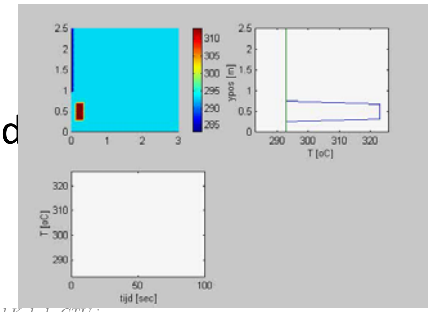
History 20.century hot-water systems

Electricity, Water systems Cast-iron boilers Coal, Gas

Boiler Strebl 1927

Present and future?

- Warm water systems
- Gas boilers controled by micropressor
- Heat emmitters located in the floor, walls and ceiling
- Computer modelling and simulation



THEORETICAL BACKGROUND

Applied thermodynamics

- Heat, heat energy
  - Heat is the energy transferred between a system and its surroundings due solely to a temperature difference between the system and some parts of its surroundings.
- Temperature
  - State variable describing kinetics energy of the particles of the system
    - Thermodynamic /Kelvin/ T [K]
    - Celsius t [°C] t= T-273,15
    - Fahrenheit [°F] 1°F=5/9°C (°F-32).5/9=°C

Basic laws of thermodynamics

- Zeroth law
  - There is a state variable TEMPERATURE. Two systems at the same temperature are in thermodynamics equilibrium.
  - The zeroth law of thermodynamics states that if for example you have a Body (A) and a Body (B), both at the same temperature; and then you have a Body (C) which is at the same temperature as Body (B); Therefore the temperature of Body (C) is equal to the temperature of Body (A).

Basic laws of thermodynamics

- 1.law
  - The total energy of the system plus the surroundings is constant.
- 2.law
  - The second law is concerned with **entropy (S)**, which is a **measure of disorder**. **The entropy of the universe increases**.
- 3.law
  - It is impossible to cool a body to absolute zero by any finite process

Heat transfer modes

- Heat Conduction
  - Heat is transferred between two systems through a connecting medium, Biot-Fourier
- Heat Convection 
  - Macroscopic movement of the matter in the forms of convection currents.
  - Newton-Richman, Fourier-Kirchhof

Heat transfer

- Transmission
  convection+conduction+convection

- Radiation
  – Electromagnetic waves

Steffan - Boltzmann Law: $E = \sigma T^4$

$\sigma = 5.6705 \times 10^{-5}$ erg - cm^2 - K^{-4} - sec^{-1}

(Steffan - Boltzmann Constant)

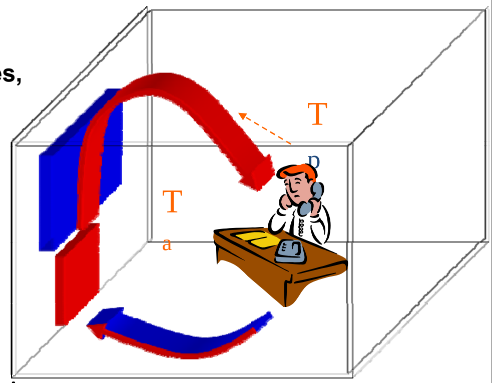
THERMAL COMFORT

Indoor environment

- Theory of the indoor environment
  - Hygrothermal microclimate
  - Acoustic microclimate
  - Psychical microclimate
  - Light microclimate
  - Electrostatic microclimate
- Hygrothermal microclimate
  - Indoor environment state from the viewpint of thermal and moisture folws between the human body and surroundings

Heat Exchange between the Human Body and the Enviroment

- **Metabolic Rate M**
  - **degree of muscular activities,**
  - **environmental conditions**
  - **body size.**
- Heat loss Q
  - Respiration
  - Convection
  - Radiation
  - Conduction
  - Evaporation
- Body thermal balance equation



M=Q comfort

M>Q hot

M<Q cold

Factors Influencing Thermal Comfort

- Human
  - **Metabolic Rate**
  - **Clothing Insulation**
- Space
  - **Air Temperature (Dry-Bulb)**
  - **Relative Humidity**
  - **Air Velocity**
  - **Radiation (Mean Radiant Temperature)**

Environmental indices

- **Operative Temperature**

$$t_g = \frac{h_c t_a + h_r t_r}{h_c + h_r}$$

- **where** t_g = operative temperature
- t_a = ambient air temperature
- t_r = mean radiant temperature
- h_c = convective heat transfer coefficient
- h_r = mean radiative heat transfer coefficient

Environmental indices

- **Mean Radiant Temperature**

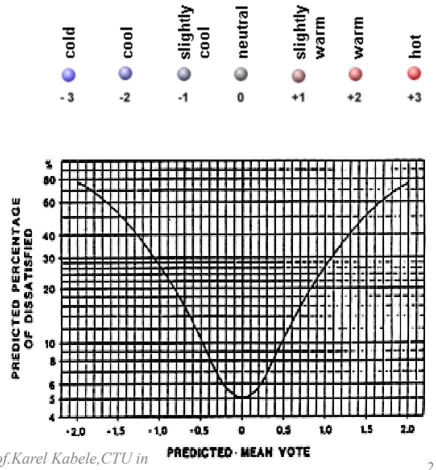
$$t_r = \sqrt[4]{\varphi_{r1}.T_1^4 + \ldots + \varphi_{rn}.T_n^4} - 273$$

