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Thermal simulation of buildings and HVAC systems: do it yourself!

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Introduction

Main information sources:

-	IEA ECBCS Annex 10	(1982-1987)
-	ASHRAE primary toolkit	(1990-1993)
-	IEA ECBCS Annex 40	(2000-2005)
-	IEA ECBCS Annex 43	(2003-2007)
-	AUDITAC	(2005-2006)
-	IEA ECBCS Annex 48	(2005-2009)

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- Simulation can help a lot all along the building life cycle, if the models are made easy to understand by all potential users.

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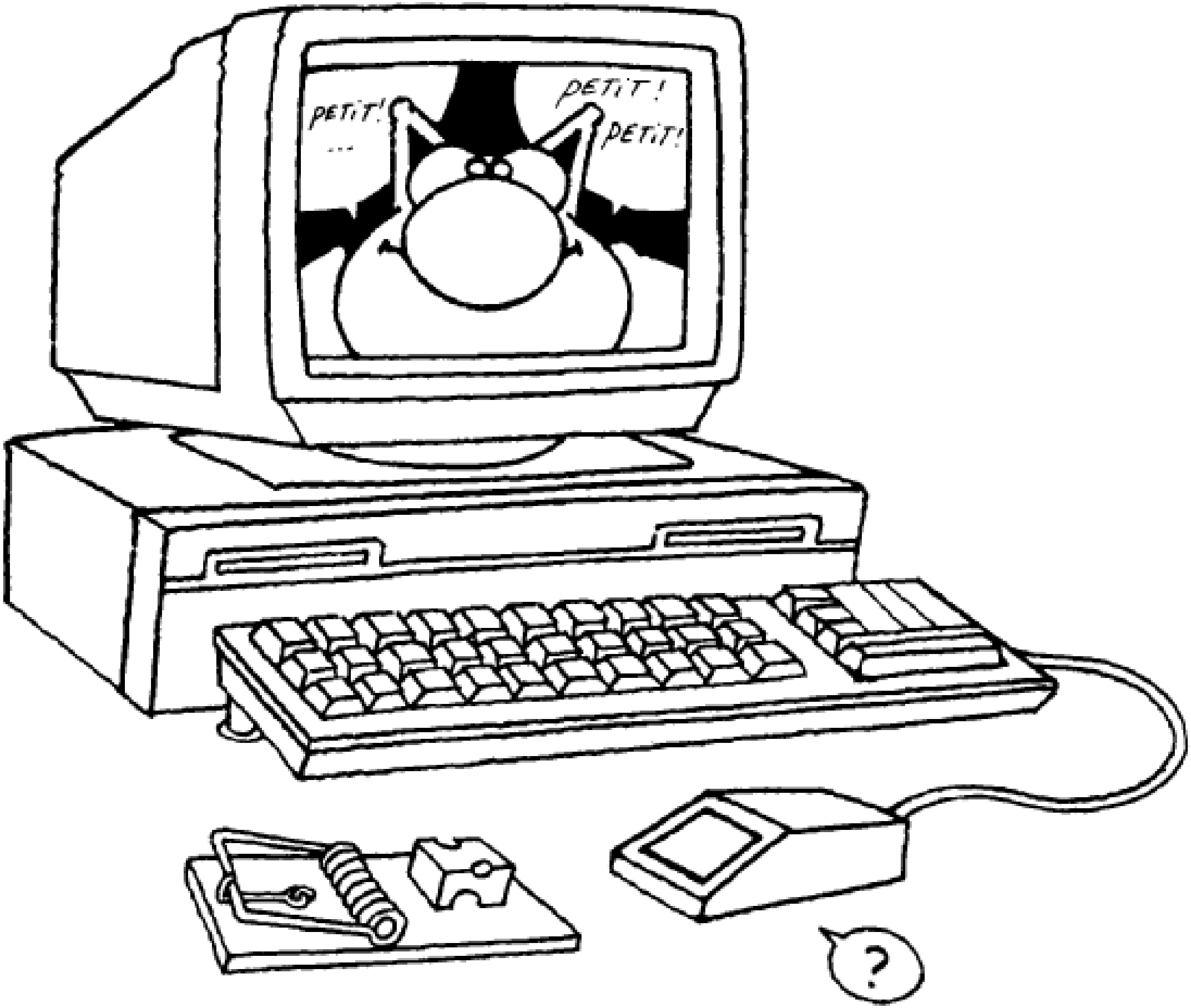
Why to simulate?


PETIT! ...
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?

