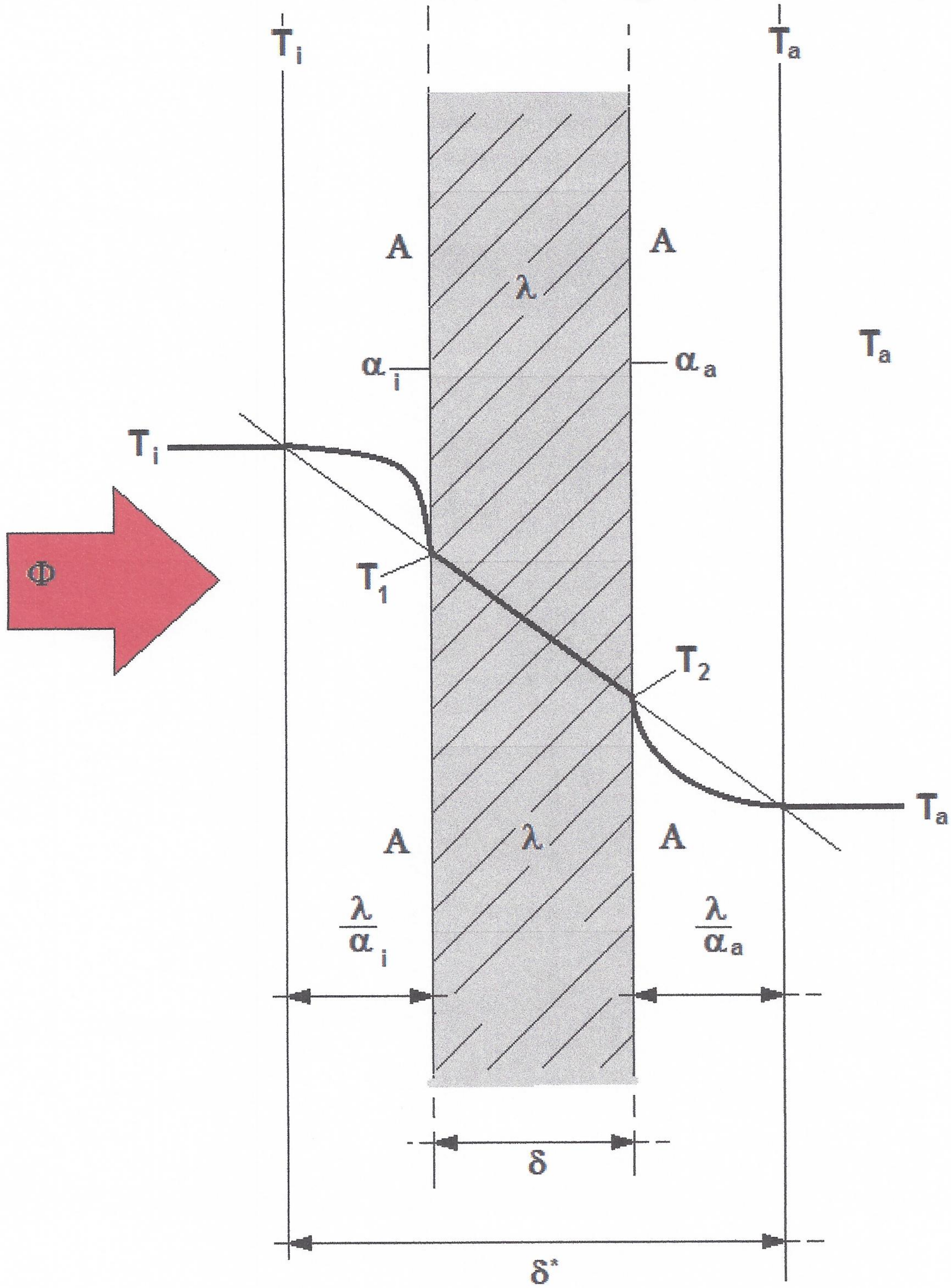
DESIGN OF A SMALL RESIDENTIAL HEATING SYSTEM

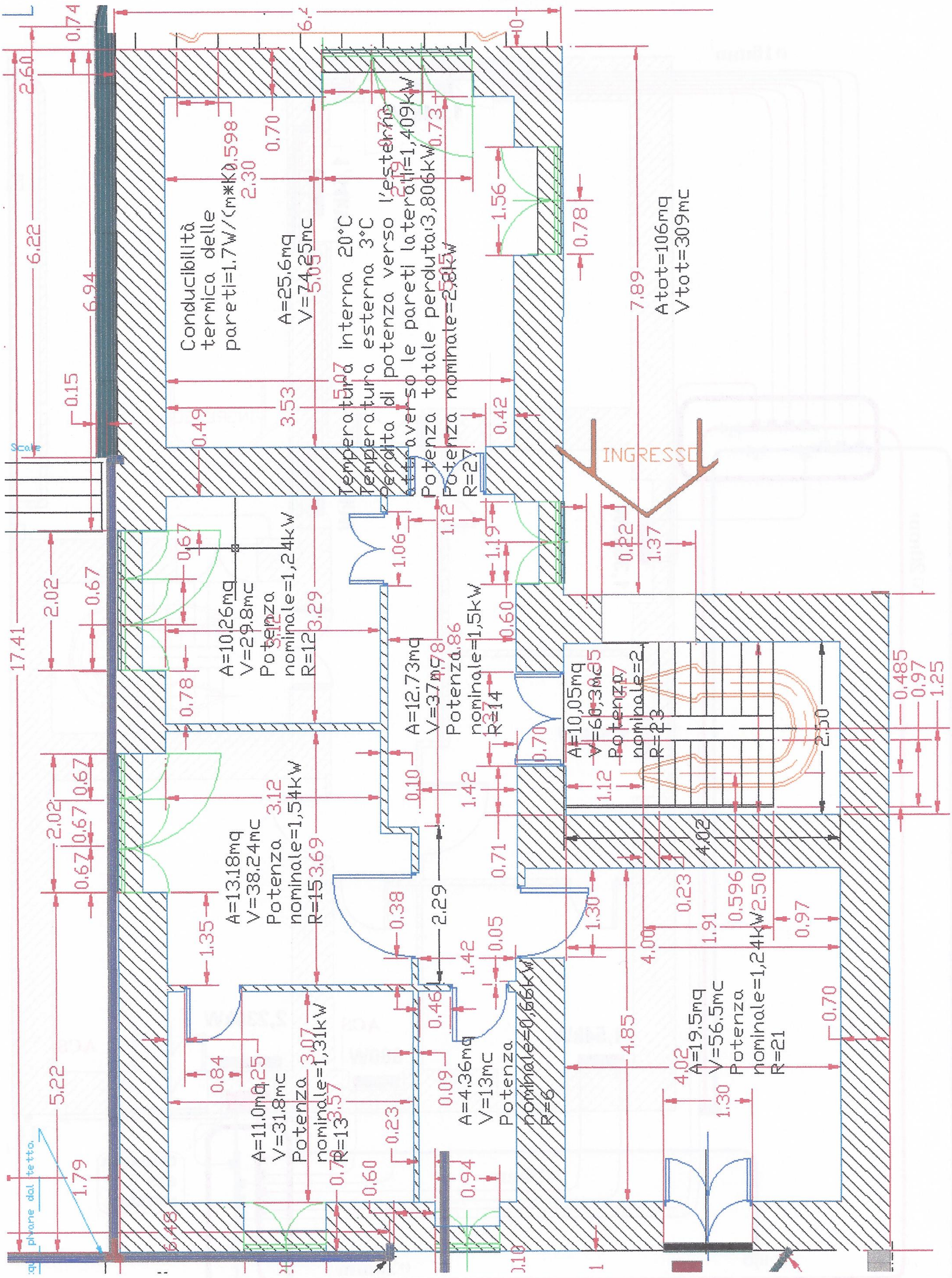
Sizing of the heating system for an apartment.
The following temperature diagram, relative to a cross section of a flat wall of a certain thickness and with a given thermal conductivity, has been used. It concerns the temperature distribution between the external environment (T_a) on the right and the internal one (T_i) on the left side.



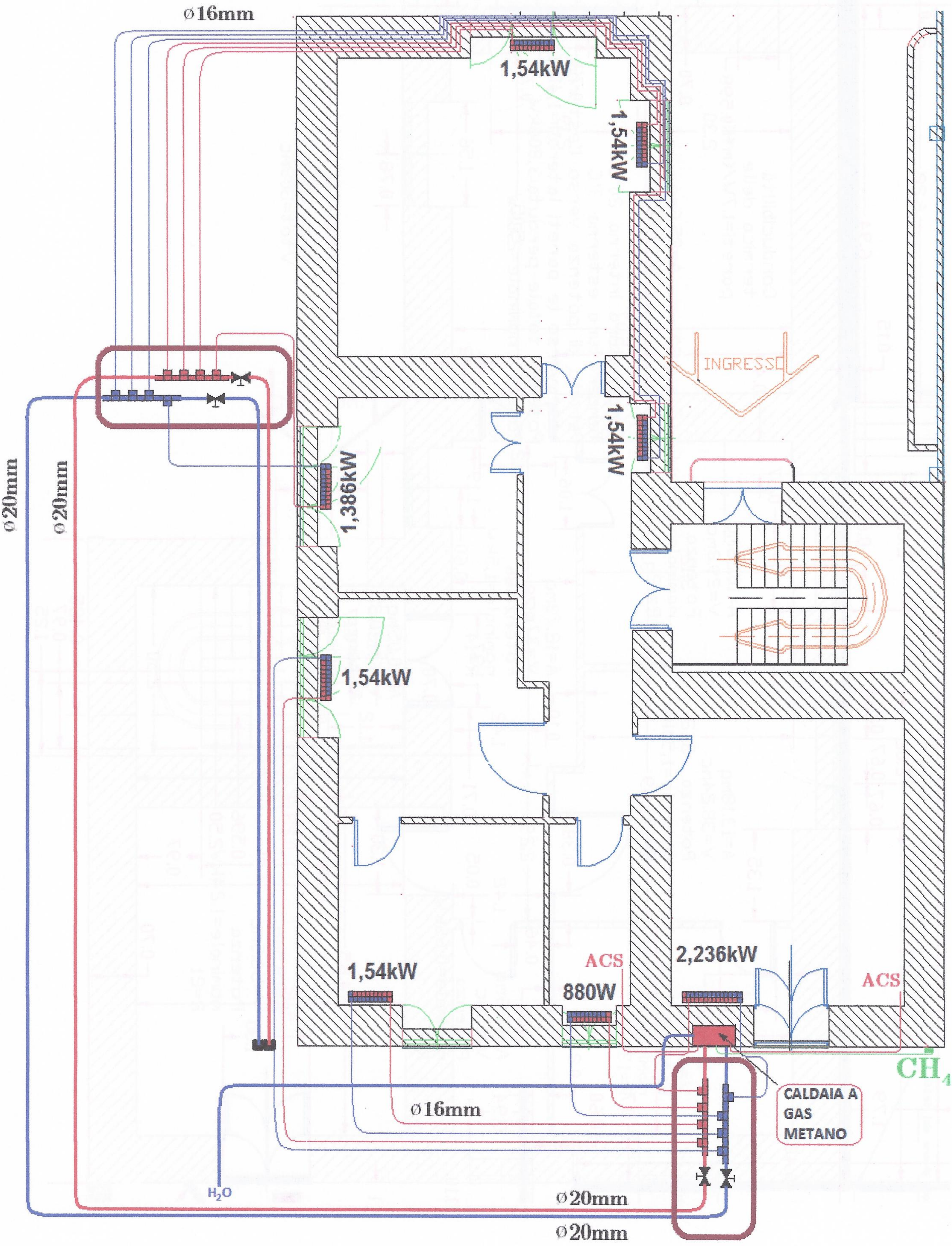
Thermal bridges haven't been taken into account. The thermal bridge is defined as the constructive discontinuity present in any building structure, whether it is built with traditional techniques, either with industrial technologies. For constructive discontinuity, it is intended that part of the structure of a building that has thermal characteristics significantly different from those surrounding. A peculiar characteristic of the thermal bridge is the thermal power dispersed whose size is much higher than that of the neighboring areas.

A thermal bridge, adversely affects on the insulation of a building because it constitutes a privileged escape for the heat exchange to and from the outside.

Plant area:


Conducibilità termica delle pareti=1.7W/(m*K)
Temperatura interna 20°C
Temperatura esterna 3°C
INGRESSO
Atot=106mq
Vtot=309mc
Scale

Water circuit to feed the radiators.



