

Mass balance of vapour

RESIDENTIAL ACTIVITIES	VAPOUR RATE
Hob (electric)	2 kg/day
Hob (gas)	3 kg/day
Dish washing	0,4 kg/day
Personnel hygiene (shower, etc.)	0.2 kg/(day px)
Washing clothes (hand or washing machine)	0.5 kg/day
Drying clothes (dryer or hanging clothes)	Up to 1.5 kg/(day px)

DAILY HUMIDITY FOR THE DIFFERENT ACTIVITIES

Number of persons	Humidity [kg/day]		
	Low rate of humidity	Average rate of humidity	High rate of humidity
1	3.5	6	9
2	4	8	11
3	4	9	12
4	5	10	14
5	6	11	15
6	7	12	16

Vapour Balance

$$G_a (x_i - x_{IN}) = G_v$$

Vapour rate

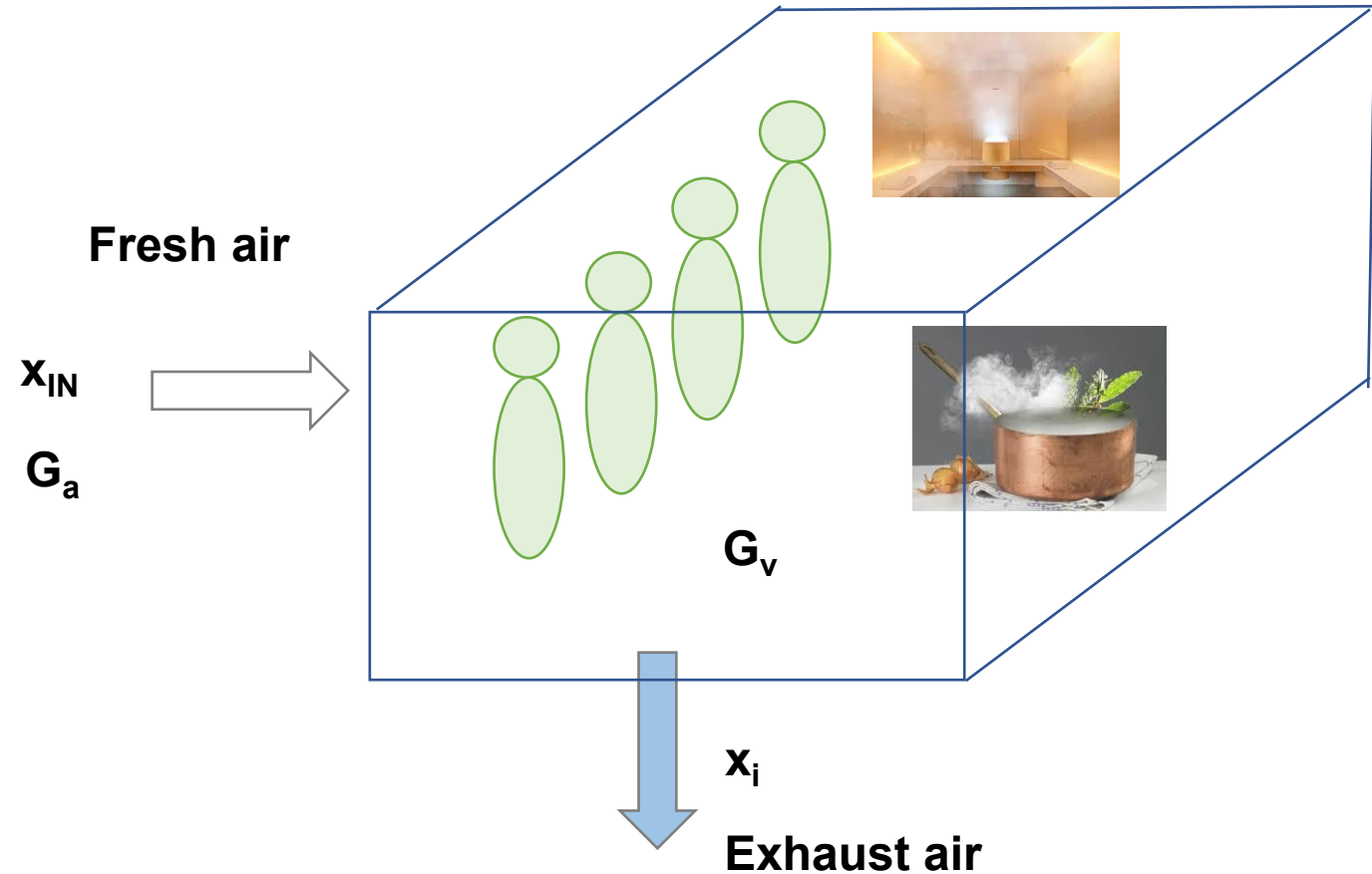
Mass flow rate of the air

x_{IN} Entering humidity ratio in the room

$$x_i = x_{IN} + G_v / G_a$$

Two cases:

1. Supply air with the outdoor humidity ratio ($x_{IN} = x_o$)
2. Supply handled air ($x_{IN} = x_o$)



Example 1 (winter):