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- To support initial design
- To size, select and optimise the system
- To adjust, balance & commission
- To optimise control, management & maintenance
- To support periodical audit
- To identify retrofit opportunities.

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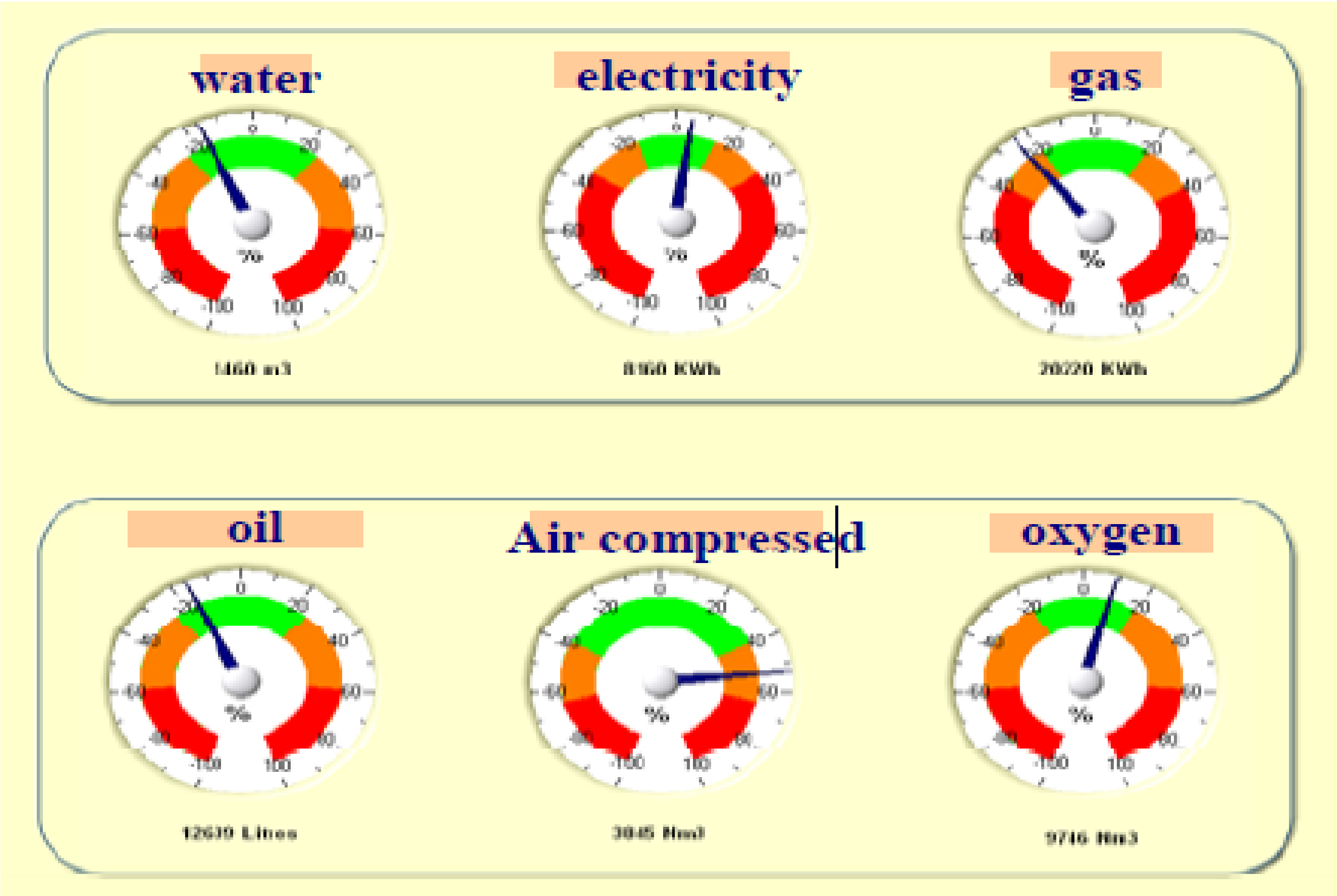
Real-time view of the energy consumptions:



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Commissioning and audit:

Simulation models can support:

- Experimental design
- Interpretation of measuring results
- Data conversion (when using some components as measuring devices)