Temperatures:

Rooms Temperatures: $T_i := (20 + 273.15) \cdot K$,

External environment Temperature: $T_a := (0 + 273.15) \cdot K$,

Inner wall Temperature: $T_{pin} := (19 + 273.15) \cdot K$,

External wall Temperature: $T_{extw} := (1 + 273.15) \cdot K$,

Water supply temperature: $T_m := (75 + 273.15) \cdot K$,

Return water temperature: $T_r := (55 + 273.15) \cdot K$

Temperature difference between the average temperature of the water and the environment:

$$\Delta T := \frac{T_m + T_r}{2} - T_a, \qquad \Delta T = 65 K$$

Height of the walls: $h_{par} := 2.9 \cdot m$,

Height of the windows: $h_{fin} := 1.60 \cdot m$

Thickness of the floor: $h_{sol} := 0.25 \cdot m$,

Thickness of the walls: $\delta_p := 0.70 \cdot m$,

Plaster thickness: $\delta_{into} := 0.02 \cdot m$,

Gap thickness: $\delta_{aria} := 0.01 \cdot m$,

internal surface heat transfer coefficient: $\alpha_i := 5.0 \cdot S_T$,

External surface heat transfer coefficient: $\alpha_a := 25.0 \cdot S_T$,

Safety factor: $C_s := 1.20$,

Coefficient of intermittency (24h): $C_i := 0.2$

Emission efficiency: $\eta_e := 0.94$,

Regulation efficiency (on-off): $\eta_c := 0.94$

Distribution yield: $\eta_d := 0.98$

Specific heat at constant pressure: $c_{pw} := 1 \cdot \frac{kcal}{kg \cdot K}$

Calorific value of natural gas: $E_{ch4} := 9503.86 \cdot \frac{kcal}{m^3}$, $E_{ch4} = 11.053 \cdot \frac{kW \cdot hr}{m^3}$

$eu := 1$

Cost of natural gas to Nmc: $C_{ch4} := 0.848 \cdot \frac{eu}{m^3}$,

VAT: $VAT := 0.22$

Times considered for the calculation of costs:

$$month \equiv \frac{1}{12} \cdot yr, \quad t := 24 \cdot hr, \quad t_{yr} := 5 \cdot month$$

$$t_{yr} = 152.184 \cdot day,$$

Days of heat generation: $N_{days} := \frac{t_{yr}}{1 \cdot day}$, $N_{days} = 152.184$,

Outer perimeter:

$P_{estern} := 17.41 \cdot m + 6.49 \cdot m + 7.89 \cdot m + 4.60 \cdot m + 9.45 \cdot m + 6.49 \cdot m + 4.60 \cdot m$, $P_{estern} = 56.93 m$,

Plant Area including the walls of the house:

$$A_{totest} := 17.41 \cdot m \cdot 6.2 \cdot m + (17.41 \cdot m - 7.89 \cdot m) \cdot 4.60 \cdot m \quad A_{totest} = 151.7 m^2$$

Area of external walls:

$$A_{estern} := P_{estern} \cdot (h_{par} + h_{sol}) \ , \ A_{estern} = 179.33 m^2 \ , \ h_{sol} = 0.25 m$$

External volume: $V_{estern} := [7.89 \cdot m \cdot 6.4 \cdot m + (17.41 \cdot m - 6.4 \cdot m) \cdot (6.4 \cdot m + 4.60 \cdot m)] \cdot 3.0 \cdot m$,

$V_{estern} = 514.818 \cdot m^3$

S / V ratio: $\frac{A_{estern} + A_{totest} \cdot 2}{V_{estern}} = 0.938 \frac{1}{m}$,

Perimeters of the individual chambers considering doors:

bedroom: $p_{cl} := (5.07 \cdot m + 5.05 \cdot m) \cdot 2 + 0.58 \cdot m \cdot 2 + 0.58 \cdot m \cdot 2$, $p_{cl} = 22.56 m$,

room 1: $p_{c1} := (3.29 \cdot m + 3.12 \cdot m) \cdot 2 + 0.58 \cdot m \cdot 2$, $p_{c1} = 13.98 m$,

room 2: $p_{c2} := (3.12 \cdot m + 3.69 \cdot m) \cdot 2 + (0.58 \cdot m \cdot 2)$, $p_{c2} = 14.78 m$,

room 3: $p_{c3} := (3.57 \cdot m + 3.07 \cdot m) \cdot 2 + 0.58 \cdot m \cdot 2$, $p_{c3} = 14.44 m$,

Bathroom: $p_{ba} := (3.07 \cdot m + 1.42 \cdot m) \cdot 2 + 0.58 \cdot m \cdot 2$, $p_{ba} = 10.14 m$

kitchen: $p_{kitch} := (4.02 \cdot m + 4.85 \cdot m) \cdot 2 + 0.70 \cdot m \cdot 2$, $p_{kitch} = 19.14 m$,

corridor: $p_{corr} := (2.29 \cdot m + 4.78 \cdot m) \cdot 2 + 0.44 \cdot m + 0.70 \cdot m \cdot 2 + 0.58 \cdot m \cdot 2$, $p_{corr} = 17.14 m$,

Total perimeter: $per_{tot} := p_{cl} + p_{c1} + p_{c2} + p_{c3} + p_{ba} + p_{kitch} + p_{corr}$, $per_{tot} = 112.18 m$.

Areas of the individual rooms considering doors and windows:

Bedroom: $S_{cl} := 5.07 \cdot m \cdot 5.05 \cdot m + 1.56 \cdot m \cdot 0.58 \cdot m + 2.19 \cdot m \cdot 0.58 \cdot m + 1.12 \cdot m \cdot 0.70 \cdot m$,

$S_{cl} = 28.563 m^2$,

room 1: $S_{c1} := 3.29 \cdot m \cdot 3.12 \cdot m + 2.02 \cdot m \cdot (0.58 \cdot m)$, $S_{c1} = 11.436 m^2$,

room 2: $S_{c2} := 3.12 \cdot m \cdot 3.69 \cdot m + 2.02 \cdot m \cdot 0.58 \cdot m$, $S_{c2} = 12.684 m^2$,

room 3: $S_{c3} := 3.57 \cdot m \cdot 3.07 \cdot m + 1.20 \cdot m \cdot 0.58 \cdot m$, $S_{c2} = 12.684 m^2$,

Bathroom: $S_{ba} := (3.07 \cdot m \cdot 1.42 \cdot m) + 0.94 \cdot m \cdot 0.58 \cdot m$, $S_{ba} = 4.905 m^2$

kitchen: $S_{kitch} := 4.02 \cdot m \cdot 4.85 \cdot m + 1.30 \cdot m \cdot 0.70 \cdot m$, $S_{kitch} = 20.407 m^2$,

corridor: $S_{corr} := 2.29 \cdot m \cdot 1.42 \cdot m + 4.78 \cdot m \cdot 1.42 \cdot m + 1.37 \cdot m \cdot 0.70 \cdot m + 1.19 \cdot m \cdot 0.58 \cdot m$,

$S_{corr} = 11.689 m^2$,

Total area: $S_{tot} := S_{cl} + S_{c1} + S_{c2} + S_{c3} + S_{ba} + S_{kitch} + S_{corr}$, $S_{tot} = 101.339 m^2$.

Windows Area:

Bedroom: $Af_{cl} := (2.18 \cdot m + 1.56 \cdot m) \cdot h_{fin}$ $\quad Af_{cl} = 5.984 m^2$

room 1: $Af_{c1} := 2.02 \cdot m \cdot h_{fin}$ $\quad Af_{c1} = 3.232 m^2$

room 2: $Af_{c2} := 2.02 \cdot m \cdot h_{fin}$ $\quad Af_{c2} = 3.232 m^2$

room 3: $Af_{c3} := 2.02 \cdot m \cdot h_{fin}$ $\quad Af_{c3} = 3.232 m^2$,

Bathroom: $Af_{ba} := 0.94 \cdot m \cdot 1 \cdot m$, $\quad Af_{ba} = 0.94 m^2$,

kitchen: -----

corridor: $Af_{corr} := 1.19 \cdot m \cdot h_{fin}$, $\quad Af_{corr} = 1.904 m^2$

Volumes of the rooms considering doors and windows:

Bedroom: $V_{cl} := S_{cl} \cdot h_{par} - 1 \cdot m \cdot 0.70 \cdot m \cdot 1.12 \cdot m$, $\quad V_{cl} = 82.047 \cdot m^3$,

room 1: $V_{c1} := S_{c1} \cdot h_{par}$, $\quad V_{c1} = 33.166 \cdot m^3$,

room 2: $V_{c2} := S_{c2} \cdot h_{par}$, $\quad V_{c2} = 36.785 \cdot m^3$,

room 3: $V_{c3} := S_{c3} \cdot h_{par}$, $\quad V_{c3} = 33.802 \cdot m^3$,

Bathroom: $V_{ba} := S_{ba} \cdot h_{par}$, $\quad V_{ba} = 14.223 \cdot m^3$

kitchen: $V_{kitch} := S_{kitch} \cdot h_{par} - 1 \cdot m \cdot 0.70 \cdot m \cdot 1.30 \cdot m$, $\quad V_{kitch} = 58.27 \cdot m^3$,

corridor: $V_{corr} := S_{corr} \cdot h_{par} - 1.37 \cdot m \cdot 0.70 \cdot m \cdot 1 \cdot m$, $\quad V_{corr} = 32.938 \cdot m^3$,

Total Volum: $V_{tot} := V_{cl} + V_{c1} + V_{c2} + V_{c3} + V_{ba} + V_{kitch} + V_{corr}$, $\quad V_{tot} = 291.231 \cdot m^3$.

$V_{estern} - V_{tot} = 223.587 \cdot m^3$

Areas of the interior walls of individual rooms, considering windows and doors:

Bedroom: $Ap_{cl} := p_{cl} \cdot h_{par}$, $\quad Ap_{cl} = 65.424 \cdot m^2$,

room 1: $Ap_{c1} := p_{c1} \cdot h_{par}$, $\quad Ap_{c1} = 40.542 \cdot m^2$,

room 2: $Ap_{c2} := p_{c2} \cdot h_{par}$, $\quad Ap_{c2} = 42.862 \cdot m^2$,

room 3: $Ap_{c3} := p_{c3} \cdot h_{par}$, $\quad Ap_{c3} = 41.876 \cdot m^2$,

Bathroom: $Ap_{ba} := p_{ba} \cdot h_{par}$, $\quad Ap_{ba} = 29.406 \cdot m^2$

kitchen: $Ap_{kitch} := p_{kitch} \cdot h_{par}$, $\quad Ap_{kitch} = 55.506 \cdot m^2$,

corridor: $Ap_{corr} := p_{corr} \cdot h_{par}$, $\quad Ap_{corr} = 49.706 \cdot m^2$,

Total area of the interior walls:

$$Ap_{tot} := Ap_{cl} + Ap_{c1} + Ap_{c2} + Ap_{c3} + Ap_{ba} + Ap_{kitch} + Ap_{corr}, \quad Ap_{tot} = 325.322 \cdot m^2 \ .$$

Thermal conductance units: $S_T \equiv \frac{W}{m^2 \cdot K}, \quad \frac{K}{\Omega_T} \cdot m = 1 \frac{1}{m} \cdot W$

Thermal resistance units: $\Omega_T \equiv \frac{K \cdot m^2}{W}, \quad k\Omega_T \equiv 10^3 \cdot \Omega_T$

Thermal conductivity of the walls and the inner and outer layer of plaster:

at 25°C $\lambda_{tufo} := 1.7 \cdot \frac{W}{m \cdot K}, \quad \lambda_{tufo} = 1.7 \cdot \frac{W}{m \cdot K}, \quad \lambda_{into} := 0.8 \cdot \frac{W}{m \cdot K}, \quad \lambda_{aria} := 0.026 \cdot \frac{W}{m \cdot K}$

Heat demand per cubic meter: $P_{fabb} := 35 \cdot \frac{W}{m^3}$.