Residential building

Volume: $3 \times 8 \times 12 = 288 \text{ m}^3$

ACH: $n = 0.5 \text{ h}^{-1}$

$G_v = 10 \text{ kg}_v / (\text{day})$

$$G_a (x_i - x_e) = G_v$$

$$x_e = 3.5 \text{ g}_v/\text{kg}_{\text{da}}$$

$$G_a = n V \rho = 0.5 \times 288 \times 1.2 = 173 \text{ kg/h}$$

$$x_i = x_e + G_v / G_a$$

$$G_v = 10 \text{ kg}_v / (\text{day}) = 10/24 = 417 \text{ g}_v/\text{h}$$

$$x_i = 3.5 + 417 / 173 = 5.9 \text{ g}_v/\text{kg}_{\text{da}}$$

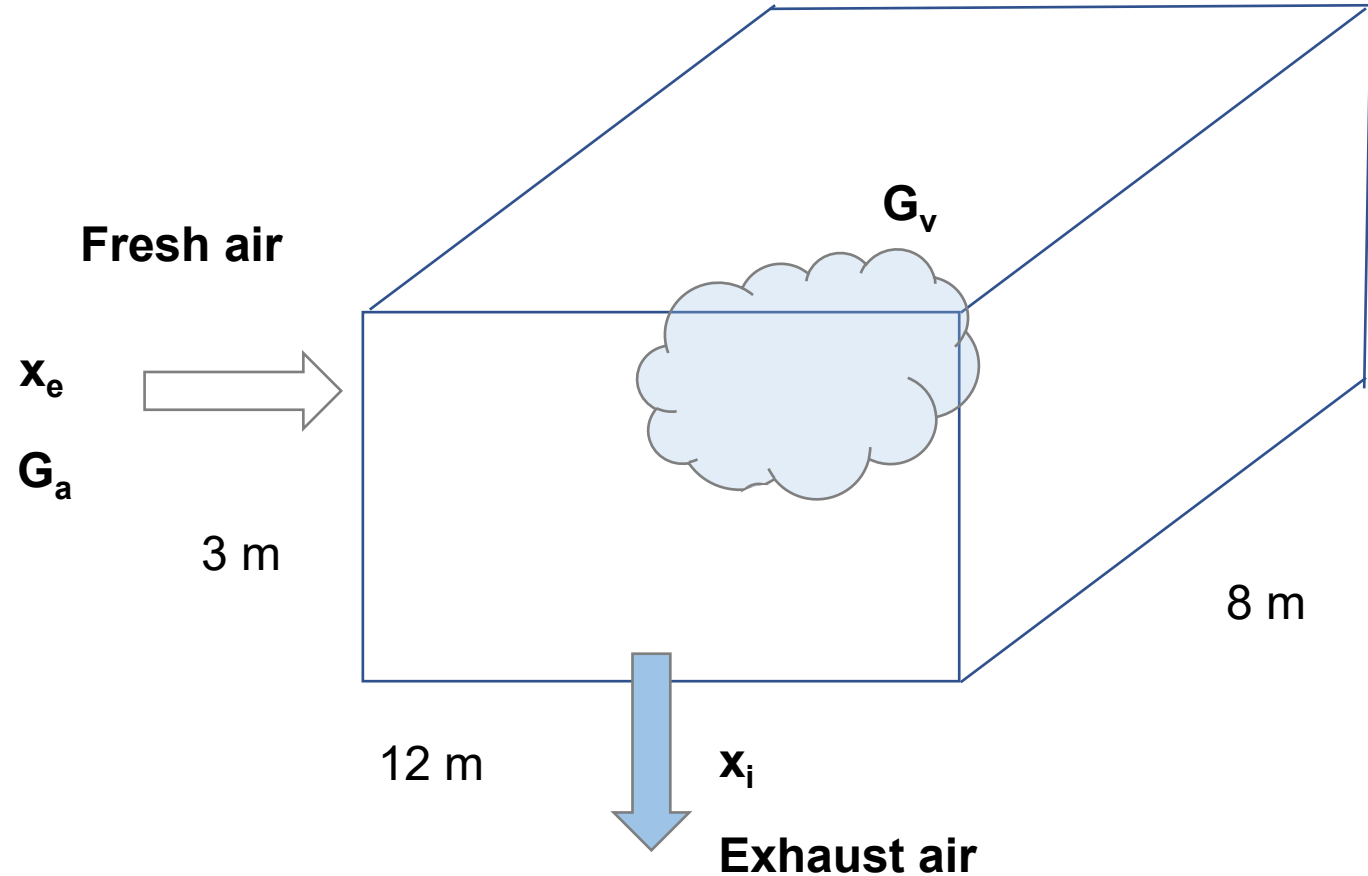
With $t_i = 20^\circ\text{C}$, $\text{RH} = 40\%$

If ACR: $n = 0.2 \text{ h}^{-1}$

$$G_a = 0.3 \times 288 \times 1.2 = 70 \text{ kg}_a / \text{h}$$

$$x_i = 3.5 + 417 / 70 = 9.75 \text{ g}_v/\text{kg}_{\text{da}}$$

With $t_i = 20^\circ\text{C}$, $\text{RH} = 65\%$



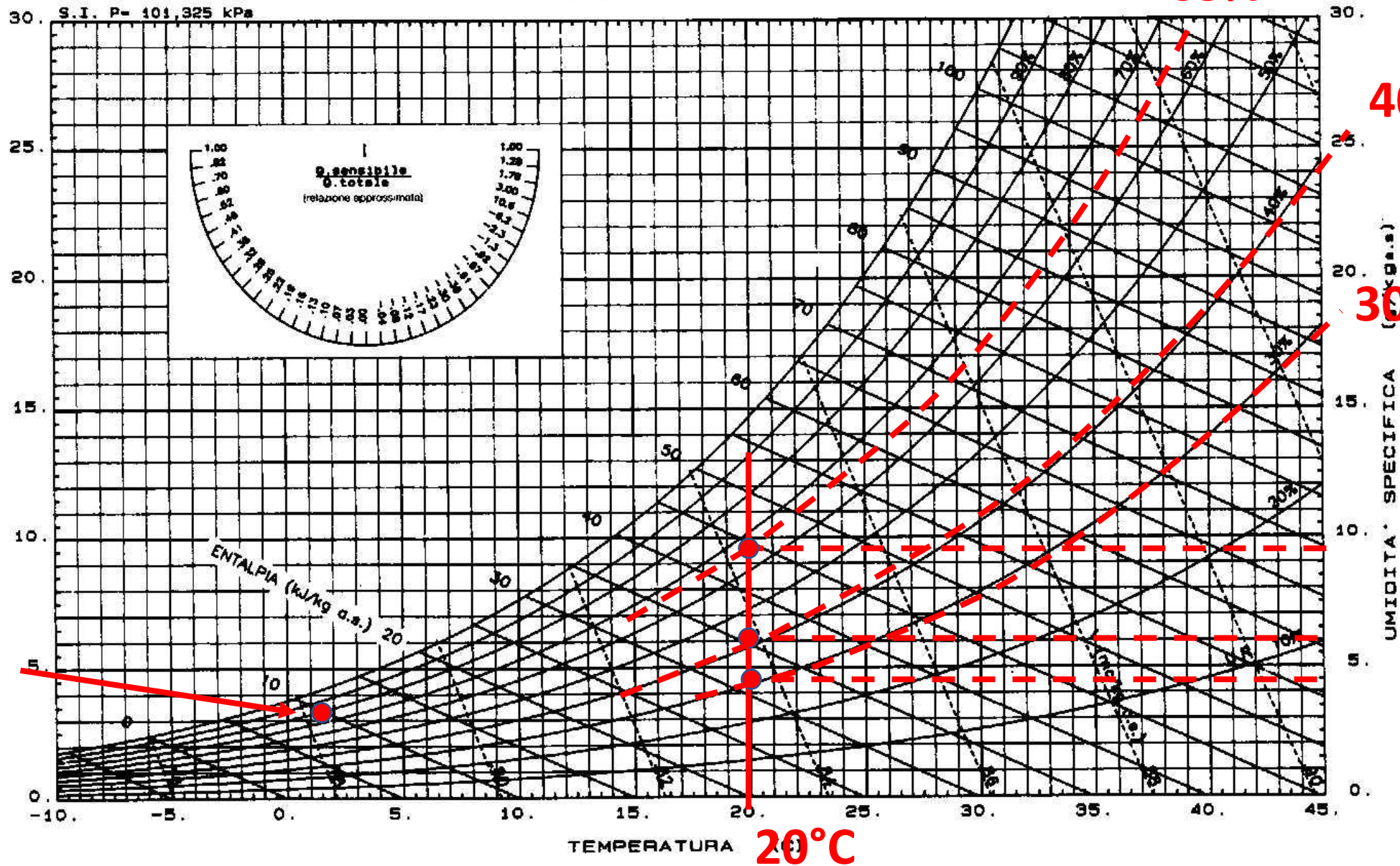
If ACR: $n = 1.0 \text{ h}^{-1}$

$$G_a = 1.0 \times 288 \times 1.2 = 346 \text{ kg}_a / \text{h}$$

$$x_i = 3.5 + 417 / 346 = 4.7 \text{ g}_v/\text{kg}_{\text{da}}$$

With $t_i = 20^\circ\text{C}$, $\text{RH} = 30\%$

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Outdoor

20°C

65%

40%

30%

Example 2 (summer):