- **where**
  - **tr = mean radiant temperature**
  - **Ti = temperature of the surrounding surface i, i=1,2,....,n**
  - **φ_{rn} = shape factor which indicates the fraction of total radiant energy leaving the clothing surface 0 and arriving directly on surface i, i=1,2,...n**

Measuring instruments

Thermal comfort evaluation

- PMV index (Predicted mean vote)
- PPD index (Predicted percentage of dissatisfied)



ENERGY CALCULATIONS

Heat loss calculation

- Preliminary heat loss calculation
  - specific thermal consumption or envelope method
  - Used for preliminary boiler design

$$Qc = V \cdot q_0 \cdot (\bar{t}_i - t_e)$$

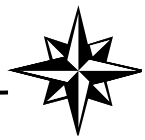
Accurate Heat Loss Calculation

$$Q_c = Q_p + Q_V (-Q_z)$$

$$k_c = \frac{Q_o}{\sum S \cdot (t_i - t_e)}$$

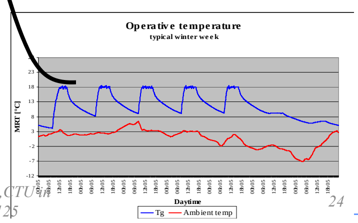
$$p_1 = 0{,}15 \cdot k_c$$

$$Q_p = Q_o \cdot (1 + p_1 + p_2 + p_3)$$



$$Q_o = \sum_{j=1}^{j=n} k_j \cdot S_j \cdot (t_i - t_{e,j})$$

Transmission



Accurate Heat Loss Calculation

$$Q_c = Q_p + Q_V(-Q_z)$$

Ventilation

$$Q_v = V \cdot c \cdot \rho \cdot (t_i - t_e)$$

$$V = \sum (i \cdot l) \cdot B \cdot M$$

Annual heat energy consumption

- Annual heat consumption
  - Degree - day method

$$Q_{heat,a} = \frac{24 \cdot Q_c \cdot \varepsilon \cdot D}{t_i - t_e}$$

$$\varepsilon = \frac{e_i \cdot e_d}{\eta_o \cdot \eta_r}$$

$$D = (\bar{t}_I - \bar{t}_E) \cdot d$$

Minimizing of the energy consumption

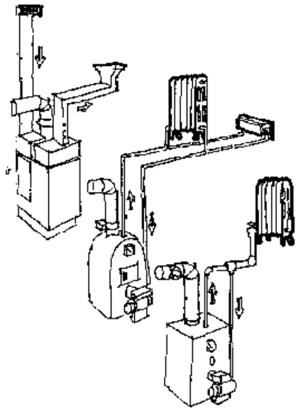
- thermal insulation of the building envelope
- size and quality of the windows
- optimizing the ventilation rate (controlled ventilation?)
- shape of the building

HEAT EMMITERS

Heating equipment

- Heat source - heat transfer medium - heat emitter

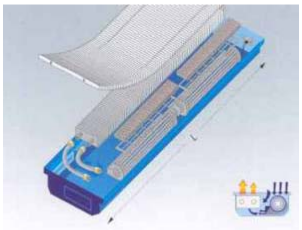
- Classification of the systems
  - local
  - floor
  - central
  - district

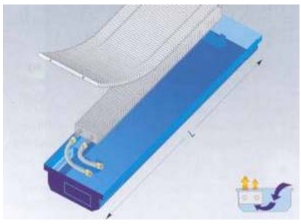


Heat emitters

- Heat emitters
  - Convectors
    - Fan convectors
    - Natural
  - Radiators
    - Banks of Pipes
    - Off peak storage
    - Columns
    - Radiant panels
    - Panels

Convectors

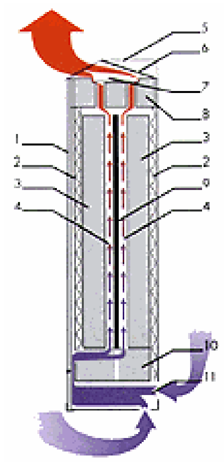




Natural
Fan-convectors
Floor
Wall

Radiators

Off-peak storage



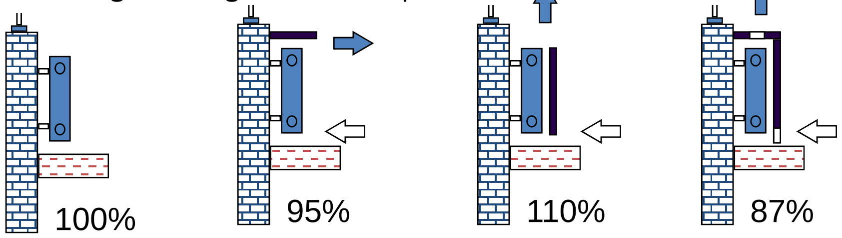
- Static
- Dynamic
- Convector
- Radiator

Heat emitters

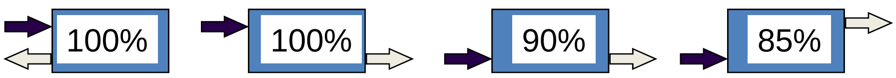
- Design principles
  - Heating output
  - Location
  - Covering - furniture
  - Connection to the pipe system
  - Type