Annual energy requirements: $P_{fabbyr} := 50 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}$

Room's Requirements:

Bedroom: $F_{cl} := V_{cl} \cdot P_{fabb}, \quad F_{cl} = 2.872 \cdot kW, \quad F_{cly} := S_{cl} \cdot P_{fabbyr}, \quad F_{cly} = 162.92 W$

room 1: $F_{c1} := V_{c1} \cdot P_{fabb}, \quad F_{c1} = 1.161 \cdot kW, \quad F_{c1y} := S_{c1} \cdot P_{fabbyr}, \quad F_{c1y} = 65.233 W$

room 2: $F_{c2} := V_{c2} \cdot P_{fabb}, \quad F_{c2} = 1.287 \cdot kW, \quad F_{c2y} := S_{c2} \cdot P_{fabbyr}, \quad F_{c2y} = 72.352 W$

room 3: $F_{c3} := V_{c3} \cdot P_{fabb}, \quad F_{c3} = 1.183 \cdot kW, \quad F_{c3y} := S_{c3} \cdot P_{fabbyr}, \quad F_{c3} = 1.183 \cdot kW$

Bathroom: $F_{ba} := V_{ba} \cdot P_{fabb}, \quad F_{ba} = 497.817 \cdot W, \quad F_{bay} := S_{ba} \cdot P_{fabbyr}, \quad F_{bay} = 27.976 W$

kitchen: $F_{kitch} := V_{kitch} \cdot P_{fabb}, \quad F_{kitch} = 2.039 \cdot kW, \quad F_{kitchy} := S_{kitch} \cdot P_{fabbyr}, \quad F_{kitch} = 2.039 \cdot kW$

corridor: $F_{corr} := V_{corr} \cdot P_{fabb}, \quad F_{corr} = 1.153 \cdot kW, \quad F_{corry} := S_{corr} \cdot P_{fabbyr}, \quad F_{corry} = 66.672 W$

Total Requirements: $F_{tot} := F_{cl} + F_{c1} + F_{c2} + F_{c3} + F_{ba} + F_{kitch} + F_{corr}, \quad F_{tot} = 10.193 \cdot kW$.

$$\frac{F_{tot}}{V_{tot}} = 306.803 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

$S_{tot} \cdot P_{fabbyr} = 0.578 \cdot kW, \quad P_{ch4} := 9.54 \cdot \frac{kW}{m^3}, \quad \frac{P_{fabbyr}}{P_{ch4}} = 0.0006 m, \quad P_{fabbyr} = 5.704 \cdot \frac{W}{m^2},$

Total energy demand: $F_{toty} := F_{cly} + F_{c1y} + F_{c2y} + F_{c3y} + F_{bay} + F_{kitchy} + F_{corry},$

$$F_{toty} = 5.067 \cdot \frac{MW \cdot hr}{yr} \ .$$

$$\frac{F_{toty}}{V_{tot}} = 17.398 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

$$A_{totest} \cdot P_{fabbyr} = 0.865 \cdot kW, \quad P_{ch4} = 9.54 \cdot \frac{kW}{m^3},$$

$$\frac{P_{fabbyr}}{P_{ch4}} = 0.5979 \cdot mm, \quad P_{fabbyr} = 5.704 \cdot \frac{W}{m^2},$$

Consider the heat flow always orthogonal to the layers and identical in every layer.

$$\lambda_1 := \lambda_{into}, \quad \lambda_2 := \lambda_{tufo}, \quad \lambda_3 := \lambda_{into}$$

In general $P = \frac{\lambda_1}{\delta_1} \cdot (T_1 - T_2) = \frac{\lambda_2}{\delta_2} \cdot (T_2 - T_3) = \frac{\lambda_3}{\delta_3} \cdot (T_3 - T_4) = \frac{\lambda_m}{\delta_m} \cdot (T_4 - T_m),$

in our case:

$$P = \frac{\lambda_{int}}{\delta_{int}} \cdot (T_1 - T_2) = \frac{\lambda_{tuf}}{\delta_{tuf}} \cdot (T_2 - T_3) = \frac{\lambda_{int}}{\delta_{int}} \cdot (T_3 - T_a),$$

$$\delta s_t := \delta_{into} + \delta_p + \delta_{into}$$

$$P = \frac{\lambda_t}{\delta_t} \cdot (T_1 - T_a),$$

$$\frac{\lambda_1}{\delta_1} \cdot (T_1 - T_2) = P, \quad \frac{\lambda_2}{\delta_2} \cdot (T_2 - T_3) = P, \quad \frac{\lambda_3}{\delta_3} \cdot (T_3 - T_4) = P,$$

$$T_1 - T_2 = \frac{\delta_1}{\lambda_1} \cdot P, \quad T_2 = T_1 - \frac{\delta_1}{\lambda_1} \cdot P,$$

$$T_2 - T_3 = \frac{\delta_2}{\lambda_2} \cdot P, \quad T_1 - \frac{\delta_1}{\lambda_1} \cdot P - T_3 = \frac{\delta_2}{\lambda_2} \cdot P,$$

$$T_1 - T_3 = \frac{\delta_2}{\lambda_2} \cdot P + \frac{\delta_1}{\lambda_1} \cdot P, \quad T_3 = T_1 - \left(\frac{\delta_2}{\lambda_2} \cdot P + \frac{\delta_1}{\lambda_1} \cdot P\right),$$

$$T_3 - T_4 = \frac{\delta_3}{\lambda_3} \cdot P,$$

$$T_1 - \left(\frac{\delta_2}{\lambda_2} \cdot P + \frac{\delta_1}{\lambda_1} \cdot P\right) - T_4 = \frac{\delta_3}{\lambda_3} \cdot P, \quad T_1 - T_4 = \left(\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}\right) \cdot P,$$

$$P = \frac{\lambda_t}{\delta_t} \cdot (T_1 - T_4) = \frac{(T_1 - T_4)}{\left(\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}\right)},$$

$$\lambda_t = \frac{\sum_{j=1}^{m} \delta_j}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}} = \frac{\delta_t}{\sum_{j=1}^{3} \frac{d_j}{\lambda_j}},$$

$$R_T = \frac{\delta_t}{\lambda_t} = \sum_{j=1}^{3} \frac{\delta_j}{\lambda_j}$$

$$P := \frac{T_i - T_a}{\frac{1}{\alpha_i} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_p}{\lambda_{tufo}} + \frac{\delta_{into}}{\lambda_{into}} + \frac{1}{\alpha_a}}, \quad P = 28.5 \frac{1}{m^2} \cdot W$$

Thermal Resistance: $R_T := \left(\frac{1}{\alpha_i} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_p}{\lambda_{tufo}} + \frac{\delta_{into}}{\lambda_{into}} + \frac{1}{\alpha_a}\right)$, $R_T = 0.702 \cdot \Omega_T$, $S_T = 1 \cdot \frac{W}{m^2 \cdot K}$

Transmittance: $U := \frac{1}{R_T}$, $U = 1.425 \cdot S_T$, $U = 1.425 \cdot \frac{W}{m^2 \cdot K}$

Power dissipated by the walls of the rooms at 25 °C without insulation:

Bedroom:	$P_{Dletto} := P \cdot (Ap_{cl} + S_{cl} \cdot 2)$,	$P_{Dletto} = 3.493 \cdot kW$,
room 1:	$P_{Dc1} := P \cdot (S_{c1} \cdot 2 + Ap_{c1})$,	$P_{Dc1} = 1.807 \cdot kW$,
room 2:	$P_{Dc2} := P \cdot (S_{c2} \cdot 2 + Ap_{c2})$,	$P_{Dc2} = 1.945 \cdot kW$,
room 3:	$P_{Dc3} := P \cdot (S_{c3} \cdot 2 + Ap_{c3})$,	$P_{Dc3} = 1.858 \cdot kW$,
Bathroom :	$P_{DBath} := P \cdot (S_{ba} \cdot 2 + Ap_{ba})$,	$P_{DBath} = 1.118 \cdot kW$,
kitchen:	$P_{Dkitch} := P \cdot (S_{kitch} \cdot 2 + Ap_{kitch})$,	$P_{Dkitch} = 2.745 \cdot kW$,
corridor:	$P_{Dcorr} := P \cdot (S_{corr} \cdot 2 + Ap_{corr})$,	$P_{Dcorr} = 2.083 \cdot kW$.

Total power scattered by the walls (not insulated):

$$P_{Dt} := P_{Dletto} + P_{Dc1} + P_{Dc2} + P_{Dc3} + P_{DBath} + P_{Dkitch} + P_{Dcorr}$$

$$P_{Dt} = 15.048 \cdot kW.$$

The power to be supplied by the source is given by the sum of the energy requirements and losses: $P_{tot} := F_{tot} + P_{Dt}$,

$$P_{tot} = 25.241 \cdot kW. \quad \frac{P_{tot}}{Ap_{tot} + 2 \cdot S_{tot}} = 419.047 \cdot \frac{kW \cdot hr}{m^2 \cdot yr},$$

$$\frac{P_{tot}}{Ap_{tot} + 2 \cdot A_{totest}} = 351.877 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}.$$

Power to be supplied to individual rooms (not insulated):

Bedroom: $P_{letto} := P_{Dletto} + F_{cl}$, $P_{letto} = 6.364 \cdot kW$,

$$\frac{P_{letto}}{Ap_{cl} + 2 \cdot S_{cl}} = 455.229 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}, \frac{P_{letto}}{V_{cl}} = 679.947 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

room 1: $P_{c1} := P_{Dc1} + F_{c1}$, $P_{c1} = 2.968 \cdot kW$,

$$\frac{P_{c1}}{Ap_{c1} + 2 \cdot S_{c1}} = 410.278 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}, \frac{P_{c1}}{V_{c1}} = 784.48 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

room 2: $P_{c2} := P_{Dc2} + F_{c2}$, $P_{c2} = 3.232 \cdot kW$,

$$\frac{P_{c2}}{Ap_{c2} + 2 \cdot S_{c2}} = 415.227 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}, \frac{P_{c2}}{V_{c2}} = 770.19 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

room 3: $P_{c3} := P_{Dc3} + F_{c3}$, $P_{c3} = 3.041 \cdot kW$,

$$\frac{P_{c3}}{Ap_{c3} + 2 \cdot S_{c3}} = 408.91 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}, \frac{P_{c3}}{V_{c3}} = 788.588 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

Bathroom : $P_{Bath} := P_{DBath} + F_{ba}$, $P_{Bath} = 1.615 \cdot kW$,

$$\frac{P_{Bath}}{Ap_{ba} + 2 \cdot S_{ba}} = 361.099 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}, \frac{P_{Bath}}{V_{ba}} = 995.588 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

kitchen: $P_{kitch} := P_{Dkitch} + F_{kitch}$, $P_{kitch} = 4.785 \cdot kW$,

$$\frac{P_{kitch}}{Ap_{kitch} + 2 \cdot S_{kitch}} = 435.428 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}, \frac{P_{kitch}}{V_{kitch}} = 719.756 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

corridor: $P_{corr} := P_{Dcorr} + F_{corr}$, $P_{corr} = 3.236 \cdot kW$,

$$\frac{P_{corr}}{Ap_{corr} + 2 \cdot S_{corr}} = 388.096 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}, \frac{P_{corr}}{V_{corr}} = 861.112 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}.$$

Limit values of energy performance for winter heating climate zone C (South Italy) (with $S / V = 0.91 m^{-1}$) = 15.6

Average density of energy per year:

$$\frac{1}{7}\cdot\left(\frac{P_{letto}}{Ap_{cl}+2\cdot S_{cl}}+\frac{P_{c1}}{Ap_{c1}+2\cdot S_{c1}}+\frac{P_{c2}}{Ap_{c2}+2\cdot S_{c2}}+\frac{P_{c3}}{Ap_{c3}+2\cdot S_{c3}}\ldots+\frac{P_{Bath}}{Ap_{ba}+2\cdot S_{ba}}+\frac{P_{kitch}}{Ap_{kitch}+2\cdot S_{kitch}}+\frac{P_{corr}}{Ap_{corr}+2\cdot S_{corr}}\right)=410.609\cdot\frac{kW\cdot hr}{m^2\cdot yr},$$

$$\frac{1}{7}\cdot\left(\frac{P_{letto}}{V_{cl}}+\frac{P_{c1}}{V_{c1}}+\frac{P_{c2}}{V_{c2}}+\frac{P_{c3}}{V_{c3}}\ldots+\frac{P_{Bath}}{V_{ba}}+\frac{P_{kitch}}{V_{kitch}}+\frac{P_{corr}}{V_{corr}}\right)=799.952\cdot\frac{kW\cdot hr}{m^3\cdot yr}.$$

$$P_{letto}+P_{c1}+P_{c2}+P_{c3}+P_{Bath}+P_{kitch}+P_{corr}=25.241\cdot kW,$$

$$P_{letto}+P_{Bath}+P_{kitch}+P_{corr}=16\cdot kW,$$

Necessary volume of gas at a time $t=24\cdot hr$, $E_{ch4}=11.053\cdot\frac{kW\cdot hr}{m^3}$, $t\cdot\frac{P_{tot}}{E_{ch4}}=54.807\cdot m^3$,

$t_{yr}=0.417\cdot yr$ **for five months:** $t\cdot N_{days}\cdot\frac{P_{tot}}{E_{ch4}}\cdot(1+VAT)=10175.735\cdot m^3$,

$t_{yr}=0.417\cdot yr$ **Cost per semester with** $VAT=22\cdot\%$ **and considering the coefficient of intermittency** C_i**:** $C_i\cdot C_{ch4}\cdot\left(t\cdot N_{days}\cdot\frac{P_{tot}}{E_{ch4}}\right)\cdot(1+VAT)=1725.805\cdot eu$

monthly cost with $VAT=22\cdot\%$ **and considering the coefficient of intermittency** C_i**:**

$$C_i\cdot C_{ch4}\cdot\left(t\cdot N_{days}\cdot\frac{P_{tot}}{E_{ch4}}\right)\cdot\frac{1+VAT}{5}=345.161$$

Insulated chambers:

Choice of the Insulator:

Solid brick: $\lambda_{matt} := 0.472 \frac{W}{m \cdot K}$,

malta: $\lambda_{malta} := 0.93 \cdot \frac{W}{m \cdot K}$,

Extruded brick face view: $\lambda_{latfv} := 0.285 \cdot \frac{W}{m \cdot K}$,

Lime plaster and cement: $\lambda_{intocc} := 0.930 \cdot \frac{W}{m \cdot K}$,

Lime and gypsum plaster: $\lambda_{intocg} := 0.015 \cdot \frac{W}{m \cdot K}$,

Rockwool dp4: $\lambda_{rocc} := 0.037 \cdot \frac{W}{m \cdot K}$, $\delta_{rocc} := 0.40 \cdot m$, **Dim.:1mX0.60m**

$Cq := 2.45 \cdot eu$

Rockwool dp4: $\lambda_{rocc50} := 0.037 \cdot \frac{W}{m \cdot K}$, $\delta_{rocc50} := 0.50 \cdot m$, **Dim.:1mX0.60m**

$Cqrck4 := 3.20 \cdot eu$

Rockwool dp10: $\lambda_{rocc10} := 0.035 \cdot \frac{W}{m \cdot K}$, $\delta_{rocc10} := 0.20 \cdot m$, **Dim.:1mX0.60m**

$Cqrck1 := 2.90 \cdot eu$

Oak wood: $\lambda_{quer} := 0.05 \cdot \frac{W}{m \cdot K}$, $coib_1 := \lambda_{quer}$, **Dim: 1.20mX0.50m,**

$Cq1 := 0.90 \cdot \frac{eu}{m^2}$, $\delta_{quer} := 1 \cdot cm$

sheets of cork: $\lambda_{sugh} := 0.037 \cdot \frac{W}{m \cdot K}$, $coib_2 := \lambda_{sugh}$ **Dim: 1.20mX0.50m,**

$Cq2 := 5.90 \cdot \frac{eu}{m^2}$, $\delta_{sugh} := 1 \cdot cm$

plasterboard: $\lambda_{crtgs} := 0.024 \cdot \frac{W}{m \cdot K}$, $coib_3 := \lambda_{crtgs}$, **Dim: 1.20mX3.0m,**

$A_{crtgs} := 1.2 \cdot m \cdot 3.0 \cdot m$ $\quad Cq3 := 0.90 \cdot \frac{eu}{m^2} \cdot 1.20 \cdot 3.0 \cdot m^2$, $\delta_{crtgs} := 1 \cdot cm$

polystyrene: $\lambda_{polistiro} := 0.05 \cdot \frac{W}{m \cdot K}$, $coib_4 := \lambda_{polistiro}$, **Dim: 1.20mX0.50m,**

$Cq4 := 0.90 \cdot \frac{eu}{m^2}$, $\delta_{polistiro} := 1 \cdot cm$

polystyrene dibipor 70: $\lambda_{dibi70} := 0.0039 \cdot \frac{W}{m \cdot K}$, $coib_5 := \lambda_{dibi70}$, **Dim: 1.20mX0.50m,**

$Cq5 := \mathbf{0.90} \cdot \frac{eu}{m^2}$, $\delta_{dibi1} := \mathbf{1} \cdot cm$

polistirene dibipor 70: $\lambda_{dibi70} := \mathbf{0.0039} \cdot \frac{W}{m \cdot K}$, $coib_6 := \lambda_{dibi70}$ **Dim: 1.20mX0.50m,**

$Cq6 := \mathbf{1.25} \cdot \frac{eu}{m^2}$, $\delta_{dibi2} := \mathbf{2} \cdot cm$

polystyrene dibor 100: $\lambda_{dibor100} := \mathbf{0.0035} \cdot \frac{W}{m \cdot K}$, $coib_7 := \lambda_{dibor100}$ **Dim: 1.00mX0.50m,**

$Cqdibor := \mathbf{2.0} \cdot \frac{eu}{m^2}$, $\delta_{dibor} := \mathbf{3} \cdot cm$

PU: $\lambda_{twin30} := \mathbf{0.023} \cdot \frac{W}{m \cdot K}$, $coib_8 := \lambda_{twin30}$, **Dim: 1.20mX1.20m,**

$Cq8 := \mathbf{14} \cdot \frac{eu}{m^2}$, $\delta_{twin30} := \mathbf{3} \cdot cm$

PU: $\lambda_{twin40} := \mathbf{0.023} \cdot \frac{W}{m \cdot K}$, $coib_9 := \lambda_{twin40}$, **Dim: 1.20mX1.20m,**

$Cq9 := \mathbf{19.20} \cdot eu$, $\delta_{twin40} := \mathbf{4} \cdot cm$

P.I.R.: $\lambda_{pir4} := \mathbf{0.028} \cdot \frac{W}{m \cdot K}$, $coib_{10} := \lambda_{pir4}$, **Dim: 1.20mX0.60m,**

$Cq10 := \mathbf{0} \cdot \frac{eu}{m^2}$, $\delta_{pir4} := \mathbf{4} \cdot cm$

P.I.R.: $\lambda_{pir5} := \mathbf{0.028} \cdot \frac{W}{m \cdot K}$, $coib_{11} := \lambda_{pir5}$, **Dim: 1.20mX0.60m,**

$Cq11 := \mathbf{0} \cdot \frac{eu}{m^2}$, $\delta_{pir5} := \mathbf{5} \cdot cm$

RF3: $\lambda_{RF3} := \mathbf{0.023} \cdot \frac{W}{m \cdot K}$, $coib_{12} := \lambda_{RF3}$, **Dim: 1.20mX1.20m,**

$Cq12 := \mathbf{0} \cdot \frac{eu}{m^2}$, $\delta_{RF3} := \mathbf{3} \cdot cm$

RF5: $\lambda_{RF5} := \mathbf{0.023} \cdot \frac{W}{m \cdot K}$, $coib_{13} := \lambda_{RF5}$, **Dim: 1.20mX1.20m,**

$Cqrf5 := \mathbf{0} \cdot \frac{eu}{m^2}$, $\delta_{RF5} := \mathbf{5} \cdot cm$

FIBERKENAF PAN-1: $\lambda_{fkpan1} := \mathbf{0.039} \cdot \frac{W}{m \cdot K}$, $coib_{14} := \lambda_{fkpan1}$, **Dim: 1.20mX1.20m,**

$Cqfkpan1 := \mathbf{0} \cdot \frac{eu}{m^2}$, $\delta_{fkpan1} := \mathbf{5} \cdot cm$

FIBERKENAF PAN-2: $\lambda_{fkpan2} := \mathbf{0.040} \cdot \frac{W}{m \cdot K}$, $coib_{15} := \lambda_{fkpan2}$, **Dim: 1.20mX1.20m,**

$Cqfkpan2 := \mathbf{0} \cdot \frac{eu}{m^2}$, $\delta_{fkpan2} := \mathbf{5} \cdot cm$

VACUUM: $\lambda_{vuoto} := 0.004 \cdot \frac{W}{m \cdot K}$,

THERMOFON: $\lambda_{therm} := 0.0074 \cdot \frac{W}{m \cdot K}$, $\delta_{therm} := 4 \cdot mm$

Each inner wall is separated from the insulating material by an interspace.
The calculation of the conductivity of the layers must then add the effect due to the air layer and the insulation.

Thickness of the Gap: $\delta_{intercap} := 0.03 \cdot m$, $\delta_{intercap} = 3 \cdot cm$, $\delta crtgs := 1.5 \cdot cm$

Thickness of the insulation: $\delta_{coib} := \delta_{rocc}$ · $\delta_{coib} = 40 \cdot cm$

Insulating chosen: $\lambda_{co} := \lambda_{rocc}$ $\lambda_{co} = 0.037 \cdot \frac{W}{m \cdot K}$

$$\delta s1_t := \delta_{into} + \delta_p + \delta_{into} + \delta_{aria} + \delta_{coib} + \delta crtgs$$

$$\Phi_T = \alpha_i \cdot A \cdot (T_i - T_1) = \lambda \cdot \frac{A}{\delta} \cdot (T_1 - T_2) = \alpha_a \cdot A \cdot (T_2 - T_a) \ ,$$

$$T_i - T_1 = \frac{\Phi_T}{(\alpha_i \cdot A)}, \ T_1 = T_i - \frac{\Phi_T}{(\alpha_i \cdot A)}, \ T_1 - T_2 = \frac{\Phi_T}{\left(\lambda \cdot \frac{A}{\delta}\right)},$$

$$T_i - \frac{\Phi_T}{(\alpha_i \cdot A)} - T_2 = \frac{\Phi_T}{\left(\lambda \cdot \frac{A}{\delta}\right)}, \ T_2 = T_i - \frac{\Phi_T}{(\alpha_i \cdot A)} - \frac{\Phi_T}{\left(\lambda \cdot \frac{A}{\delta}\right)}, \ T_2 - T_a = \frac{\Phi_T}{(\alpha_a \cdot A)},$$

$$T_i - \frac{\Phi_T}{(\alpha_i \cdot A)} - \frac{\Phi_T}{\left(\lambda \cdot \frac{A}{\delta}\right)} - T_a = \frac{\Phi_T}{(\alpha_a \cdot A)} \ ,$$

$$T_i - T_a = \frac{\Phi_T}{(\alpha_a \cdot A)} + \frac{\Phi_T}{(\alpha_i \cdot A)} + \frac{\Phi_T}{\left(\lambda \cdot \frac{A}{\delta}\right)} = \frac{\Phi_T}{A} \cdot \left(\frac{1}{\alpha_i} + \frac{1}{\alpha_a} + \frac{\delta}{\lambda}\right),$$

$$\Phi_T = \frac{A \cdot (T_i - T_a)}{\frac{1}{\alpha_i} + \frac{1}{\alpha_a} + \frac{\delta}{\lambda}} = \frac{(Ap_{tot} + S_{tot}) \cdot (T_i - T_a)}{\frac{1}{\alpha_i} + \frac{1}{\alpha_a} + \left(\frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_p}{\lambda_{tufo}} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_{aria}}{\lambda_{aria}} + \frac{\delta_{coib}}{\lambda_{co}} + \frac{\delta crtgs}{\lambda_{crtgs}}\right)} \ ,$$

$$\Phi_T := \frac{(Ap_{tot} + S_{tot}) \cdot (T_i - T_a)}{\frac{1}{\alpha_i} + \frac{1}{\alpha_a} + \left(\frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_p}{\lambda_{tufo}} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_{aria}}{\lambda_{aria}} + \frac{\delta_{coib}}{\lambda_{co}} + \frac{\delta crtgs}{\lambda_{crtgs}}\right)},$$

$$\Phi_T = 0.681 \cdot kW$$

$$\lambda_t := \frac{\delta s1_t}{\left(\frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_p}{\lambda_{tufo}} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_{aria}}{\lambda_{aria}} + \frac{\delta_{coib}}{\lambda_{co}} + \frac{\delta crtgs}{\lambda_{crtgs}}\right)} \ , \ \lambda_t = 0.095 \cdot \frac{W}{m \cdot K}$$

Thermal Resistance: $Rcoib_T := \frac{1}{\alpha_i} + \left(\frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_p}{\lambda_{tufo}} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_{aria}}{\lambda_{aria}} + \frac{\delta_{coib}}{\lambda_{co}} + \frac{\delta crtgs}{\lambda_{crtgs}} \right) + \frac{1}{\alpha_a},$

$Rcoib_T = \mathbf{12.522} \cdot \Omega_T,$

Transmittance: $U_{coib} := \frac{1}{Rcoib_T}, \quad U_{coib} = \mathbf{0.08} \cdot S_T, \quad U_{coib} = \mathbf{79.858} \cdot \frac{mW}{K \cdot m^2}$

$$P6 := \frac{T_i - T_a}{Rcoib_T},$$

$$P6 = \mathbf{1.597} \cdot \frac{W}{m^2}$$

$$\frac{P - P6}{P} = \mathbf{94.396} \cdot \%,$$

Thermal Resistance: $R5_T := \frac{1}{\alpha_i} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_p}{\lambda_{tufo}} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_{aria}}{\lambda_{aria}} + \frac{\delta_{coib}}{\lambda_{co}} + \frac{1}{\alpha_a}, \quad R5_T = \mathbf{11.897} \cdot \Omega_T$

$R6_T := \frac{1}{\alpha_i} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_p}{\lambda_{tufo}} + \frac{\delta_{into}}{\lambda_{into}} + \frac{\delta_{coib}}{\lambda_{co}} + \frac{\delta_{therm}}{\lambda_{therm}} + \frac{\delta crtgs}{\lambda_{crtgs}} + \frac{1}{\alpha_a}, \quad R6_T = \mathbf{12.678} \cdot \Omega_T$

Transmittance: $U5 := \frac{1}{R5_T}, \quad U5 = \mathbf{0.084} \cdot S_T, \quad U5 = \mathbf{84.053} \cdot \frac{mW}{m^2 \cdot K}$

$U6 := \frac{1}{R6_T}, \quad U6 = \mathbf{0.079} \cdot S_T, \quad U6 = \mathbf{78.876} \cdot \frac{mW}{K \cdot m^2}$