Residential building

Volume: $3 \times 8 \times 12 = 288 \text{ m}^3$

ACR: $n = 0.5 \text{ h}^{-1}$

$G_v = 10 \text{ kg}_v / (\text{day})$

$$G_a (x_i - x_e) = G_v$$

$$x_e = 13.5 \text{ g}_v/\text{kg}_{\text{da}}$$

$$G_a = n V \rho = 0.5 \times 288 \times 1.2 = 173 \text{ kg/h}$$

$$x_i = x_e + G_v / G_a$$

$$G_v = 10 \text{ kg}_v / (\text{day}) = 10/24 = 417 \text{ g}_v/\text{h}$$

$$x_i = 13.5 + 417 / 173 = 15.9 \text{ g}_v/\text{kg}_{\text{da}}$$

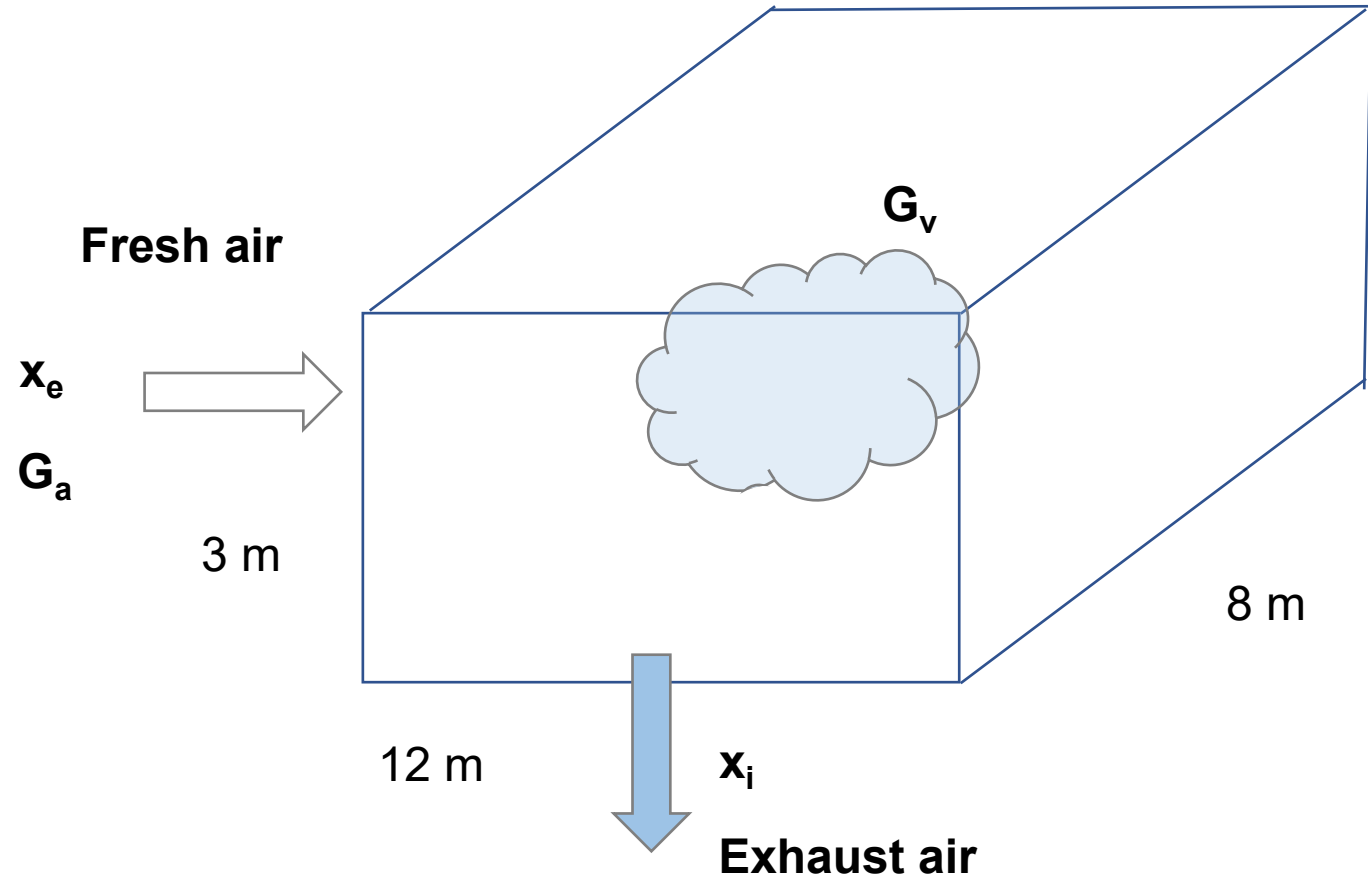
With $t_i = 26^\circ\text{C}$, $\text{RH} = 75\%$

If ACR: $n = 1.0 \text{ h}^{-1}$

$$G_a = 1.0 \times 288 \times 1.2 = 346 \text{ kg}_a / \text{h}$$

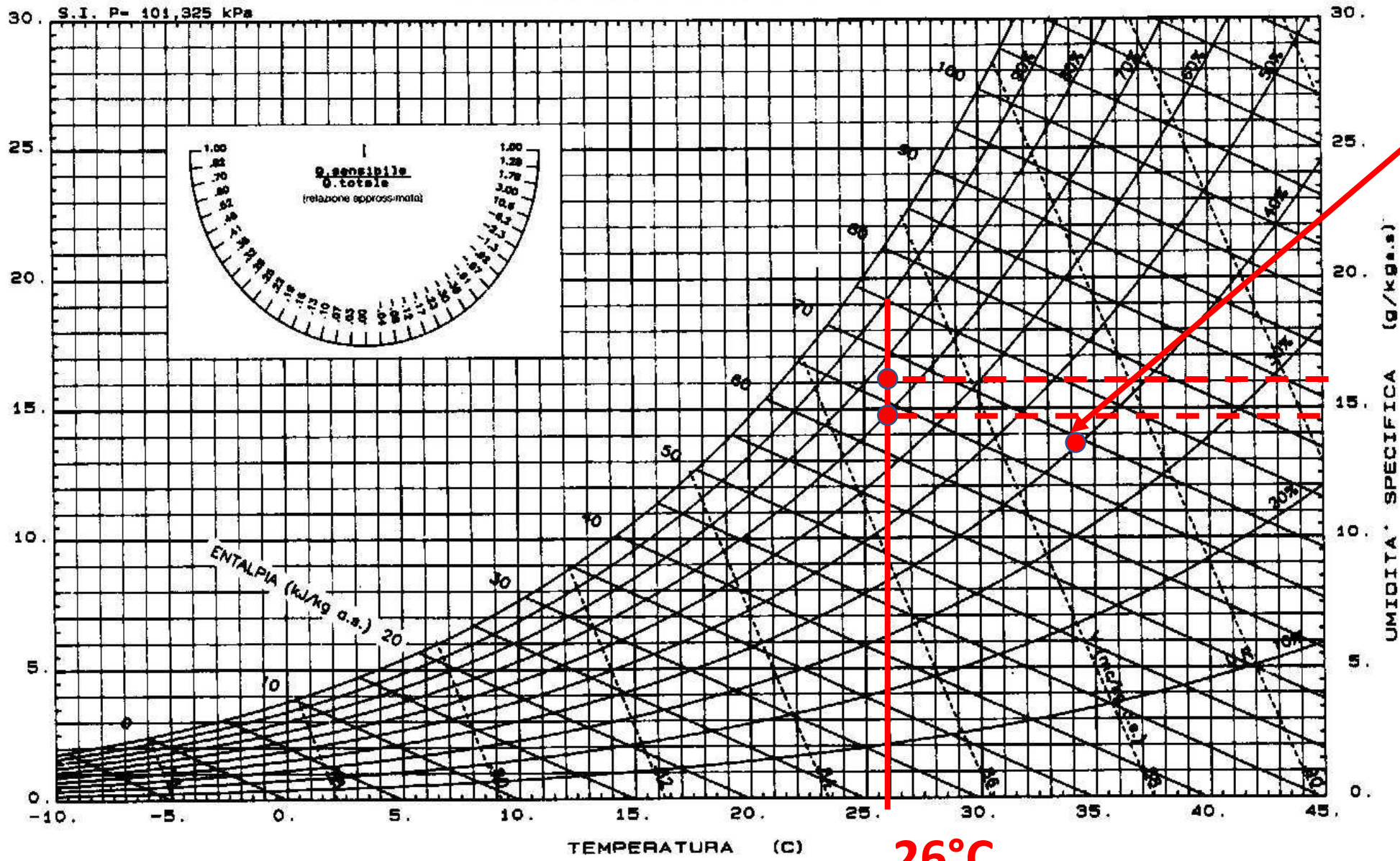
$$x_i = 13.5 + 417 / 70 = 14.7 \text{ g}_v/\text{kg}_{\text{da}}$$