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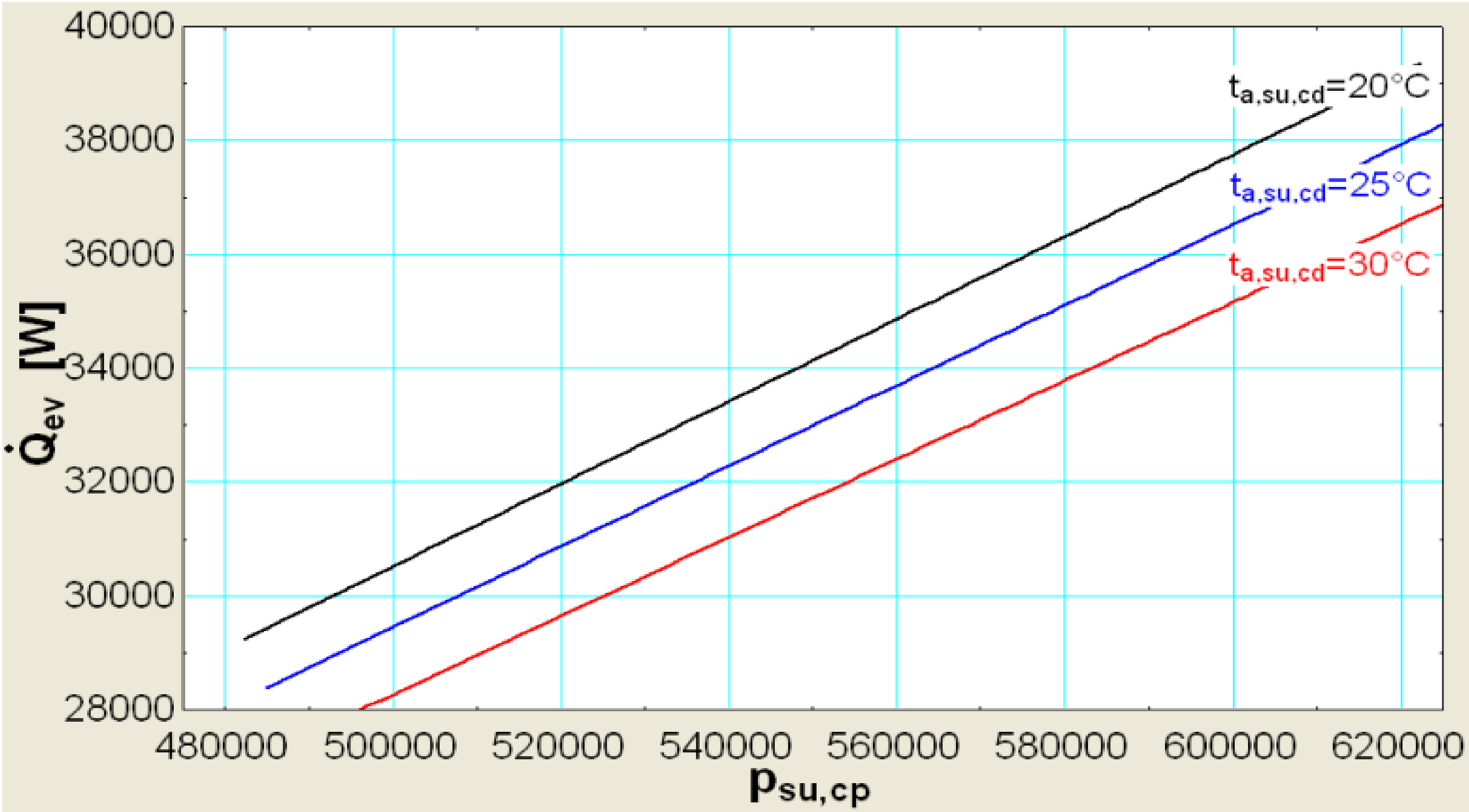
Cooling power defined as function of pressure at compressor supply:



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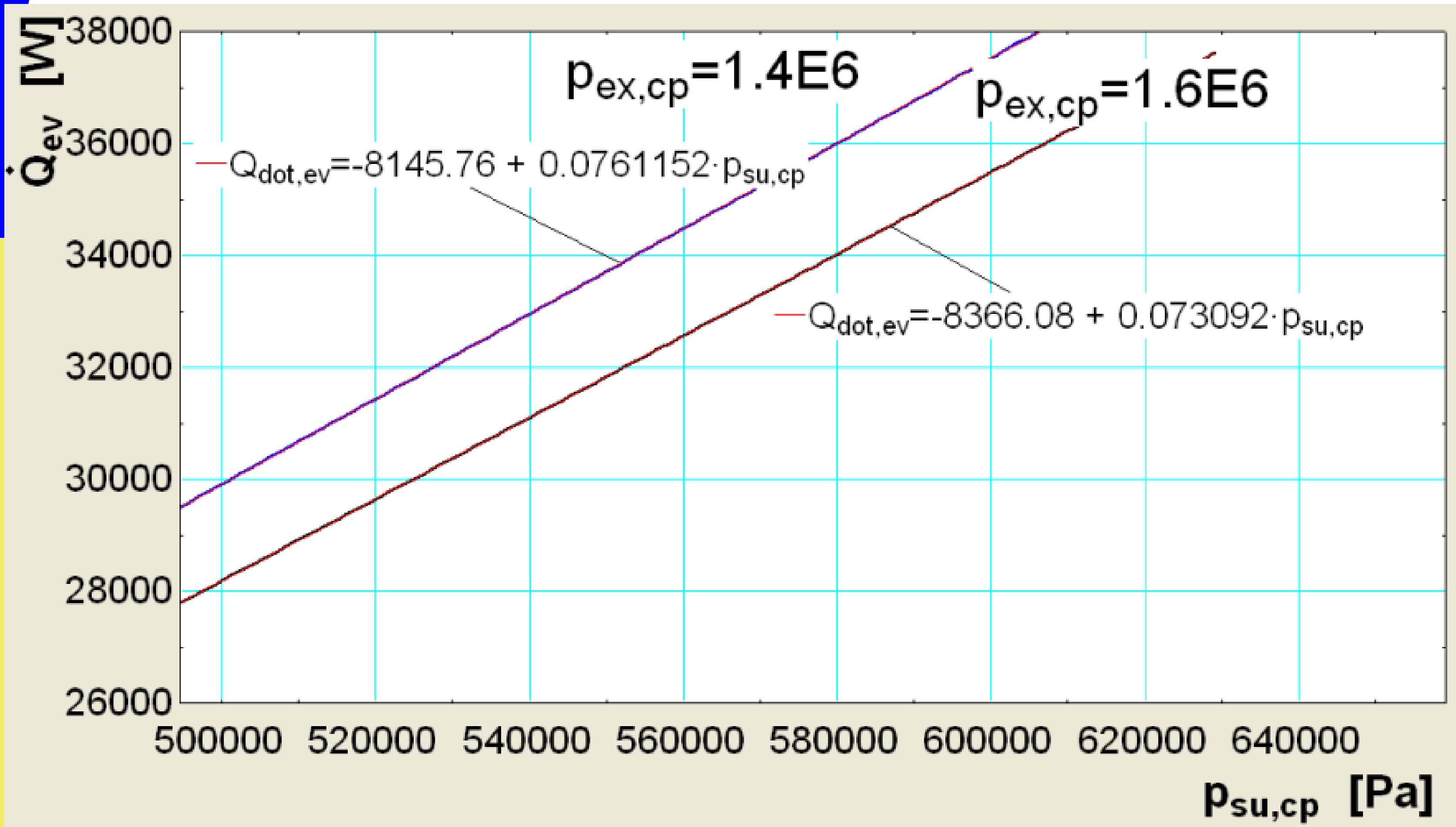
Shift function of condensing pressure:



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How to simulate?

- "*Causalities*" are for *our* understanding (not for the computer!):
- We like to speak of "Causes" and "Consequences"
- i.e. of "*Inputs*" and "*Outputs*"
- Constant inputs are "*parameters*"

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Simulation must be adapted to:

- objectives
- information looked for

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Make sure that:

- The output variables correspond to what the user is asking for;
- The calculation is accurate enough;
- The input variables are accessible;
- The parameters are identified without ambiguity;
- The user can understand!

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- Computer capabilities are growing much faster than our understanding of the physical phenomena we pretend to simulate