Power loss through the walls at 25 °C with air gap and insulating:

Bedroom: $P6_{Dletto} := P6 \cdot \left(Ap_{cl} + S_{cl} \cdot 2\right), \quad P6_{Dletto} = \mathbf{195.731} \cdot W,$

$P_{Dletto} = \mathbf{3.493} \cdot kW, \quad \frac{P_{Dletto} - P6_{Dletto}}{P_{Dletto}} = \mathbf{94.396} \cdot \%$

room 1: $P6_{Dc1} := P6 \cdot \left(S_{c1} \cdot 2 + Ap_{c1}\right), \quad P6_{Dc1} = \mathbf{101.284} W,$

$P_{Dc1} = \mathbf{1.807} \cdot kW, \quad \frac{P_{Dc1} - P6_{Dc1}}{P_{Dc1}} = \mathbf{94.396} \cdot \%$

room 2: $P6_{Dc2} := P6 \cdot \left(S_{c2} \cdot 2 + Ap_{c2}\right), \quad P6_{Dc2} = \mathbf{108.976} W,$

$P_{Dc2} = \mathbf{1.945} \cdot kW, \quad \frac{P_{Dc2} - P6_{Dc2}}{P_{Dc2}} = \mathbf{94.396} \cdot \%$

room 3: $P6_{Dc3} := P6 \cdot \left(S_{c3} \cdot 2 + Ap_{c3}\right), \quad P6_{Dc3} = \mathbf{104.116} W,$

$P_{Dc3} = 1.858 \cdot kW,$ $\quad \dfrac{P_{Dc3} - P6_{Dc3}}{P_{Dc3}} = 94.396 \cdot \%$

Bathroom : $P6_{DBath} := P6 \cdot \left(S_{ba} \cdot 2 + Ap_{ba}\right),$ $\quad P6_{DBath} = 62.633\,W,$

$P_{DBath} = 1.118 \cdot kW,$ $\quad \dfrac{P_{DBath} - P6_{DBath}}{P_{DBath}} = 94.396 \cdot \%$

kitchen: $P6_{Dkitch} := P6 \cdot \left(S_{kitch} \cdot 2 + Ap_{kitch}\right),$ $\quad P6_{Dkitch} = 153.839 \cdot W,$

$P_{Dkitch} = 2.745 \cdot kW,$ $\quad \dfrac{P_{Dkitch} - P6_{Dkitch}}{P_{Dkitch}} = 94.396 \cdot \%$

corridor: $P6_{Dcorr} := P6 \cdot \left(S_{corr} \cdot 2 + Ap_{corr}\right),$ $\quad P6_{Dcorr} = 116.726\,W,$

$P_{Dcorr} = 2.083 \cdot kW,$ $\quad \dfrac{P_{Dcorr} - P6_{Dcorr}}{P_{Dcorr}} = 94.396 \cdot \%$

Total power loss through the walls:

$$P6_{Dt} := P6_{Dletto} + P6_{Dc1} + P6_{Dc2} + P6_{Dc3} + P6_{DBath} + P6_{Dkitch} + P6_{Dcorr}$$

$P6_{Dt} = 843.304\,W.$ $\quad (P_{Dt} = 15.048 \cdot kW)$

$$\frac{P_{Dt} - P6_{Dt}}{P_{Dt}} = 94.396 \cdot \%$$

The power to be supplied by the source is given by: $P6_{tot} := F_{tot} + P6_{Dt},$

$V_{tot} = 291.231 \cdot m^3,$ $\quad P6_{tot} = 11.036 \cdot kW,$

Without isolating: $P_{tot} = 25.241 \cdot kW$

$\dfrac{P6_{tot}}{V_{tot}} = 332.186 \cdot \dfrac{kW \cdot hr}{m^3 \cdot yr},$ $\quad \dfrac{1}{2} \cdot \dfrac{P6_{tot}}{V_{tot}} = 166.093 \cdot \dfrac{kW \cdot hr}{m^3 \cdot yr},$

Limit values of energy performance for winter heating climatic zone C (south Italy) (with S / V = 0.91m⁻¹) = 15.6 kW hr/m³yr.

$$\frac{1}{7} \cdot \left(\frac{P6_{Dletto}}{V_{cl}} + \frac{P6_{Dc1}}{V_{c1}} + \frac{P6_{Dc2}}{V_{c2}} + \frac{P6_{Dc3}}{V_{c3}} \cdots + \frac{P6_{DBath}}{V_{ba}} + \frac{P6_{Dkitch}}{V_{kitch}} + \frac{P6_{Dcorr}}{V_{corr}} \right) = 27.637 \cdot \frac{kW \cdot hr}{m^3 \cdot yr}$$

Power to be supplied to individual rooms:

Bedroom: $P6_{letto} := P6_{Dletto} + F_{cl},$ $\quad P6_{letto} = 3.067 \cdot kW,$ $\quad P_{letto} = 6.364 \cdot kW,$

$F_{cl} = 2.872 \cdot kW$ $\quad \dfrac{P_{letto} - P6_{letto}}{P_{letto}} = 51.803 \cdot \%$

room 1: $P6_{c1} := P6_{Dc1} + F_{c1},$ $\quad P6_{c1} = 1.262 \cdot kW,$ $\quad P_{c1} = 2.968 \cdot kW,$

$$\frac{P_{c1} - P6_{c1}}{P_{c1}} = 57.478 \cdot \%$$

room 2: $P6_{c2} := P6_{Dc2} + F_{c2}$, $P6_{c2} = 1.396 \cdot kW$, $P_{c2} = 3.232 \cdot kW$,

$$\frac{P_{c2} - P6_{c2}}{P_{c2}} = 56.793 \cdot \%$$

room 3: $P6_{c3} := P6_{Dc3} + F_{c3}$, $P6_{c3} = 1.287 \cdot kW$, $P_{c3} = 3.041 \cdot kW$,

$$\frac{P_{c3} - P6_{c3}}{P_{c3}} = 57.671 \cdot \%$$

Bathroom : $P6_{Bath} := P6_{DBath} + F_{ba}$, $P6_{Bath} = 560.45\,W$, $P_{Bath} = 1.615 \cdot kW$,

$$\frac{P_{Bath} - P6_{Bath}}{P_{Bath}} = 65.307 \cdot \%$$

kitchen: $P6_{kitch} := P6_{Dkitch} + F_{kitch}$, $P6_{kitch} = 2.193 \cdot kW$, $P_{kitch} = 4.785 \cdot kW$

$$\frac{P_{kitch} - P6_{kitch}}{P_{kitch}} = 54.159 \cdot \%$$

corridor: $P6_{corr} := P6_{Dcorr} + F_{corr}$, $P6_{corr} = 1.27 \cdot kW$, $P_{corr} = 3.236 \cdot kW$,

$$\frac{P_{corr} - P6_{corr}}{P_{corr}} = 60.764 \cdot \%$$

$$P6_{letto} + P6_{c1} + P6_{c2} + P6_{c3} + P6_{Bath} + P6_{kitch} + P6_{corr} = 11.036 \cdot kW,$$

$$P6_{tot} = 11.036 \cdot kW$$

$$\frac{P_{tot} - P6_{tot}}{P_{tot}} = 56.276 \cdot \%$$

$$\frac{P6_{tot}}{Ap_{tot} + 2 \cdot S_{tot}} = 183.225 \cdot \frac{kW \cdot hr}{m^2 \cdot yr},$$

$$\frac{1}{7} \cdot \left(\frac{P6_{letto}}{Ap_{cl} + 2 \cdot S_{cl}} + \frac{P6_{c1}}{Ap_{c1} + 2 \cdot S_{c1}} + \frac{P6_{c2}}{Ap_{c2} + 2 \cdot S_{c2}} + \frac{P6_{c3}}{Ap_{c3} + 2 \cdot S_{c3}} \cdots + \frac{P6_{Bath}}{Ap_{ba} + 2 \cdot S_{ba}} + \frac{P6_{kitch}}{Ap_{kitch} + 2 \cdot S_{kitch}} + \frac{P6_{corr}}{Ap_{corr} + 2 \cdot S_{corr}} \right) = 174.788 \cdot \frac{kW \cdot hr}{m^2 \cdot yr}$$

RADIATORS

heat transfer coefficient of internal and external surface:

$$\alpha_i = 5 \cdot \frac{W}{m^2 \cdot K}, \ \alpha_a = 25 \cdot \frac{W}{m^2 \cdot K}, \ \alpha_i = 5 \cdot S_T, \ \alpha_a = 25 \cdot S_T$$

Conductivity of the insulating: $\lambda_{co} = 0.037 \cdot \frac{W}{m \cdot K}$ $\quad \alpha_i = 5 \cdot S_T \quad \alpha_a = 25 \cdot S_T$

Bedroom: radiator spacing 70cm , power of a single radiator element: $p_{70} := 154 \cdot W$,

n. of elements: $n_{cl} := \text{ceil}\left(\frac{P6_{letto}}{p_{70}}\right)$, $n_{cl} = 20$, **Internal volume:** $V_{rcl} := n_{cl} \cdot \frac{1}{4} \cdot L$, $V_{rcl} = 5L$

Cost of radiator: $c_{rletto} := n_{cl} \cdot \frac{110}{10}$, $c_{rletto} = 220$, **Installed:** $20 \cdot p_{70} = 3.08 \cdot kW$.

room 1: radiator spacing 70cm , power of a single radiator element: $p_{70} = 154W$,

n. of elements: $n_{c1} := \text{ceil}\left(\frac{P6_{c1}}{p_{70}}\right)$, $n_{c1} = 9$, **internal volume:** $V_{rc1} := n_{c1} \cdot \frac{1}{4} \cdot L$, $V_{rc1} = 2.25L$

Cost of radiator: $c_1 := n_{c1} \cdot \frac{110}{10}$, $c_1 = 99$, **Installed:** $9 \cdot p_{70} = 1.386 \cdot kW$.

room 2: radiator spacing 70cm , power of a single radiator element: $p_{70} = 154W$,

n. of elements: $n_{c2} := \text{ceil}\left(\frac{P6_{c2}}{p_{70}}\right)$, $n_{c2} = 10$, **internal volume:** $V_{rc2} := n_{c2} \cdot \frac{1}{4} \cdot L$, $V_{rc2} = 2.5L$

Cost of radiator: $c_2 := n_{c2} \cdot \frac{110}{10}$, $c_2 = 110$, **Installed:** $10 \cdot p_{70} = 1.54 \cdot kW$.

room 3: radiator spacing 70cm , power of a single radiator element: $p_{70} = 154W$,

n. of elements: $n_{c3} := \text{ceil}\left(\frac{P6_{c3}}{p_{70}}\right)$, $n_{c3} = 9$, **internal volume:** $V_{rc3} := n_{c3} \cdot \frac{1}{4} \cdot L$, $V_{rc3} = 2.25L$

Cost of radiator: $c_3 := n_{c3} \cdot \frac{110}{10}$, $c_3 = 99$, **Installed:** $10 \cdot p_{70} = 1.54 \cdot kW$.

Bathroom: radiator spacing 35cm , power of a single radiator element: $p_{35} := 88 \cdot W$,

n. of elements: $n_b := \text{ceil}\left(\frac{P6_{Bath}}{p_{35}}\right)$, $n_b = 7$, **internal volume:** $V_{rb} := n_b \cdot \frac{1}{4} \cdot L$, $V_{rb} = 1.75L$

Cost of radiator: $c_b := n_b \cdot \frac{90}{10}$, $c_b = 63$, **Installed:** $10 \cdot p_{35} = 0.88 \cdot kW$.

kitchen: radiator spacing 80cm , power of a single radiator element: $p_{80} := 172 \cdot W$,

n. of elements: $n_{kitch} := \text{ceil}\left(\frac{P6_{kitch}}{p_{80}}\right)$, $n_{kitch} = 13$, **internal volume:** $V_{rcu} := n_{kitch} \cdot \frac{2}{4} \cdot L$,

$V_{rcu} = 6.5L$

Cost of radiator: $c_{kitch} := n_{kitch} \cdot \frac{120}{10}$, $c_{kitch} = 156$, Installed: $13 \cdot p_{80} = 2.236 \cdot kW$.

corridor: radiator spacing 70cm , power of a single radiator element: $p_{70} = 154\,W$,

n. of elements: $n_{co} := ceil\left(\frac{P6_{corr}}{p_{70}}\right)$, $n_{co} = 9$, internal volume: $V_{rco} := n_{co} \cdot \frac{1}{4} \cdot L$, $V_{rco} = 2.25\,L$

Cost of radiator: $c_{co} := n_{co} \cdot \frac{110}{10}$, $c_{co} = 99$,Installed: $10 \cdot p_{70} = 1.54 \cdot kW$.

Total cost: $c_{tot} := c_{rletto} + c_1 + c_2 + c_3 + c_b + c_{kitch} + c_{co}$, $c_{tot} = 846 \cdot eu$

$p_{70} \cdot (n_{cl} + n_{c1} + n_{c2} + n_{c3} + n_{co}) + p_{35} \cdot n_b + p_{80} \cdot n_{kitch} = 11.63 \cdot kW$.