With $t_i = 26^\circ\text{C}$, $\text{RH} = 70\%$



In summer it is necessary to dehumidify the air

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Outdoor

26°C

Example 3 (summer):

Residential building

Volume: $3 \times 8 \times 12 = 288 \text{ m}^3$

ACR: $n = 0.5 \text{ h}^{-1}$

$G_v = 10 \text{ kg}_v / (\text{day})$

$$G_a (x_i - x_e) = G_v$$

$$x_e = 13.5 \text{ g}_v/\text{kg}_{\text{da}}$$

$$G_a = n V \rho = 0.5 \times 288 \times 1.2 = 173 \text{ kg/h}$$

$$x_i = x_{\text{IN}} + G_v / G_a$$

$$G_v = 10 \text{ kg}_v / (\text{day}) = 10/24 = 417 \text{ g}_v/\text{h}$$

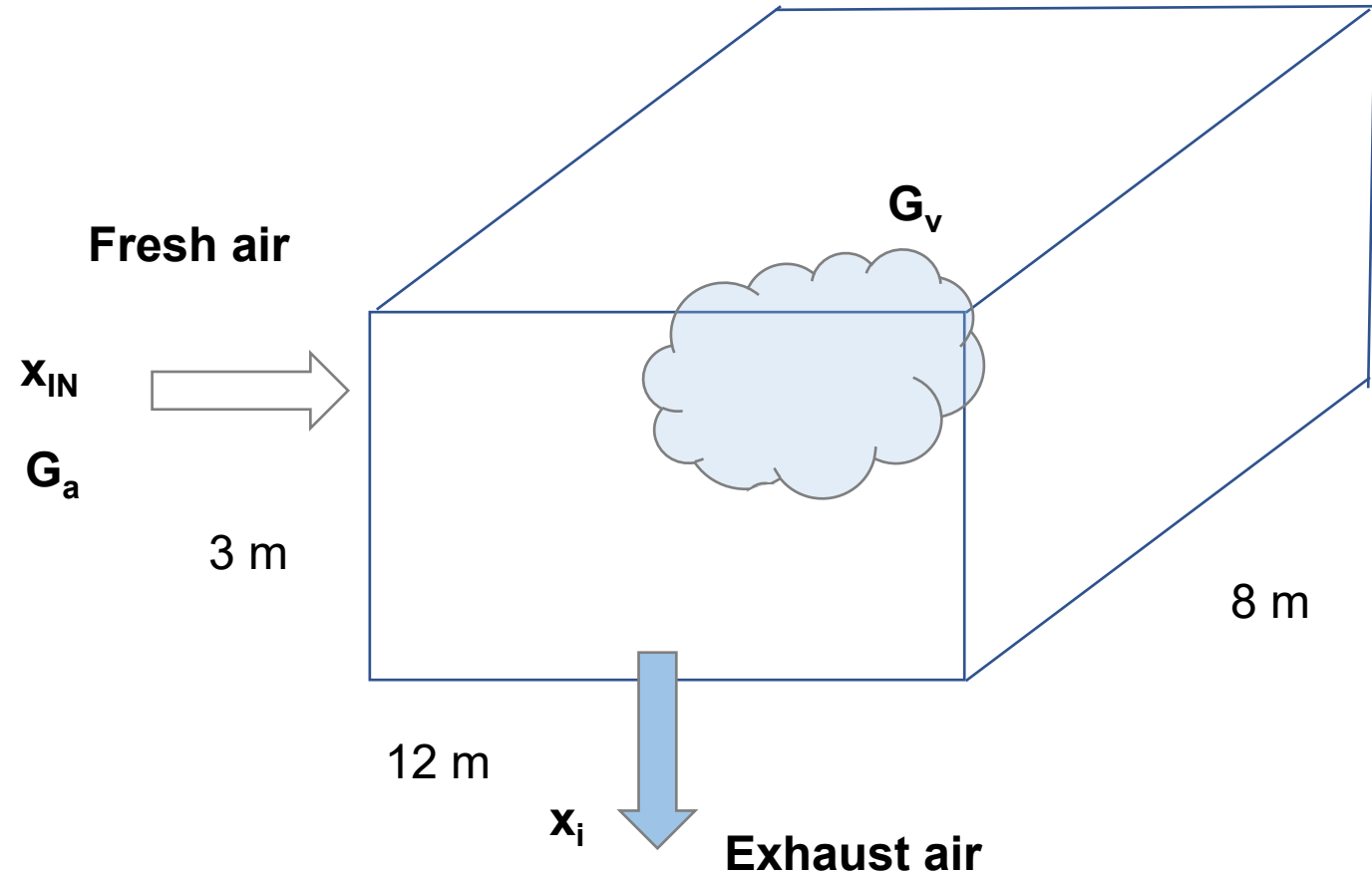
Cooling and dehumidification coil

$$t_{\text{IN}} = 16^\circ\text{C}$$

$$x_{\text{IN}} = 8.5 \text{ g}_v/\text{kg}_{\text{as}}$$

$$x_i = 8.5 + 417 / 173 = 10.9 \text{ g}_v/\text{kg}_{\text{da}}$$

With $t_i = 26^\circ\text{C}$, $\text{RH} = 50\%$



Cooling and dehumidification coil

$$t_{iN} = 16^{\circ}\text{C}$$

$$x_{iN} = 8.5 \text{ g}_v/\text{kg}_{as}$$

$$x_i = 8.5 + 417 / 173 = 10.9 \text{ g}_v/\text{kg}_{da}$$