Heater emitters design

- Covering = changes in the output



- Connection to the piping system

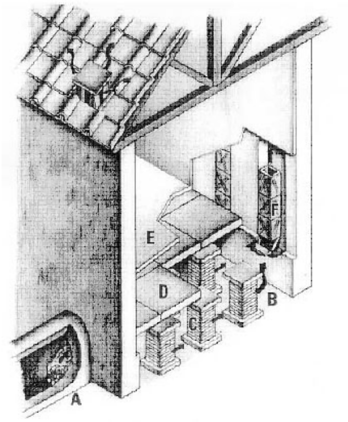


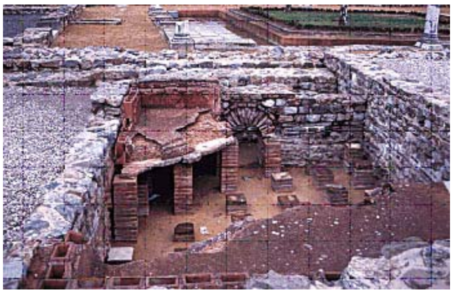
Low - temperature radiant heating

- floor, wall and/or ceiling with embedded pipes or el.wires in concrete slab
  - Temperature distribution

Underfloor heating

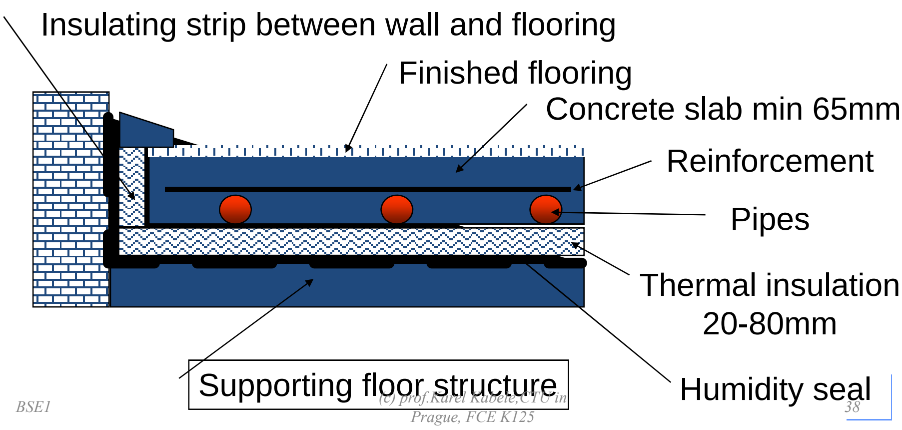
- History



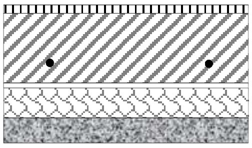


Low - temperature radiant heating

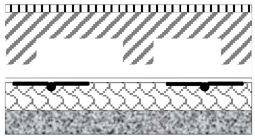
- Floor structure



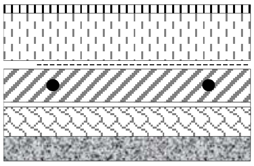
Underfloor heating - structure



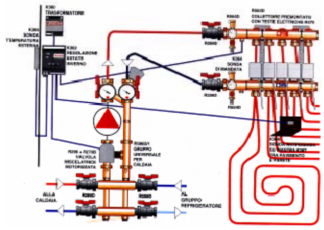
TYP A



TYP B

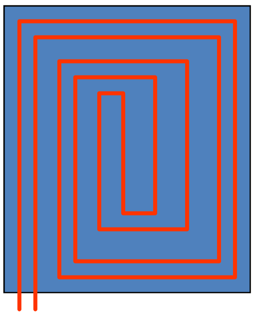


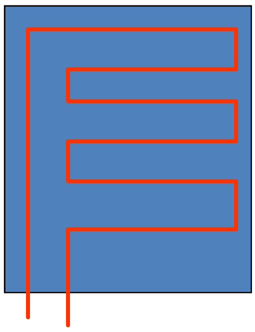
TYP C



Low - temperature radiant heating

- Technical solution
  - Pipe layout





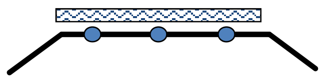
Low - temperature radiant heating

- Output
  - Limited surface temperature   limited output cca 100 $W.m^{-2}$
- Energy savings
  - Lower air temperature   lower heat losses
- Control
  - Low temperature difference   autocontrol effect

Underfloor heating - examples

Radiant panels

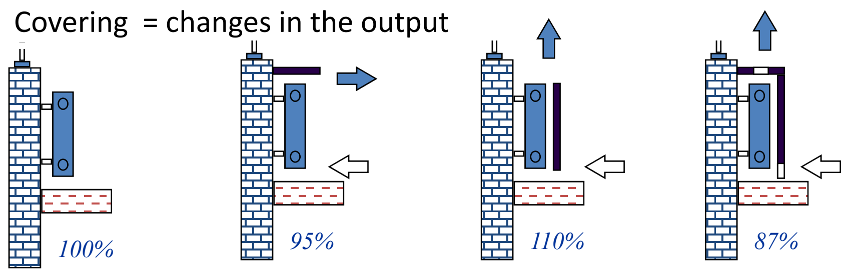
- Low temperature
  - heaters max 110 °C (water, steam, el.power)