Total volume of the radiators (water):

$$V_{rt} := V_{rcl} + V_{rc1} + V_{rc2} + V_{rc3} + V_{rb} + V_{rcu} + V_{rco}$$
$$V_{rt} = 22.5\,L$$

Total length of pipes: $L_{16} := (10 \cdot m + 5 \cdot m + 2 \cdot m + 1 \cdot m) \cdot 2 + (20 \cdot m + 15 \cdot m + 10 \cdot m + 1 \cdot m) \cdot 2$,

$$\frac{L_{16}}{2} = 64\,m$$

$$L_{20} := (15 \cdot m + 9 \cdot m) \cdot 2, \quad \frac{L_{20}}{2} = 24\,m$$

Volume of water in the pipes:

$d_{i16} := 14 \cdot mm$, Section of the pipe to 16mm: $A_{16} := \pi \cdot \left(\frac{d_{i16}}{2}\right)^2$, $A_{16} = 1.539 \cdot cm^2$,

Volume: $V_{16} := A_{16} \cdot L_{16}$, $V_{16} = 19.704\,L$

$d_{i20} := 18 \cdot mm$, Section of the pipe to 20mm: $A_{20} := \pi \cdot \left(\frac{d_{i20}}{2}\right)^2$, $A_{20} = 2.545 \cdot cm^2$,

Volume: $V_{20} := A_{20} \cdot L_{20}$, $V_{20} = 12.215\,L$

Total volume of water in the pipes: $V_{1620} := V_{16} + V_{20}$,

$$V_{1620} = 31.919\,L$$

Total volume of water to be heated:

$$V_{rt} + V_{1620} = 54.419\,L$$

Power of Installed Radiators:

$$P_{installed} := 20 \cdot p_{70} + 9 \cdot p_{70} + 10 \cdot p_{70} + 10 \cdot p_{70} + 10 \cdot p_{35} + 13 \cdot p_{80} + 10 \cdot p_{70}$$

$$p_{35} = 88\,W \quad , \quad p_{70} = 154\,W \quad , \quad p_{80} = 172\,W$$

Total power required with non-insulated rooms: $P_{tot} = 25.241 \cdot kW$,

Total Power of Installed Radiators: $P_{installed} = 12.202 \cdot kW$,

Total power required with insulated rooms: $P6_{tot} = 11.036 \cdot kW$

Required power with 4 radiators: $20 \cdot p_{70} + 10 \cdot p_{70} + 10 \cdot p_{35} + 13 \cdot p_{80} = 7.736 \cdot kW$,

$$T_i = 293.15\,K \quad , \quad T_a = 273.15\,K \quad , \Delta T = 65\,K$$

$$K_{35} := 0.578 \cdot \frac{W}{m^2} , \quad N_{35} := 1.284 , \quad \Phi_{35} := K_{35} \cdot \left(\frac{\Delta T}{50 \cdot K}\right)^{N_{35}} , \quad \Phi_{35} = 0.81 \cdot \frac{W}{m^2} ,$$

$$\Phi_{35} \cdot (Ap_{ba} + 2 \cdot S_{ba}) \cdot n_b = 222.22 \cdot W$$

$$K_{70\_3} := 0.879 \cdot \frac{W}{m^2} , \quad N_{70\_3} := 1.336 , \quad \Phi_{70\_3} := K_{70\_3} \cdot \left(\frac{\Delta T}{50 \cdot K}\right)^{N_{70\_3}} , \Phi_{70\_3} = 1.248 \cdot \frac{W}{m^2} ,$$

$$\frac{\Phi_{70\_3}}{3} \cdot n_{c1} \cdot (Ap_{c1} + 2 \cdot S_{c1}) = 237.426 \cdot W$$

$$K_{70\_10} := 0.909 \cdot \frac{W}{m^2} , \; N_{70\_10} := 1.311 \quad \Phi_{70\_10} := K_{70\_10} \cdot \left(\frac{\Delta T}{50 \cdot K}\right)^{N_{70\_10}} , \Phi_{70\_10} = 1.282 \cdot \frac{W}{m^2} ,$$

$$\Phi_{70\_10} \cdot \left[Ap_{c2} + Ap_{c3} + 2 \cdot (S_{c2} + S_{c3})\right] \cdot (n_{c2} + n_{c3}) = 3.25 \cdot kW$$

$$K_{70\_8} := K_{70\_10} , \quad N_{70\_8} := N_{70\_10} , \quad \Phi_{70\_8} := K_{70\_8} \cdot \left(\frac{\Delta T}{50 \cdot K}\right)^{N_{70\_8}} , \Phi_{70\_8} = 1.282 \cdot \frac{W}{m^2} ,$$

$$\left(\Phi_{70\_8} + \frac{\Phi_{70\_3}}{3}\right) \cdot (Ap_{c1} + 2 \cdot S_{c1}) \cdot n_{c1} = 0.969 \cdot kW$$

$$K_{80} := 0.958 \cdot \frac{W}{m^2} , \quad N_{80} := 1.325 , \quad \Phi_{80} := K_{80} \cdot \left(\frac{\Delta T}{50 \cdot K}\right)^{N_{80}} , \Phi_{80} = 1.356 \cdot \frac{W}{m^2} ,$$

$$\left(\Phi_{80} + \frac{\Phi_{80}}{10} \cdot 3\right) \cdot (Ap_{kitch} + 2 \cdot S_{kitch}) \cdot n_{kitch} = 2.208 \cdot kW$$

$$P_{termo} := \Phi_{35} \cdot (Ap_{ba} + 2 \cdot S_{ba}) \cdot n_b + \frac{\Phi_{70\_3}}{3} \cdot 1 \cdot (Ap_{c1} + 2 \cdot S_{c1}) \cdot n_{c1} \ldots$$
$$+ \Phi_{70\_10} \cdot \left[Ap_{c2} + Ap_{c3} + Ap_{corr} + 2 \cdot (S_{c2} + S_{c3} + S_{corr})\right] \cdot (n_{c2} + n_{c3} + n_{co}) \ldots$$
$$+ \left(\Phi_{70\_8} + \frac{\Phi_{70\_3}}{3}\right) \cdot (Ap_{c1} + 2 \cdot S_{c1}) \cdot n_{c1} + \left(\Phi_{80} + \frac{\Phi_{80}}{10} \cdot 3\right) \cdot (Ap_{kitch} + 2 \cdot S_{kitch}) \cdot n_{kitch}$$

$$P_{termo} = 11.05 \cdot kW \; .$$

The power that the radiator system must provide to the locations can also be calculated taking into account the yield and the coefficients, using the formula:

emission efficiency: $\eta_e = 0.94$,

regulation efficiency: $\eta_c = 0.94$,

coefficient of intermittency: $C_i = 0.2$, safety factor: $C_s = 1.2$,

$$\Phi_{rd} := \frac{P_{termo}}{\eta_e \cdot \eta_c} \cdot C_i \cdot C_s , \quad \Phi_{rd} = 3.001 \cdot kW,$$

Boiler power:

$$P_g := \frac{\Phi_{rd}}{\eta_d} , \quad P_g = 3.063 \cdot kW$$

Running time per day: $t = 24 \cdot hr$, **Yearly:** $t_{yr} = 0.417 \cdot yr$

Necessary volume of gas pro die: $V_{gasday} := t \cdot \frac{P6_{tot}}{E_{ch4}}$, **for five months:** $t_{yr} \cdot \frac{P6_{tot}}{E_{ch4}} = 3646.94 \cdot m^3$,

Cost of gas per cubic meter: $C_{ch4} = 0.848 \cdot m^{-3}$,

Total cost with VAT and considering the coefficient of intermittency C_i:

$t = 24 \cdot hr$, $t_{yr} = 0.417 \cdot yr$, $C_i \cdot C_{ch4} \cdot (N_{days} \cdot V_{gasday}) \cdot (1 + VAT) = 754.596 \cdot eu$

Monthly Payment with $VAT = 22 \cdot \%$: $C_i \cdot C_{ch4} \cdot (N_{days} \cdot V_{gasday}) \cdot \frac{1 + VAT}{5} = 150.919 \cdot eu$

$N_{days} = 152.184$ $E_{ch4} = 11.053 \cdot \frac{kW \cdot hr}{m^3}$ $V_{gasday} = 23.964 \cdot m^3$

Reduced power consumption with four radiators not working:

$$P3 := P6_{letto} + P6_{Bath} + P6_{kitch}$$

Necessary volume of gas pro die: $V3_{gasday} := t \cdot \frac{P3}{E_{ch4}}$, $V3_{gasday} = 12.64 m^3$

for five months: $t_{yr} \cdot \frac{P3}{E_{ch4}} = 1923.574 \cdot m^3$,

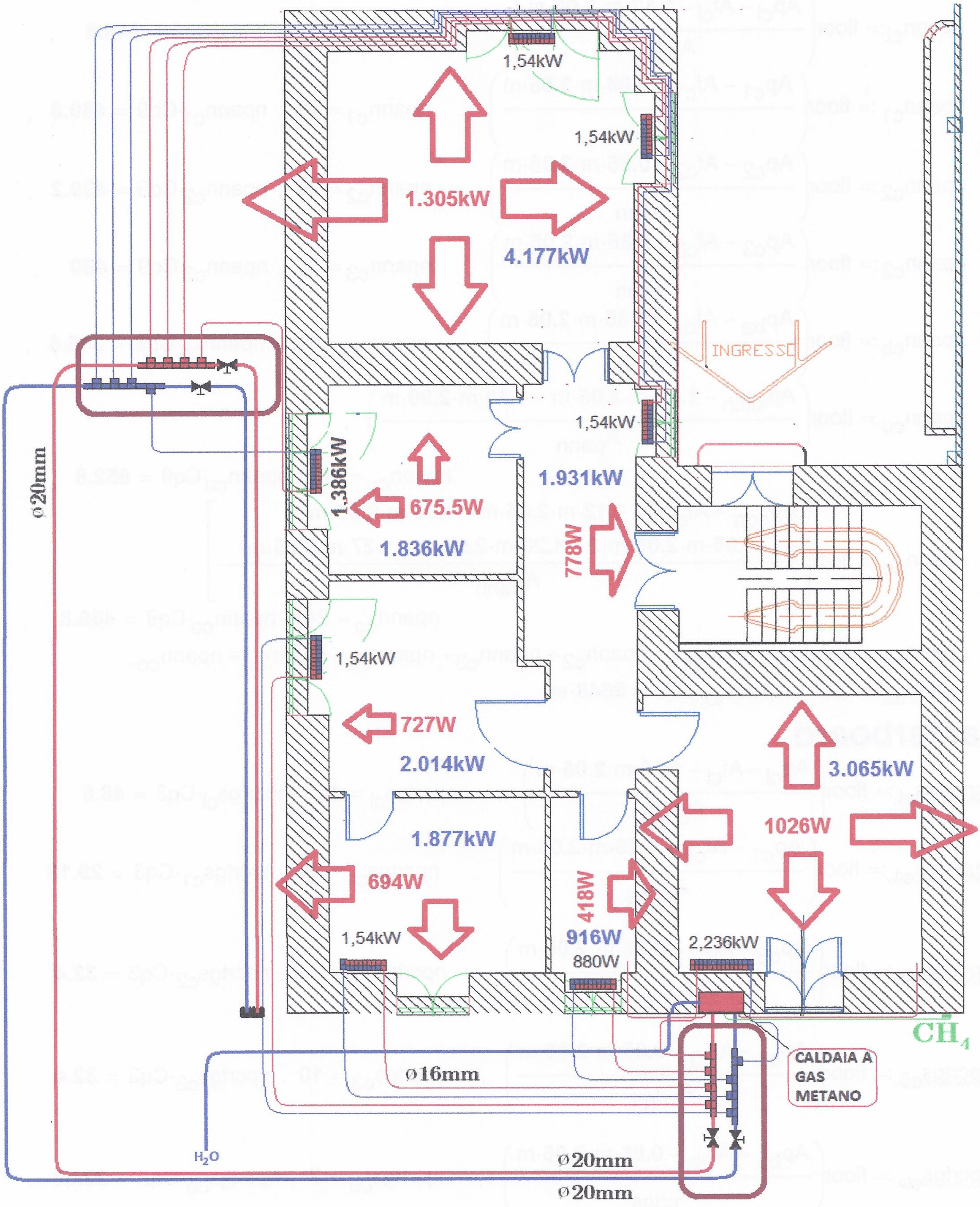
Cost of gas per cubic meter: $C_{ch4} = 0.848 \cdot m^{-3}$,

Total cost with VAT and considering the coefficient of intermittency C_i:

$t = 24 \cdot hr$, $t_{yr} = 0.417 \cdot yr$, $C_i \cdot C_{ch4} \cdot (N_{days} \cdot V3_{gasday}) \cdot (1 + VAT) = 398.01 \cdot eu$

Monthly Payment with $VAT = 22 \cdot \%$: $C_i \cdot C_{ch4} \cdot (N_{days} \cdot V3_{gasday}) \cdot \frac{1 + VAT}{5} = 79.602 \cdot eu$

The drawing shows the power loss through the walls with and without insulation.