With $t_i = 26^{\circ}\text{C}$, $\text{RH} = 50\%$

If $n = 1.0 \text{ h}^{-1}$

$$G_a = 1.0 \times 288 \times 1.2 = 346 \text{ kg}_a / \text{h}$$

$$x_i = 8.5 + 417 / 346 = 9.7 \text{ g}_v/\text{kg}_{da}$$

With $t_i = 26^{\circ}\text{C}$, $\text{RH} = 45\%$

If $n = 2.0 \text{ h}^{-1}$

$$G_a = 2.0 \times 288 \times 1.2 = 692 \text{ kg}_a / \text{h}$$

$$x_i = 8.5 + 417 / 692 = 9.1 \text{ g}_v/\text{kg}_{da}$$

With $t_i = 26^{\circ}\text{C}$, $\text{RH} = 43\%$

If $n = 3.0 \text{ h}^{-1}$

$$G_a = 3.0 \times 288 \times 1.2 = 1038 \text{ kg}_a / \text{h}$$

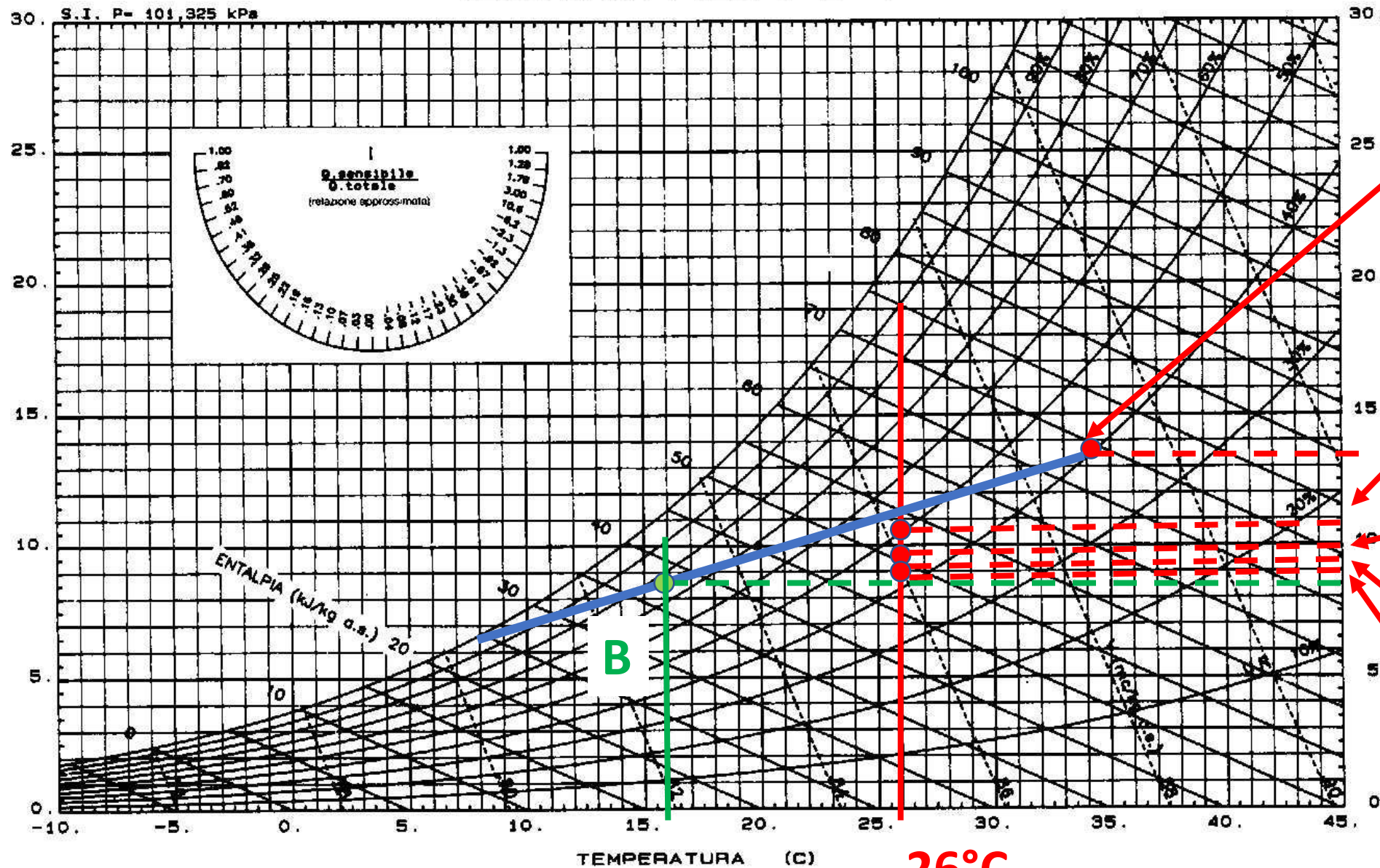
$$x_i = 8.5 + 417 / 1038 = 8.9 \text{ g}_v/\text{kg}_{da}$$

With $t_i = 26^{\circ}\text{C}$, $\text{RH} = 42\%$

x_i does not change much because we kept $x_{iN} = 8.5 \text{ g}_v/\text{kg}_{as}$

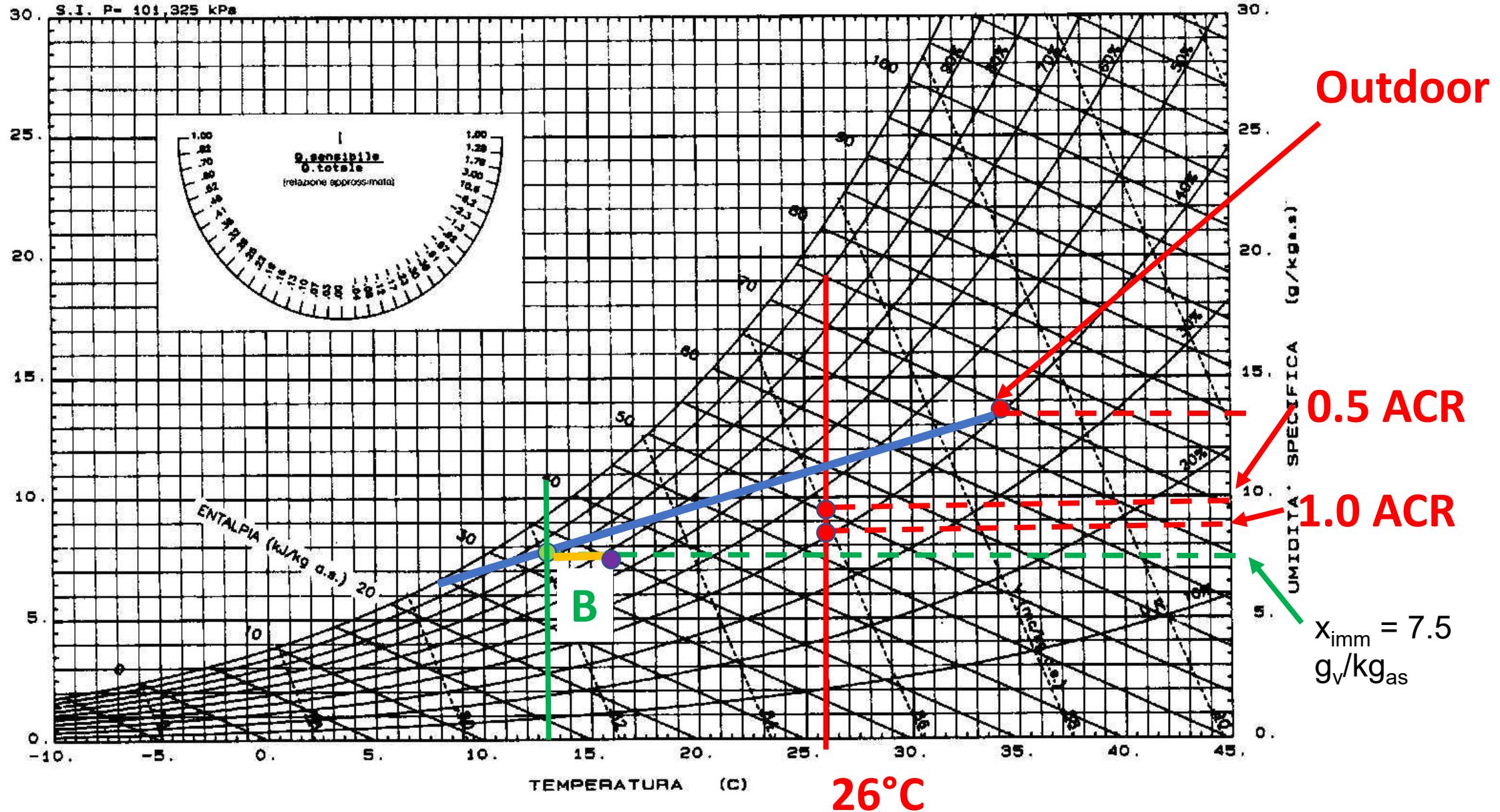
We could lower the x_{iN} , but then we should re-heat the air up to 16°C , to avoid condensation in the ducts/air terminal devices (ATD)
Example of re-heat coil in slide 11 for ACR 0.5 h^{-1} and 1.0 h^{-1}