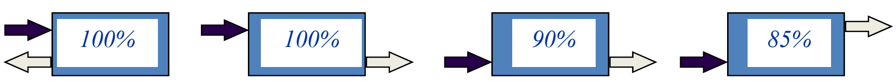
- High temperature
  - dark - about 350°C - radiant tube heating system (gas)
  - light - about 800 °C - flameless surface gas combustion

Heaters design

- Covering = changes in the output



- *Connection to the piping system*



Low - temperature radiant heating

- floor, wall and/or ceiling with embedded pipes or el.wires in concrete slab
  - Temperature distribution

Low - temperature radiant heating

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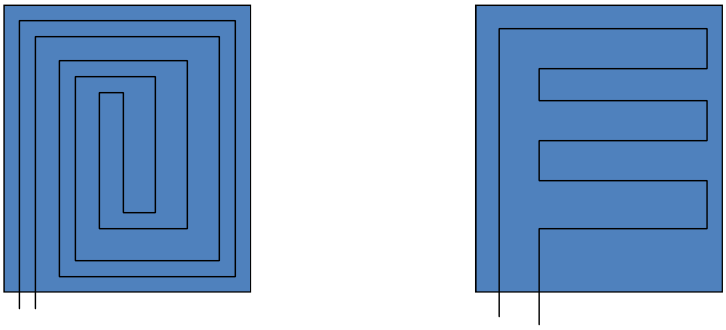
Low - temperature radiant heating

- Technical solution
  - Pipe layout



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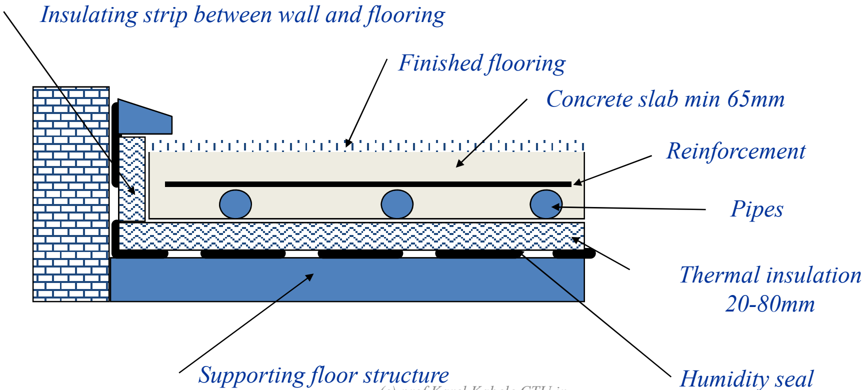
Low - temperature radiant heating

- Floor structure



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Radiant panels

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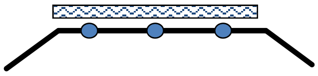

- High temperature
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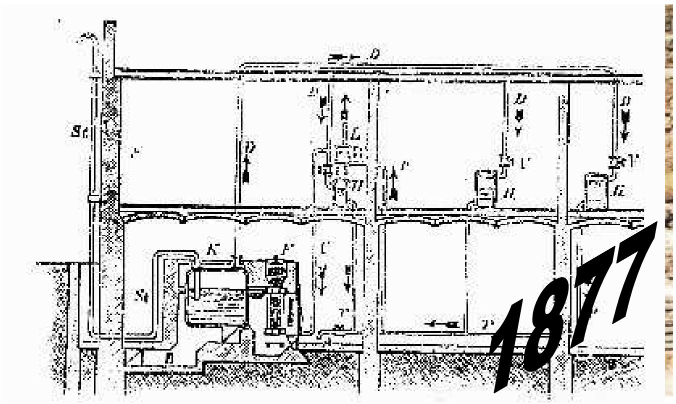
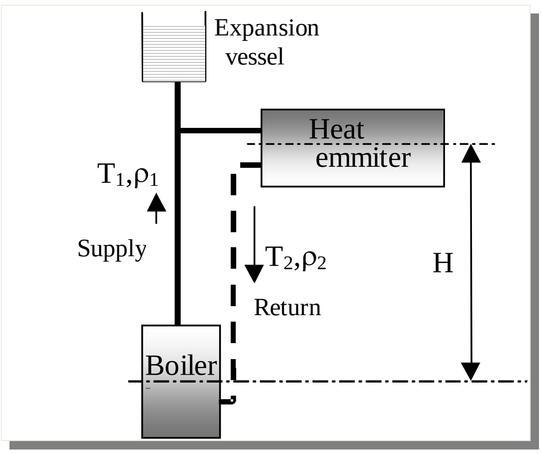
HEATING SYSTEMS

Hot water heating yesterday...