Panels number of insulating material for each room.

$A_{pann} := 1.20 \cdot m \cdot 1.20 \cdot m$, $\lambda_{co} = 0.037 \cdot \frac{W}{m \cdot K}$ $Cq9 = 19.2 \cdot eu$

$npann_{cl} := floor\left(\frac{Ap_{cl} - Af_{cl} - 1.12 \cdot m \cdot 2.05 \cdot m}{A_{pann}}\right)$, $npann_{cl} = 39$, $npann_{cl} \cdot Cq9 = 748.8$,

$npann_{c1} := floor\left(\frac{Ap_{c1} - Af_{c1} - 1.06 \cdot m \cdot 2.05 \cdot m}{A_{pann}}\right)$, $npann_{c1} = 24$, $npann_{c1} \cdot Cq9 = 460.8$,

$npann_{c2} := floor\left(\frac{Ap_{c2} - Af_{c2} - 0.85 \cdot m \cdot 2.05 \cdot m}{A_{pann}}\right)$, $npann_{c2} = 26$, $npann_{c2} \cdot Cq9 = 499.2$,

$npann_{c3} := floor\left(\frac{Ap_{c3} - Af_{c3} - 0.85 \cdot m \cdot 2.05 \cdot m}{A_{pann}}\right)$, $npann_{c3} = 25$, $npann_{c3} \cdot Cq9 = 480$,

$npann_{cb} := floor\left(\frac{Ap_{ba} - Af_{ba} - 0.85 \cdot m \cdot 2.05 \cdot m}{A_{pann}}\right)$, $npann_{cb} = 18$, $npann_{cb} \cdot Cq9 = 345.6$,

$npann_{cu} := floor\left(\frac{Ap_{kitch} - 1.20 \cdot m \cdot 2.05 \cdot m - 1.30 \cdot m \cdot 2.90 \cdot m}{A_{pann}}\right)$,

$npann_{cu} = 34$, $npann_{cu} \cdot Cq9 = 652.8$,

$$npann_{co} := floor\left[\frac{Ap_{corr} - Af_{corr} - 1.12 \cdot m \cdot 2.05 \cdot m - 1.06 \cdot m \cdot 2.05 \cdot m \ldots + (-0.85 \cdot m \cdot 2.05 \cdot m \cdot 2 - 1.20 \cdot m \cdot 2.05 \cdot m - 1.27 \cdot m \cdot 2.05 \cdot m)}{A_{pann}}\right] ,$$

$npann_{co} = 24$, $npann_{co} \cdot Cq9 = 460.8$,

$npann_{tot} := npann_{cl} + npann_{c1} + npann_{c2} + npann_{c3} + npann_{cb} + npann_{cu} + npann_{co}$,

$npann_{tot} = 190$, $npann_{tot} \cdot Cq9 = 3648 \cdot eu$

Plasterboard

$npcrtgs_{cl} := floor\left(\frac{Ap_{cl} - Af_{cl} - 1.12 \cdot m \cdot 2.05 \cdot m}{A_{crtgs}}\right)$, $npcrtgs_{cl} = 15$, $npcrtgs_{cl} \cdot Cq3 = 48.6$,

$npcrtgs_{c1} := floor\left(\frac{Ap_{c1} - Af_{c1} - 1.06 \cdot m \cdot 2.05 \cdot m}{A_{crtgs}}\right)$, $npcrtgs_{c1} = 9$, $npcrtgs_{c1} \cdot Cq3 = 29.16$

,

$npcrtgs_{c2} := floor\left(\frac{Ap_{c2} - Af_{c2} - 0.85 \cdot m \cdot 2.05 \cdot m}{A_{crtgs}}\right)$, $npcrtgs_{c2} = 10$, $npcrtgs_{c2} \cdot Cq3 = 32.4$

,

$npcrtgs_{c3} := floor\left(\frac{Ap_{c3} - Af_{c3} - 0.85 \cdot m \cdot 2.05 \cdot m}{A_{crtgs}}\right)$, $npcrtgs_{c3} = 10$, $npcrtgs_{c3} \cdot Cq3 = 32.4$

,

$npcrtgs_{cb} := floor\left(\frac{Ap_{ba} - Af_{ba} - 0.85 \cdot m \cdot 2.05 \cdot m}{A_{crtgs}}\right)$, $npcrtgs_{cb} = 7$, $npcrtgs_{cb} \cdot Cq3 = 22.68$,

$$npcrtgs_{cu} := floor\left(\frac{Ap_{kitch} - \mathbf{1.20}\cdot m\cdot \mathbf{2.05}\cdot m - \mathbf{1.30}\cdot m\cdot \mathbf{2.90}\cdot m}{A_{crtgs}}\right), \quad npcrtgs_{cu} = \mathbf{13},$$

$$npcrtgs_{cu}\cdot Cq3 = \mathbf{42.12},$$

$$npcrtgs_{co} := floor\left[\frac{Ap_{corr} - Af_{corr} - \mathbf{1.12}\cdot m\cdot \mathbf{2.05}\cdot m - \mathbf{1.06}\cdot m\cdot \mathbf{2.05}\cdot m \ldots + (-\mathbf{1})\cdot \mathbf{0.85}\cdot m\cdot \mathbf{2.05}\cdot m\cdot \mathbf{2} - \mathbf{1.20}\cdot m\cdot \mathbf{2.05}\cdot m - \mathbf{1.27}\cdot m\cdot \mathbf{2.05}\cdot m}{A_{crtgs}}\right], \quad npcrtgs_{co} = \mathbf{9},$$

$$npcrtgs_{co}\cdot Cq3 = \mathbf{29.16}\cdot eu,$$

$$npcrtgs_{tot} := npcrtgs_{cl} + npcrtgs_{c1} + npcrtgs_{c2} + npcrtgs_{c3} + npcrtgs_{cb} + npcrtgs_{cu} + npcrtgs_{co},$$

$$npcrtgs_{tot} = \blacksquare, \quad npcrtgs_{tot}\cdot Cq3 = \blacksquare\cdot eu$$

$$npann_{tot}\cdot Cq9 + npcrtgs_{tot}\cdot Cq3 = \blacksquare\cdot eu$$

IKEA TUNDRA laminate flooring $c_{pav} := \mathbf{7.99}\cdot\frac{eu}{m^2}$,

Each pack covers: $s_{conf} := \mathbf{2.39}\cdot m^2$. $c_{conf} := \mathbf{19.10}$

cost for each room:

Bedroom: $S_{cl}\cdot c_{pav} = \mathbf{228.214}$, N. of packs: $ceil\left(\frac{S_{cl}}{s_{conf}}\right) = \mathbf{12}$

room 1: $S_{c1}\cdot c_{pav} = \mathbf{91.377}$, N. of packs: $ceil\left(\frac{S_{c1}}{s_{conf}}\right) = \mathbf{5}$

room 2: $S_{c2}\cdot c_{pav} = \mathbf{101.348}$, N. of packs: $ceil\left(\frac{S_{c2}}{s_{conf}}\right) = \mathbf{6}$

room 3: $S_{c3}\cdot c_{pav} = \mathbf{93.131}$, N. of packs: $ceil\left(\frac{S_{c3}}{s_{conf}}\right) = \mathbf{5}$

corridor: $S_{corr}\cdot c_{pav} = \mathbf{93.392}$ N. of packs: $ceil\left(\frac{S_{corr}}{s_{conf}}\right) = \mathbf{5}$

Total N. of packs: $ceil\left[\frac{(S_{cl} + S_{c1} + S_{c2} + S_{c3} + S_{corr})}{s_{conf}}\right] = \mathbf{32}$ ....!?!?!

Total cost of packs: $ceil\left[\frac{(S_{cl} + S_{c1} + S_{c2} + S_{c3} + S_{corr})}{s_{conf}}\right]\cdot c_{conf} = \mathbf{611.2}\cdot eu$

Subtotal: $(S_{cl} + S_{c1} + S_{c2} + S_{c3} + S_{corr})\cdot c_{pav} = \mathbf{607.462}\cdot eu$,

Coating NIVÅ: $c_{niv} := \mathbf{1.49}\cdot\frac{eu}{m^2}$,

Subtotal: $(S_{cl} + S_{c1} + S_{c2} + S_{c3} + S_{corr})\cdot c_{niv} = \mathbf{113.281}\cdot eu$

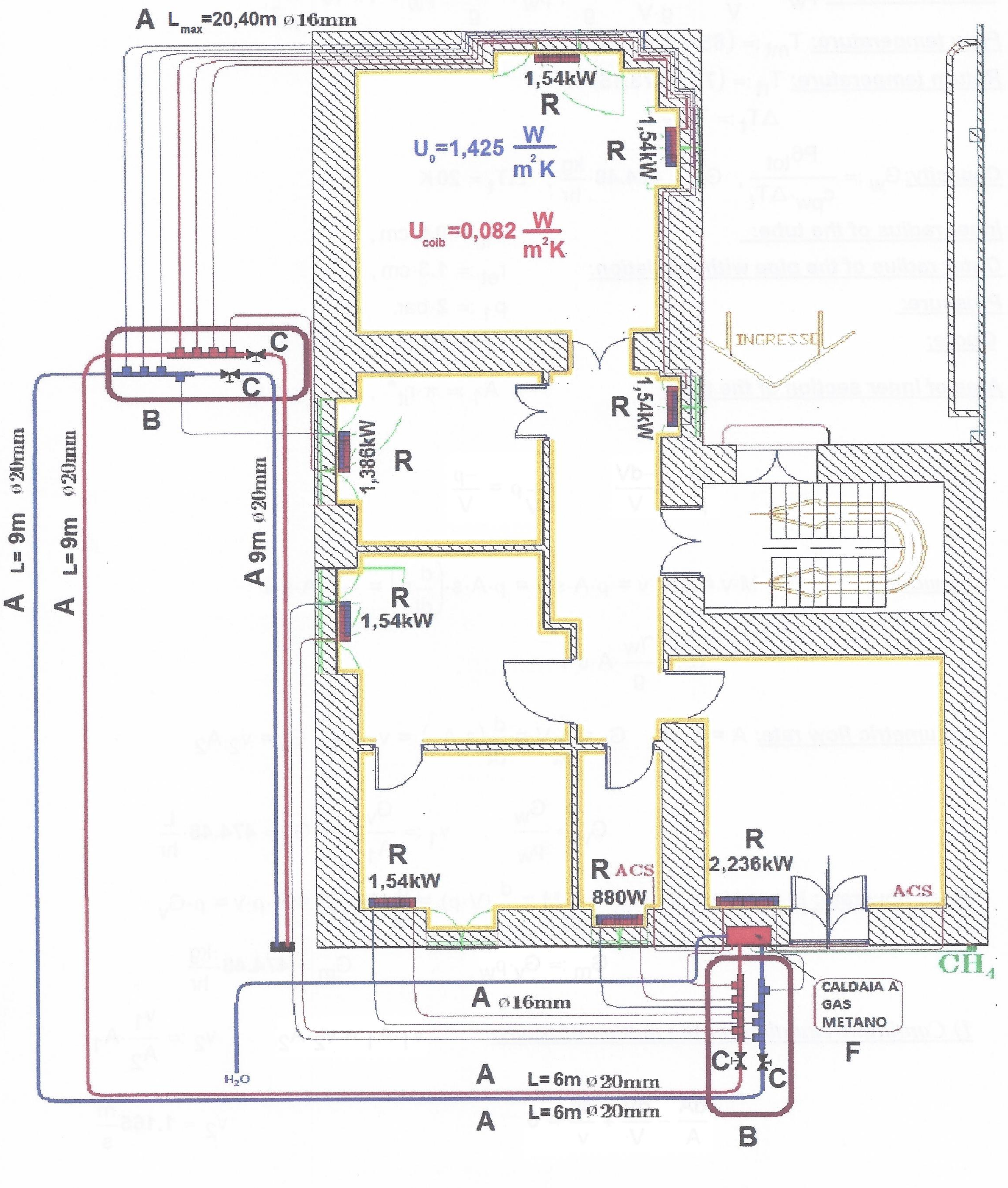
Total: $(S_{cl} + S_{c1} + S_{c2} + S_{c3} + S_{corr})\cdot(c_{pav} + c_{niv}) = \mathbf{720.744}\cdot eu$, With SPÄRRA $c_{spar} := \mathbf{1.39} \cdot \frac{eu}{m^2}$

$$\text{Total:} \left(S_{cl} + S_{c1} + S_{c2} + S_{c3} + S_{corr}\right) \cdot \left(c_{pav} + c_{niv} + c_{spar}\right) = \mathbf{826.422} \cdot eu,$$

$$\frac{Ap_{cl}}{4} = \mathbf{16.356}\, m^2$$

$$\left(S_{cl} + S_{c1} + S_{c2} + S_{c3} + S_{corr}\right) \cdot \left(c_{pav} + c_{niv} + c_{spar}\right) \cdot \mathbf{0.9} = \mathbf{743.78}$$

The following drawing shows the plan of the house and in particular the powers of Each radiator.