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With re-heat coil

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At the same time the supply air at 16°C will provide cooling:

In case of ACR = 0.5 h⁻¹:

$$q_g = G_a c_p (t_{iN} - t_i) = 173 \times 1007 \times (16 - 26) / 3600 = -483 \text{ W}$$

$$q_{g,\text{specific}} = q_g / A_f = 483 / 96 = -5 \text{ W/m}^2 \quad \longrightarrow \quad \text{Useful cooling for the dwelling}$$

$$q_{\text{coil}} = G_a (h_B - h_o) = 173 \times (37 - 69) / 3600 = -1.54 \text{ kW} \quad \longrightarrow \quad \text{Power of the chiller}$$


In case of ACR = 1.0 h⁻¹:

$$q_g = G_a c_p (t_{iN} - t_i) = 346 \times 1007 \times (16 - 26) / 3600 = -967 \text{ W}$$

$$q_{g,\text{specific}} = q_g / A_f = -967 / 96 = -10 \text{ W/m}^2 \quad \longrightarrow \quad \text{Useful cooling for the dwelling}$$

$$q_{\text{coil}} = G_a (h_B - h_o) = 346 \times (37 - 69) / 3600 = -3.07 \text{ kW} \quad \longrightarrow \quad \text{Power of the chiller}$$

For a dwelling we could assume at least 30 W/m² (check your cooling peak loads in each room)

Supposing a specific power 30 W/m²: $P_{\text{dwelling}} = -30 \times 96 = -2880 \text{ W}$  Power of the dwelling

$$G_a = P_{\text{dwelling}} / [c_p (t_{\text{IN}} - t_i)] = -2880 / [1007 \times (16 - 26)] = 0.286 \text{ kg/s}$$

$$n = G_a \times 3600 / (\rho V) = 0.286 \times 3600 / (1.2 \times 288) = 3 \text{ h}^{-1}$$

There are 2 options:

- All fresh air

$$q_{\text{coil}} = G_a (h_B - h_o) = 0.286 \times (37 - 69) = -9.1 \text{ kW}$$
  Power of the chiller

With heat recovery unit:

$$q_{\text{coil}} = G_a (h_B - h_o) = 0.286 \times (39 - 63) = -6.9 \text{ kW}$$

- Recirculating air:

$$n = 1 \text{ h}^{-1} \text{ outdoor air} \quad t_o = 34^\circ\text{C}, \text{ RH}_o = 40\%$$

$$n = 2 \text{ h}^{-1} \text{ recirculation air} \quad t_i = 26^\circ\text{C}, \text{ RH}_o = 45\%$$

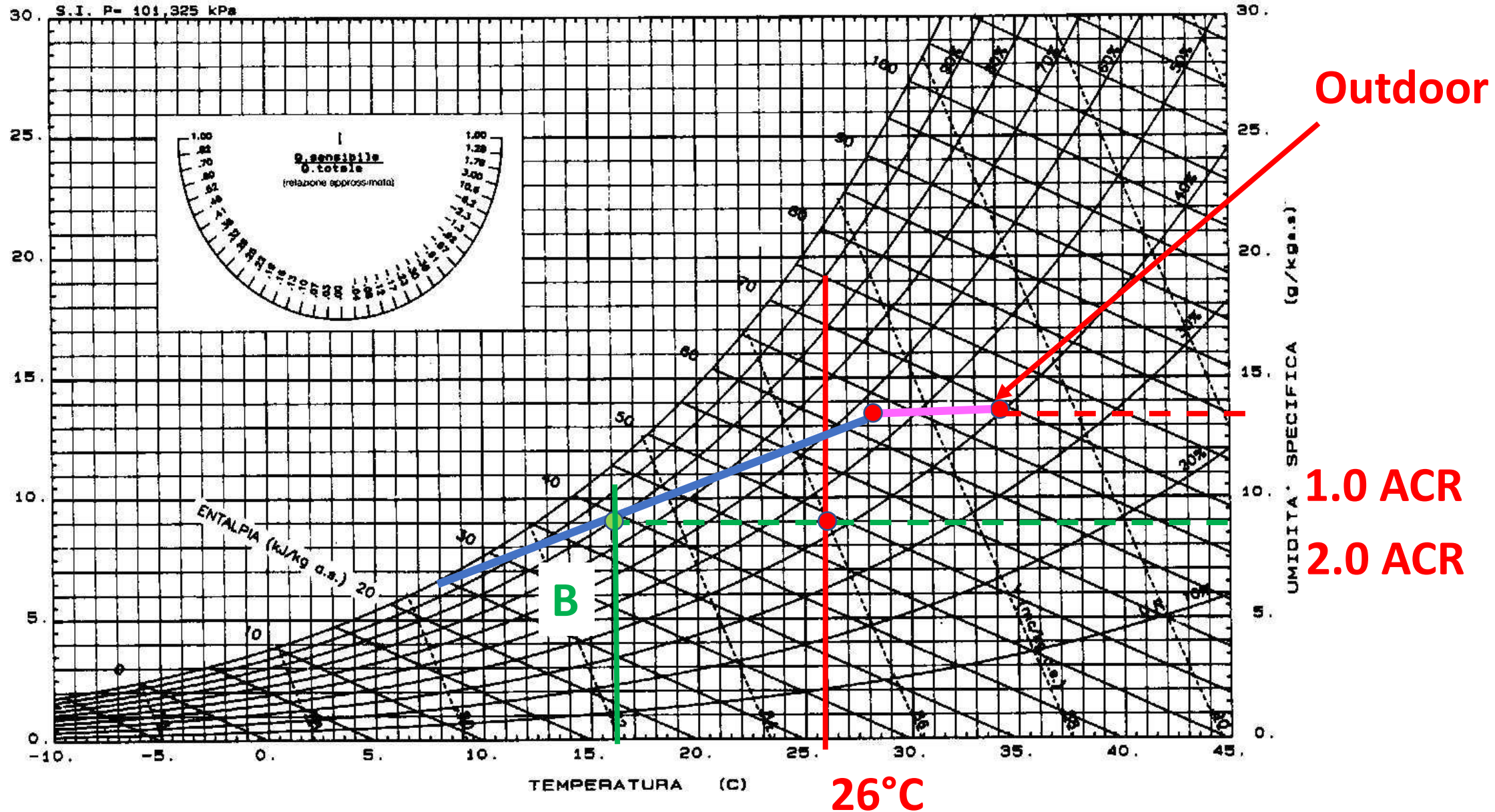
$$q_{\text{coil}} = G_a (h_B - h_o) = 0.286 \times (37 - 56) = -5.7 \text{ kW}$$
  Power of the chiller