Hot water heating … and today

- Principle
  - Heating system
    - Heat source
    - Distribution network
    - Heat emitter
  - Heat transfer medium
    - water
    - steam
    - air



Heating systems

- Function:
  - transfer of the heat from the source to the heat emitter
- Heat transfer medium
  - water, steam, air

Heating system decision

- Initial information about building
  - Type
    - industrial, office, dwelling
  - Operation
    - continuous, intermittent
    - single, multiple
  - Structure
    - heavy, light
    - new, reconstruction

Heating system design
Optimisation criterions

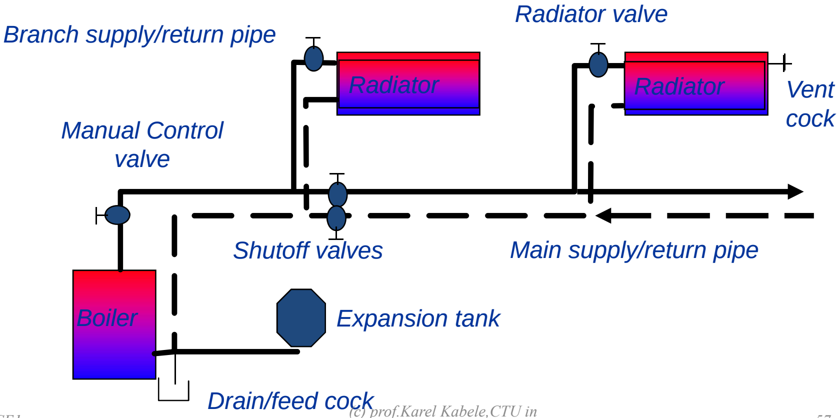
- *Length of the pipes*
- *Location of the heat emmiters*
- *Control of the system*
- *Investment costs*
- *Operational costs*
- *Maintenance*

•Hot-water heating
Technical remarks

- Water quality
- Pipework
  – materials, insulation, placing,deaeration,draining
- Fittings
  – shutoff, control, radiator valves
  – drain / feed cocks, deaerating devices
  – pumps, filters

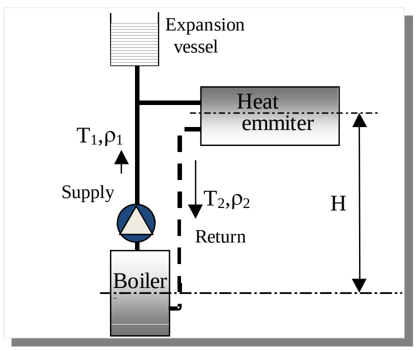
Hot-water heating

- Terminology



Water circulation

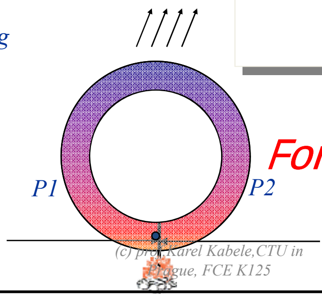
- Natural – without pump



$P1=h.\rho_1.g$

$P2=h.\rho_2.g$

$\Delta P_n=P_2-P_1=h.(\rho_2-\rho_1).g$



Forced – with pump

$\Delta P_F=\Delta P_n+\Delta P_P$

Geometry of the system

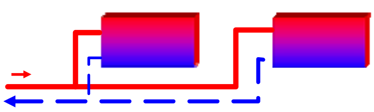
- Relative connection of the heat emitters
  - One-pipe, two-pipe
- Main pipe lay-out
  - Upper, lower, combined
- Branch pipes lay-out
  - vertical, horizontal , microbore

Geometry of the system

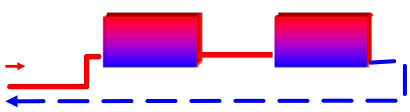
Relative connection of the heat emitters

Relative connection of the heat emitters

- *Two-pipe system*

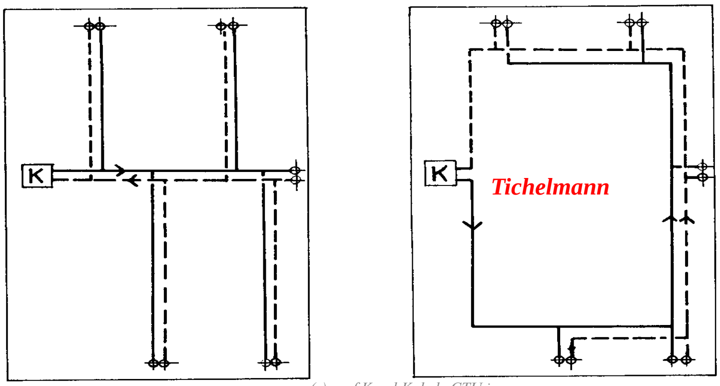


- *One-pipe system*



Two-pipe systems

- Contraflow, parallel flow



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One-pipe systems

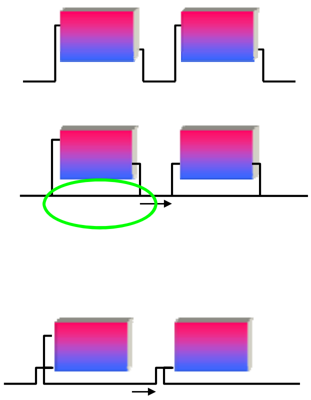
Basic schemes of the connection

•*Serial*

- *With By-Pass*
  - *"Horse Rider"*
  - *Controlled by-pass*

•*With mixing valve*

•*Two-point*
•*One-point*



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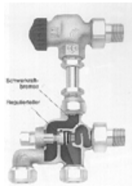
One-pipe systems