PIPES.

Specific weight of water: $\gamma_w := 1000 \cdot \frac{kgf}{m^3}$ $\gamma_w = 1 \times 10^3 \cdot \frac{kgf}{m^3}$,

Density of water: $\rho_w = \frac{Mass}{V} = \frac{P_w}{g \cdot V} = \frac{\gamma_w}{g}$, $\rho_w := \frac{\gamma_w}{g}$, $\rho_w = 1 \times 10^3 \cdot \frac{kg}{m^3}$,

Flow temperature: $T_{mt} := (85 + 273.15) \cdot K$,

Return temperature: $T_{rt} := (75 + 273.15) \cdot K$,

$$\Delta T_t := T_m - T_r$$

Capacity: $G_w := \frac{P6_{tot}}{c_{pw} \cdot \Delta T_t}$, $G_w = 474.48 \cdot \frac{kg}{hr}$, $\Delta T_t = 20\,K$

Inner radius of the tube: $r_{it} := 0.6 \cdot cm$,

Outer radius of the pipe with insulation: $r_{et} := 1.3 \cdot cm$,

Pressure: $p_1 := 2 \cdot bar$,

Quote: $z_1 := 1.0 \cdot m$, $z_2 := z_1$

Area of Inner section of the tube: $A_1 := \pi \cdot r_{it}^2$, $A_2 := \pi \cdot r_{it}^2$

$$\frac{d\rho}{\rho} = \frac{-dV}{V} \qquad \frac{d}{dV}\rho = \frac{-\rho}{V}$$

Momentum: $\Pi = M \cdot v = \rho \cdot V \cdot v = \rho \cdot A \cdot s \cdot v = \rho \cdot A \cdot s \cdot \left(\frac{d}{dt}s\right) = \frac{\gamma_w}{g} \cdot A \cdot s \cdot v$

$$\Pi := \frac{\gamma_w}{g} \cdot A \cdot s \cdot v$$

Volumetric flow rate: $A = cost$, $G_v = \frac{d}{dt}V = \frac{d}{dt}(s \cdot A_1) = v_1 \cdot A_1$, $G_v = v_2 \cdot A_2$

$$G_v := \frac{G_w}{\rho_w}, \quad v_1 := \frac{G_v}{A_1}, \quad G_v = 474.48 \cdot \frac{L}{hr}$$

Mass flow rate: $M = \rho \cdot V$, per cui: $G_m = \frac{d}{dt}M = \frac{d}{dt}(V \cdot \rho) = \frac{d}{dt}(A \cdot \rho \cdot s) = A \cdot \rho \cdot v = \rho \cdot G_v$

$$G_m := G_v \cdot \rho_w, \quad G_m = 474.48 \cdot \frac{kg}{hr}$$

1) Continuity equation for the motion of fluids: $v_1 \cdot A_1 = v_2 \cdot A_2$ $\quad v_2 := \frac{v_1}{A_2} \cdot A_1$

$$\frac{dA}{A} - \frac{dV}{V} + \frac{dv}{v} = 0 \qquad v_2 = 1.165 \frac{m}{s}$$

2)Bernoulli Theorem strictly valid only for stationary motion:

$$\frac{1}{2}\cdot\gamma_w\cdot\frac{v_1^2}{g}+p_1+\gamma_w\cdot z_1=\frac{1}{2}\cdot\gamma_w\cdot\frac{v_2^2}{g}+p_2+\gamma_w\cdot z_2=P_t=\text{constant}$$

$$\frac{1}{2}\cdot\gamma_w\cdot\frac{G_v^2}{A_1^2\cdot g}+p_1+\gamma_w\cdot z_1=2.105\cdot\text{bar}$$

$$\frac{1}{2}\cdot\gamma_w\cdot\frac{G_v^2}{A_1^2\cdot g}+p_1+\gamma_w\cdot z_1=\frac{1}{2}\cdot\gamma_w\cdot\frac{G_v^2}{A_2^2\cdot g}+p_2+\gamma_w\cdot z_2=P_t=\text{constant}$$

Bernoulli trinomio: $P_t:=\frac{1}{2}\cdot\gamma_w\cdot\frac{v_1^2}{g}+p_1+\gamma_w\cdot z_1$

$$p_2:=P_t-\left(\frac{1}{2}\cdot\gamma_w\cdot\frac{G_v^2}{A_2^2\cdot g}+\gamma_w\cdot z_2\right)\qquad p_2=2\cdot\text{bar}$$

Dividing the trinomial of Bernoulli for the specific gravity γ_w, we get ***the total energy (mechanical) owned unit of weight of the liquid***: $E_1:=z_1+\frac{p_1}{\gamma_w}+\frac{v_1^2}{2\cdot g}=\text{cost.}$

geometrical height: $z_1=1\,m$

pressure head: $\frac{p_1}{\gamma_w}=20.394\,m$

kinetics height: $\frac{v_1^2}{2\cdot g}=69.243\cdot mm$

piezometric: $h_p:=z_1+\frac{p_1}{\gamma_w}$ $\qquad h_p=21.394\,m$

the piezometric level is the quota of the free surface of the piezometer respect to the plane of reference and should not be confused with the piezometric height which is the distance between the free surface of the piezometer and the barycentre of section in which it is placed.

Total (Mechanical) energy owned by the unit weight of the liquid:

$$E_1=210.486\cdot\frac{J}{kgf},\qquad E_1=21.464\,m$$

3) Theorem of momentum: $\Pi(t) = \frac{\gamma_w}{g} \cdot A \cdot \frac{s}{t} \cdot v$

$$\Pi_1 := \gamma_w \cdot \frac{v_1}{g} \cdot A_1 \cdot |v_1| \quad , \quad \Pi_2 := \gamma_w \cdot \frac{v_2}{g} \cdot A_2 \cdot |v_2|$$

$$F = \Pi_2 - \Pi_1 = \frac{\gamma_w}{g} \cdot G_v \cdot (v_2 - v_1)$$

Fluid temperature: $T_f := T_m$,

Temperature of the inner surface of the tube: $T_{it} := T_m$,

Temperature of the outer surface of the tube: $T_{outt} := T_m - 1 \cdot K$,

Temperature of the outer surface of the insulation: $T_{eiso} := (0.5 + 273.15) \cdot K$,

Ambient temperature: $T_a = 273.15K$,

Length of enclosure: $L_{iso} := 15 \cdot m$,

Length of the tube: $L_{Tu} := 15 \cdot m$

Thermal conductivity of the enclosure: $\lambda_{iso} := 0.05 \cdot \frac{W}{m \cdot K}$,

Transmittance of the inner surface: $\alpha_{it} := 0.03 \cdot S_T$,

Transmittance of the outer surface: $\alpha_{et} := 0.04 \cdot S_T$,

h = f + r, f is the coefficient of convection laminar, r is the coefficient of irradiation.The amount of heat which, in the time unit (Power), flows from the inside of the tube outside ie transversely to the tube axis, i given by the following relationship:

$$P_T := \frac{T_{it} - T_a}{R_T} \quad \left(\frac{kcal}{hr} \text{ o W}\right)$$

where R is the total resistance expressed by the formula:

$$R_T := \frac{L_{Tu}}{2 \cdot \pi} \cdot \left(\frac{1}{\alpha_{it} \cdot r_{it}} + \frac{1}{\lambda_{iso}} \cdot \ln\left(\frac{r_{et}}{r_{it}}\right) + \frac{1}{\alpha_{et} \cdot r_{et}} \right) \text{ in } (\Omega_T)$$

$$R_T = 17.891 \cdot k\Omega_T$$

In the tube flows a liquid which should not freeze even if the ambient temperature, outside the tube, is less than 0 °C.The amount of heat dP transmitted per unit of time outside, by an infinitesimal element of tube length dL, is given by:

$$dP = \frac{T_{it} - T_a}{\rho} \cdot dL,$$

where $\rho := \frac{1}{2 \cdot \pi \cdot \lambda_{iso}} \cdot \ln\left(\frac{r_{et}}{r_{it}}\right) + \frac{1}{2 \cdot \pi \cdot r_{et} \cdot \alpha_{et}}$. $\rho = 308.528 \cdot \frac{\Omega_T}{m}$

In the infinitesimal segment of pipe dL, the amount of heat lost from the fluid and transmitted outside is given by:

$$dP = -G_w \cdot c_{pw} \cdot dT_{it}$$

where: G_w is the fluid flow rate in kg / hr,

c_{pw} is the specific heat of the fluid in kcal / (kg. °'b0 C) or kJ / (kg °'b0 C),

dT_i is the cooling of the fluid in the tract dL.

So one can also write:

$$dP = -G_w \cdot c_{pw} \cdot d(T_i - T_a).$$

Then equality must hold: *lost power* = *power transmitted* by the fluid outside, that is:

$$-G_w \cdot c_{pw} \cdot d(T_{it} - T_a) = \frac{T_{it} - T_a}{\rho} \cdot dL,$$

$$\frac{1}{G_w \cdot \rho} \cdot dL = -c_{pw} \cdot \frac{d(T_{it} - T_a)}{T_{it} - T_a}.$$

By integrating both members one get:

$$\frac{L_i}{c_{pw} \cdot G_w \cdot \rho} = \ln\left[\frac{(T_{1i} - T_a)}{T_{1u} - T_a}\right],$$

or:

$$\frac{L_i \cdot 2 \cdot \pi \cdot r_e}{c_{pw} \cdot G_w \cdot \rho \cdot 2 \cdot \pi \cdot r_e} = \ln\left[\frac{(T_{1i} - T_a)}{T_{1u} - T_a}\right],$$

namely:

$$\frac{S_e}{c_{pw} \cdot G_w \cdot \rho 1} = \ln\left[\frac{(T_{1i} - T_a)}{T_{1u} - T_a}\right]$$

with:

$S_e := L_{iso} \cdot 2 \cdot \pi \cdot r_{et}$ outer surface of the tube

$R1 := \rho \cdot 2 \cdot \pi \cdot r_{et}$

$R1 = 25.201 \cdot \Omega_T$

T_{1i} is the temperature of the incoming fluid to tract L_{iso},

T_{1u} is the temperature of the fluid in output to tract L_{iso}.

The minimum temperature that the fluid can reach is:

$$\frac{(T_{1i} - T_a)}{T_{1u} - T_a} = e^{\frac{S_e}{c_{pw} \cdot G_w \cdot R1}},$$

$$\frac{(T_{1u} - T_a)}{T_{1i} - T_a} = e^{-\frac{S_e}{c_{pw} \cdot G_w \cdot R1}},$$

$S_e = 1.225 m^2$ $T_{1i} := (85 + 273.15) \cdot K$, , $R1 = 25.201 \cdot \Omega_T$, $T_a = 273.15 K$

$$T_{1u} := (T_{1i} - T_a) \cdot e^{-\frac{S_e}{c_{pw} \cdot G_w \cdot R1}} + T_a$$

$$T_{1u} = 84.993 \cdot {}^\circ C.$$

From the above formula can also be derived R1 and therefore to know the thickness of the insulation (assuming that it is not known):

$$R1 = \frac{S_e}{c_{pw} \cdot G_w \cdot \ln\left[\frac{(T_{1i} - T_a)}{T_{1u} - T_a}\right]} = \frac{2 \cdot \pi \cdot r_{et} \cdot L_T}{c_{pw} \cdot G_w \cdot \ln\left[\frac{(T_{1i} - T_a)}{T_{1u} - T_a}\right]},$$

$$R1 = \mathbf{25.201} \cdot \Omega_T.$$

$$r_{et} := \frac{R1 \cdot c_{pw} \cdot G_w}{2 \cdot \pi \cdot L_{Tu}} \cdot \ln\left[\frac{(T_{1i} - T_a)}{T_{1u} - T_a}\right],$$

$$r_{et} - r_{it} = \mathbf{7} \cdot mm$$

The minimum flow rate for the water does not freeze is:

$$G_{wt} := \frac{S_e}{c_{pw} \cdot R1 \cdot \ln\left[\frac{(T_{1i} - T_a)}{T_{1u} - T_a}\right]},$$

$$G_{wt} = \mathbf{474.48} \cdot \frac{kg}{hr},$$

$$G_{vw} := \frac{G_w}{\rho_w} \qquad G_{vw} = \mathbf{0.132} \cdot \frac{L}{s}$$

$$y(T_1) := \frac{S_e}{c_{pw} \cdot R1 \cdot \ln\left[\frac{(T_1 - T_a)}{T_{1u} - T_a}\right]}$$

Minimum flow rate v/s the internal temperature in the pipe entry.