With heat recovery unit:

$$q_{\text{coil}} = G_a (h_B - h_o) = 0.286 \times (37 - 53) = -4.6 \text{ kW}$$

All fresh air Heat recovery unit

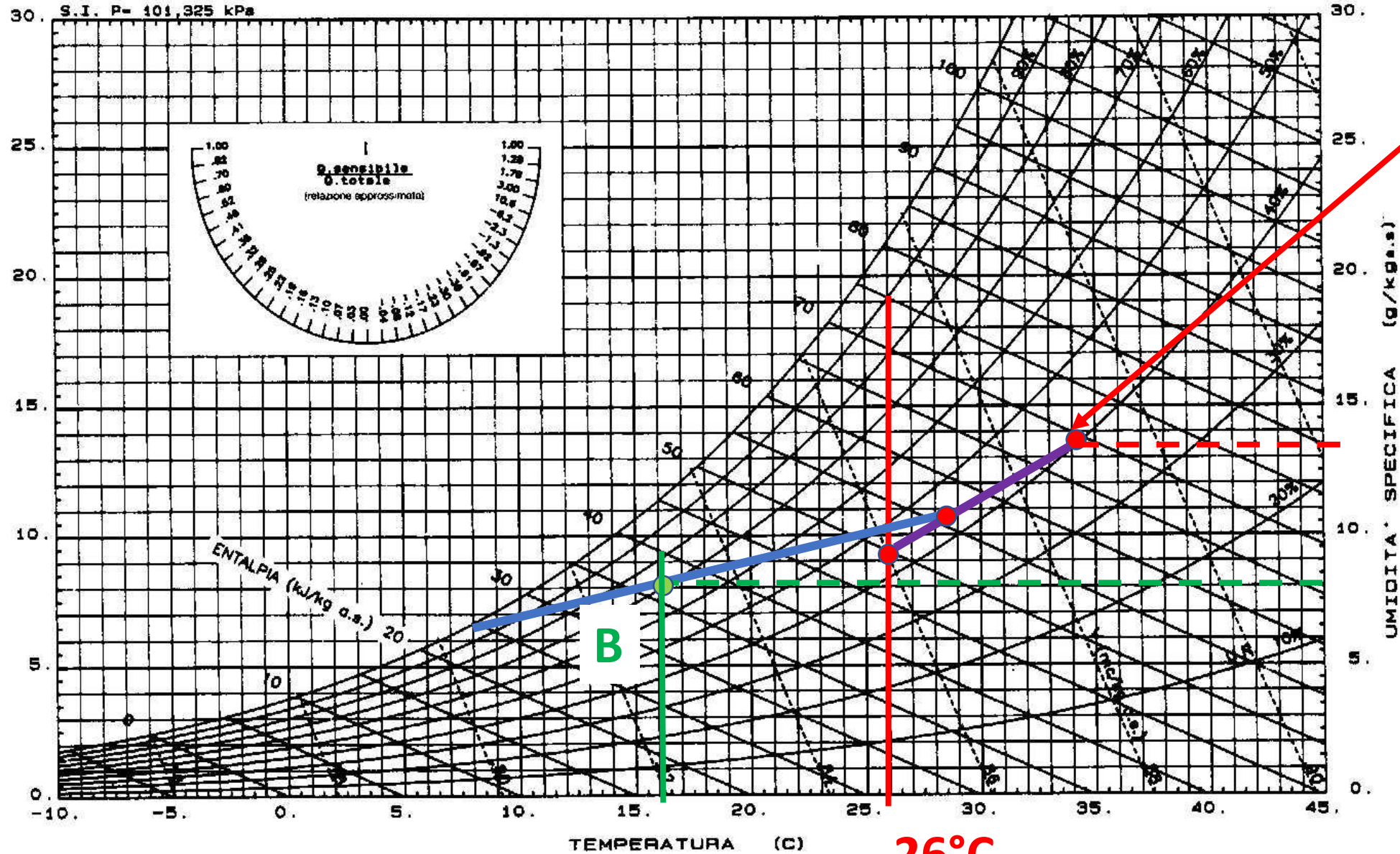
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1.0 ACR fresh air