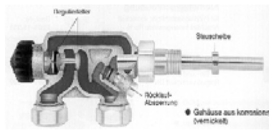
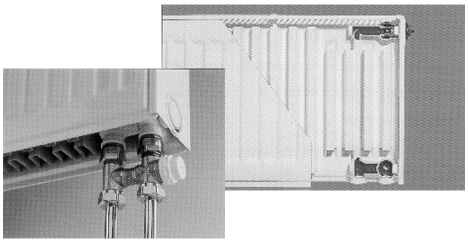
Mixing valves

Two-point valves

One-point valves

Ventil compact

Relative connection of the heat emitters

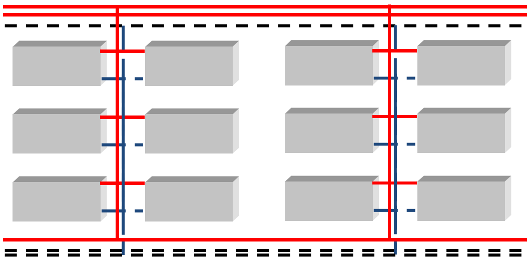
Conclusion

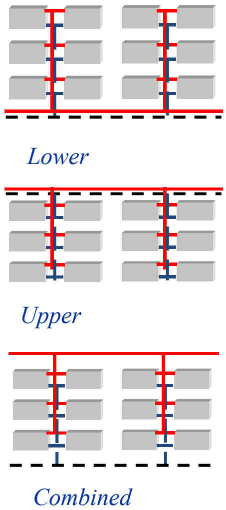
Two-pipe X one-pipe system

- *Length of the pipes*
- *Water circulation*
- *Measuring and control*
- *Pressures in the system*

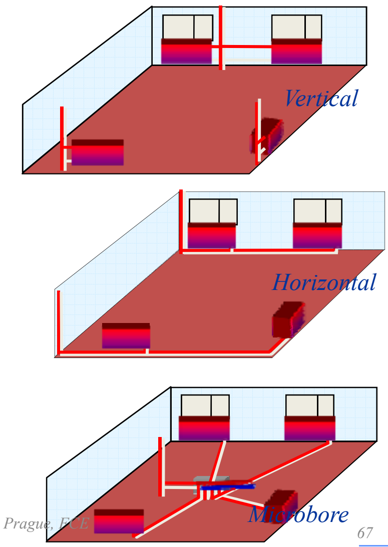
Geometry of the system

Main-pipe layout





Branch pipes lay-out



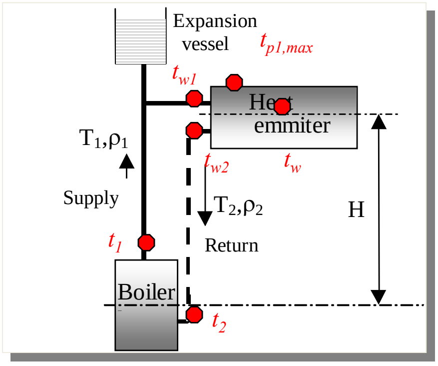
Temperature in the system

- Heat transferred by the system

$$\dot{Q} = M \cdot c \cdot (t_1 - t_2)$$

- Heat transferred by the emitter

$$\dot{Q}_t = h \cdot A \cdot (t_w - t_i)$$



Temperatures
Design Criterions

- *Economical criterions*
- *Physical properties of the medium*
- *Hygiene requirements*
- *Technical properties of the heat source*

Temperature Parameters design

- Heating system supply temperature
  - Low- temperature t_1 <=65°C
  - Medium - temperature 65°C< t_1 <= 115°C
  - High temperature t_1 > 115°C
- Temperature difference
  - 10K - 25K, high temperature 40K - 50K.
  - 90/70 °C, 80/60°C, 75/55°C, 55/45°C

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Temperature Parameters Design

- Emitter
  - Maximal surface temperature (85 - 90°C)

$$t_{Tp\max} = t_{w1} - 2{,}5$$

  - Temperature difference
    - Two-pipe = system temperature difference (15 - 25 K)
    - one-pipe < system temperature difference OS (5 - 10 K)

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Piping materials

– The material should be selected at the beginning of the design process
– Used materials
  - steel
  - copper
  - plastic

Piping materials
Steel

- Traditional material
- Welding

Piping material
Copper

- Lower material usage
- Chemical reaction with water pH min7
- Electrochemical corrosion (Al)
- soldering , torch brazing

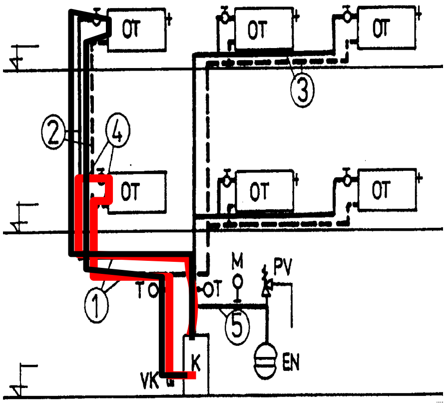
Piping material
Plastic

- Materials
  - *Netted polyethylene (PEX, VPE),*
  - *polybuten (polybutylen, polybuten-1,PB),*
  - *polypropylen (PP-R, PP-RC,PP-3),*
  - *Chlorided PVC (C-PVC, PVC-C)*
  - *Multilayer pipes with metal*
- Life-cycle !!!
- Oxygen barierre ?