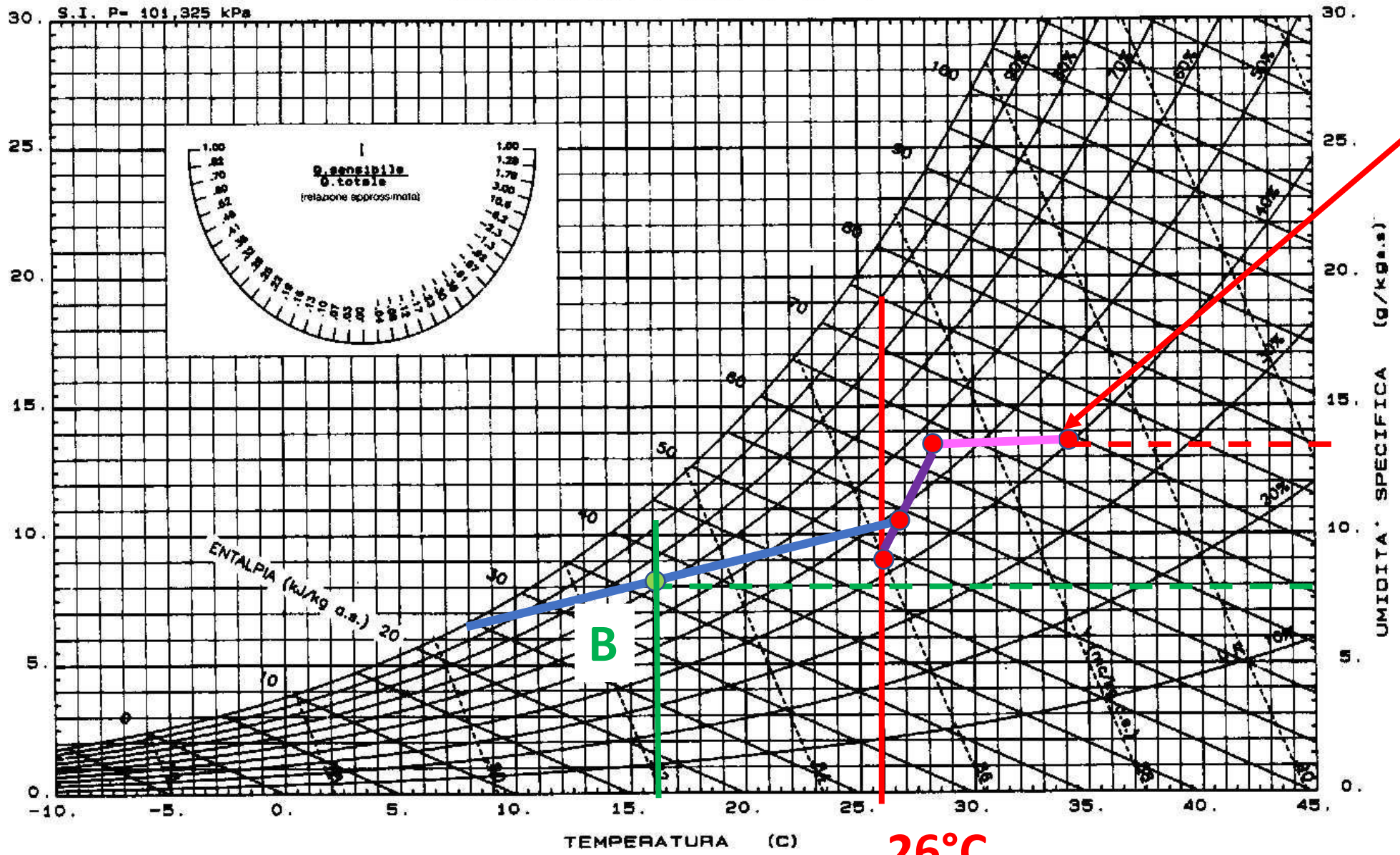
2.0 ACR recirculation

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Recirculation Heat recovery unit

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Winter power:

Residential building

$$P_{\text{transmission}} = 3900 \text{ W}$$

Let's fix: $t_{\text{IN}} = 40^\circ\text{C}$

$$G_a = P_{\text{transmission}} / [c_p (t_{\text{IN}} - t_i)] = 3900 / [1007 \times (40 - 20)] = 0.174 \text{ kg/s}$$

$$n = G_a \times 3600 / (\rho V) = 0.174 \times 3600 / (1.2 \times 288) = 1.8 \text{ h}^{-1}$$

$$P_{\text{coil}} = G_a \times c_p (t_{\text{IN}} - t_o) = 0.174 \times 1007 \times (40 + 5) = 7885 \text{ W}$$

Residential building

$$P_{\text{transmission}} = 1050 \text{ W}$$

$$n = 1.0 \text{ h}^{-1}$$

$$G_a = n \times \rho \times V / 3600 = 1.0 \times 1.2 \times 288 / 3600 = 0.096 \text{ kg/s}$$

$$t_{\text{IN}} = t_i + P_{\text{transmission}} / (G_a \times c_p) = 20 + 1050 / (0.096 \times 1007) = 31^\circ\text{C}$$

$$P_{\text{coil}} = G_a \times c_p (t_{\text{IN}} - t_o) = 0.096 \times 1007 \times (31 + 5) = 3480 \text{ W}$$

With heat recovery unit:

Residential building

$$P_{\text{transmission}} = 3900 \text{ W}$$

$$P_{\text{coil}} = G_a \times c_p (t_{\text{IN}} - t_o) = 0.174 \times 1007 \times (40 - 13,8) = 4590 \text{ W}$$

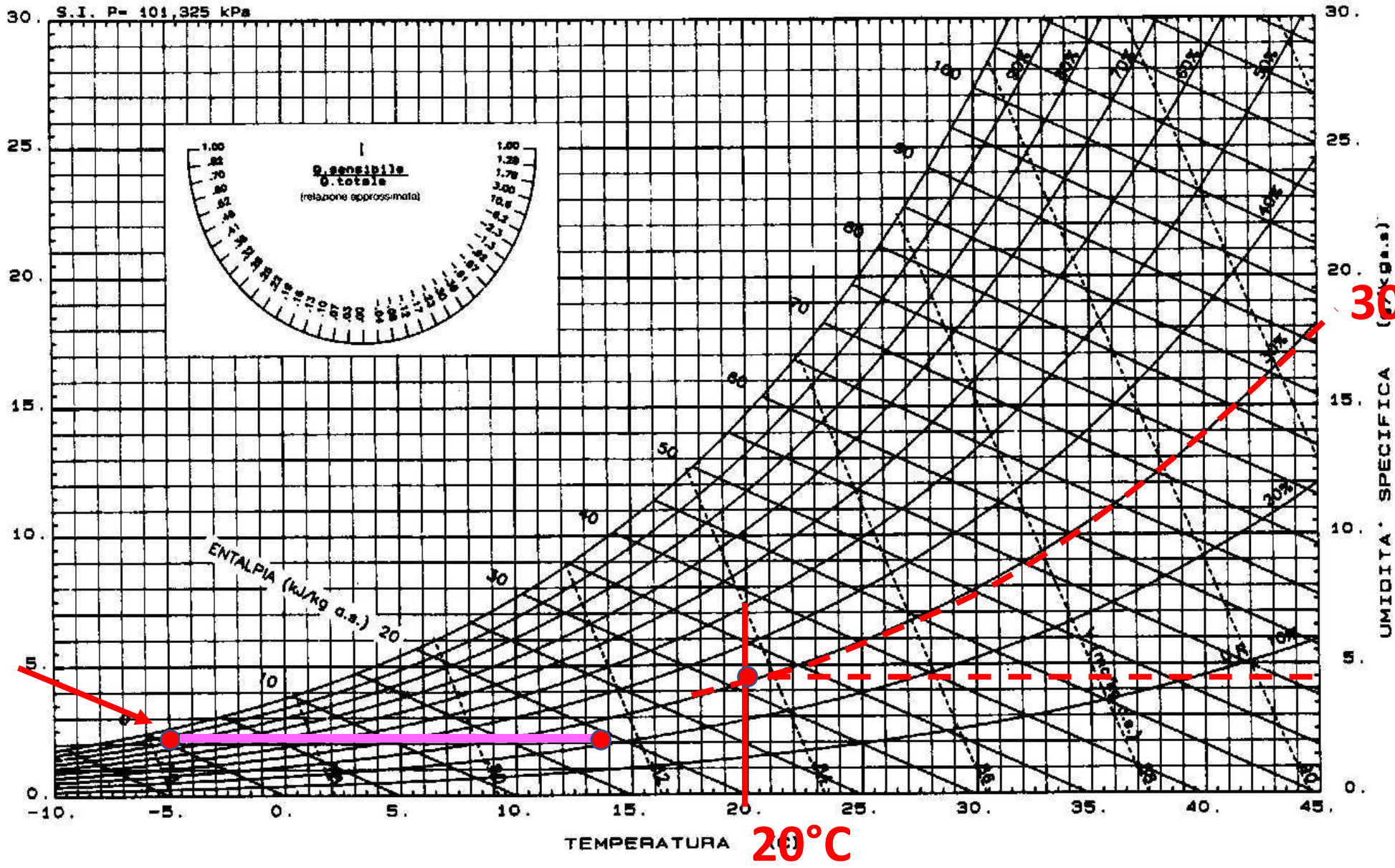
Residential building

$$P_{\text{transmission}} = 1050 \text{ W}$$

$$P_{\text{coil}} = G_a \times c_p (t_{\text{IN}} - t_o) = 0.096 \times 1007 \times (31 - 13,8) = 1660 \text{ W}$$

Heat recovery unit design winter

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30%

Outdoor

20°C