HEATING SYSTEM - HYDRAULIC CALCULATION

Calculation

- Temp difference setup
- Transferred output
- Circulation mode
- Hydraulic scheme, sections, circuits
- Water flow rate



Design of the pipe diameter

Natural circulation
– *method given pressure difference*
buoyancy

- Forced circulation
  - method *economical specific pressure loss* 60 - 200 Pa.m^{-1}
  - method *optimal velocity*
    - 0,05 - 1,0 m.s^{-1} (!!! Noise)
  - method *given pressure difference*
    - buoyancy + pump head
    - 10-70 kPa

Pressure loss calculation

- Pressure loss
  - friction
  - Local resistance
- Pressure loss of the circuit compare with the pump head

HEAT SOURCES

Heat sources

- boiler plants
  - combustion process in the boilers
- heat-exchanger plants
  - district heating
- renewable sources
  - utilization of solar, wind, geothermal energy, co-generation, heat pumps

BOILER PLANTS

Boiler plants classification

- Fuel
  - solid, gas, liquid
- Burner
  - atmospheric
  - pressurized
- Operating temperature
  - steam
  - hot water
  - low temperature - condensing boilers

Boiler plants classification

- Output
  - I.category
    - >3500 kW
  - II.category
    - >500 <3500 kW
  - III.category
    - >50 <500 kW

Boiler rooms function

- Air supply
  - combustion
  - ventilation
  - heat gains removal
- Air outlet
  - ventilation
- Waste gases removal
  - atmospheric
  - pressurized
  - “turbo” boilers

Boiler rooms function

- Fuel supply
  - solid, liquid, gas (natural x propane)
- Heat distribution
  - heating
  - hot water generation
  - air-condition heater
  - technology

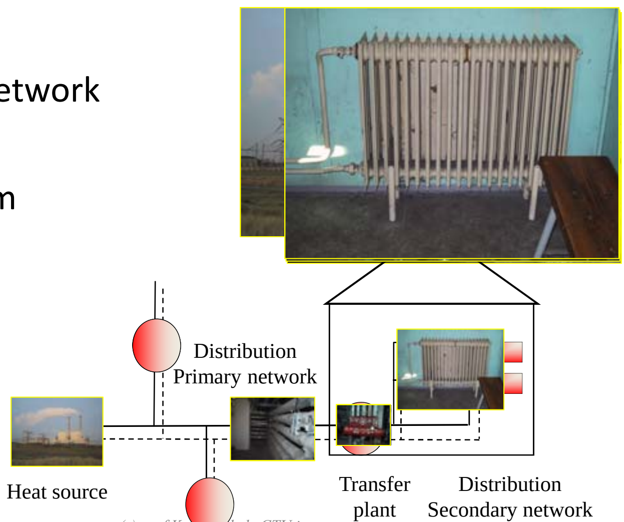
Boiler rooms function

- Safety devices
  - Expansion vessel, pressure relief valves
- Control of the boiler output
  - Electronic control
- Requirements to the building construction
  - Supports of the piping, foundation below heavy elements (hw tanks, boiler)
- Operation

DISTRICT HEATING

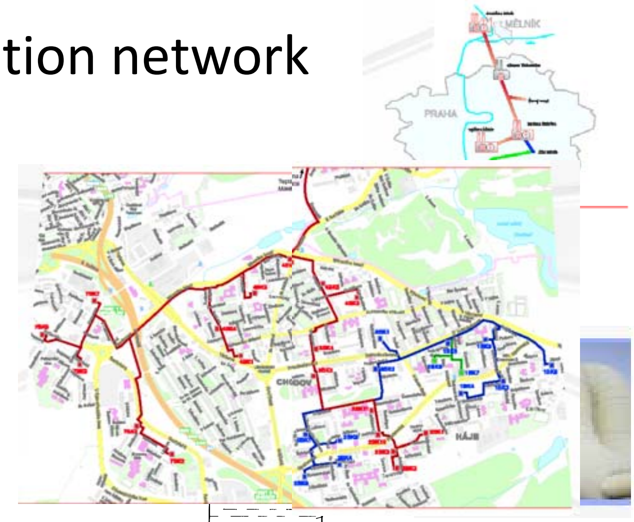
District heating

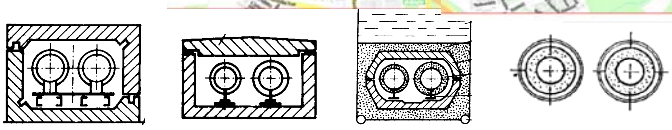
- Heat source
- Distribution network
- Transfer plant
- Heating system



Distribution network

- duct
- ductless
- collector
- surface

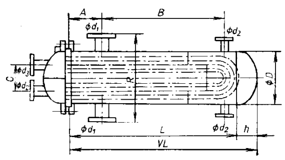


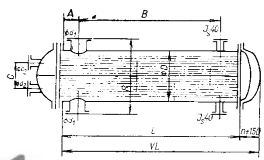


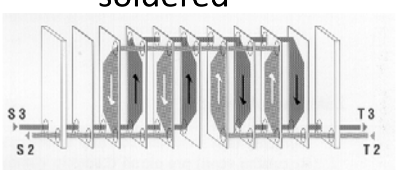
a) b) c) d)

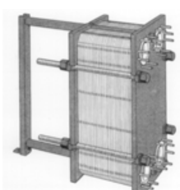
Heat exchangers

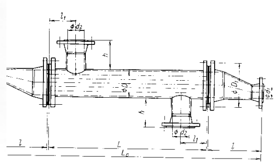
- Tubular
  - U-tubes
  - Kit
- Plate
  - sealed and screwed
  - soldered





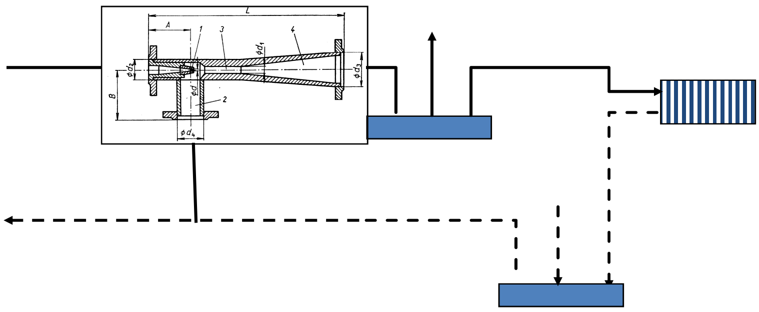






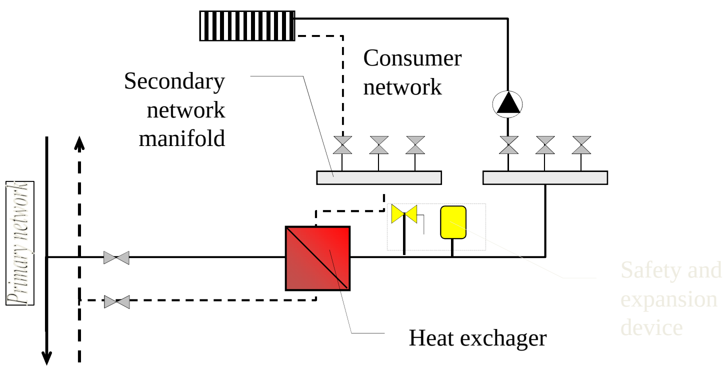
Heat transfer plant

- Pressure dependent, water-water



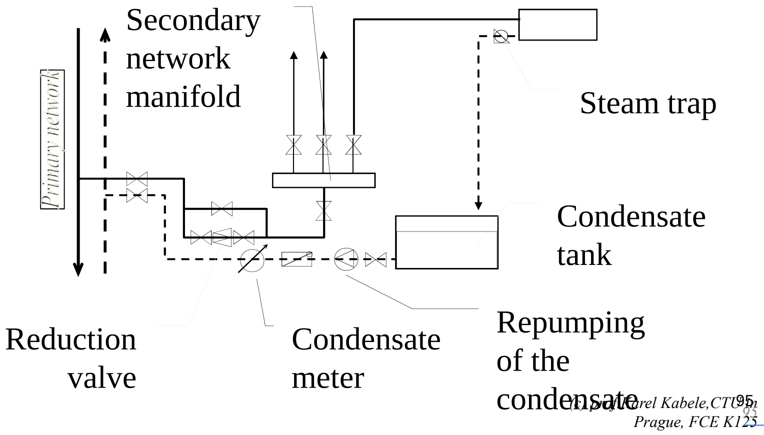
Heat transfer plant

- Pressure independent - water - water

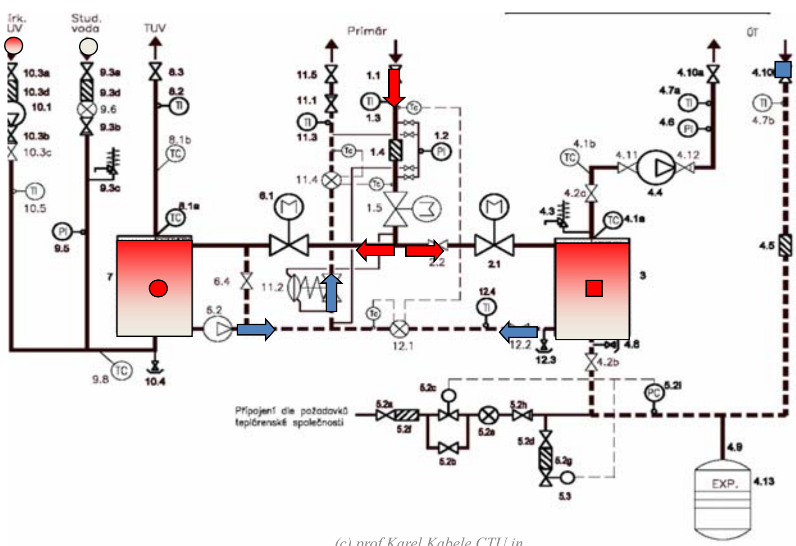


Heat transfer plant

- Pressure dependent - steam - steam



Example of heat transfer plant water-water



Example of transfer plant