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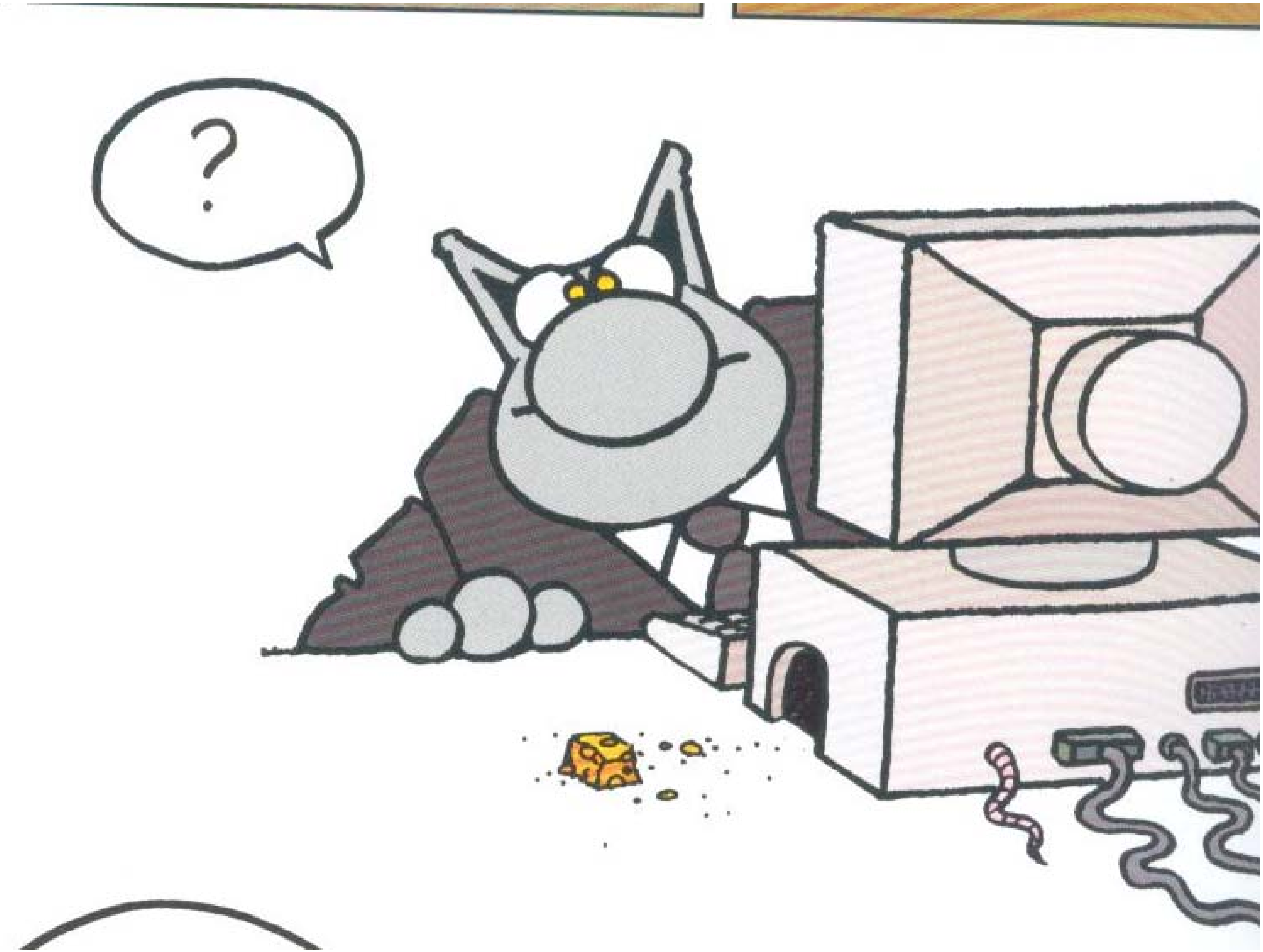
- “Observe” each component according to its actual impact on global simulation results
- Take profit of all filtering effects



Information flow diagrams

- Start from the end (as in daily life!):
- “What are we looking for?”
- And travel up-stream, until the begin:
- “What do we need?”

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“Mother”, “daughter” and “orphan” models:

- *How to choose?*

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Two typical cases:

1) “Simplified” model preferred when the component is well known

2) More detailed model preferred when the component “makes problem”, i.e. its characteristics must be (re)identified

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. “Mother” models:

- Based on real physics,
- Application-oriented
- Based on old children game: “let’s do as if”.

- The possibility of simulating in the detail a whole HVAC system with the help of an equation solver has been already demonstrated. Models libraries and practical simulation tools produced are already available.

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Tuning, validation and evaluation

- Caution to accuracy and to meaning of experimental and simulation data
- “The most beautiful girl couldn’t give more than what she has!”

Tuning:

- Even if “mechanistic”, the model has to be tuned *before* validation
- There is no shame in that,
- But the tuning should not depend on the humour of the user…

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Validation:

It can be performed in three ways:

- Analytically
- By comparison with *other* simulation results
- By comparison with experimental results.

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Evaluation:

Qualitative evaluation must integrate:

validation results

tuning easiness

Robustness

…

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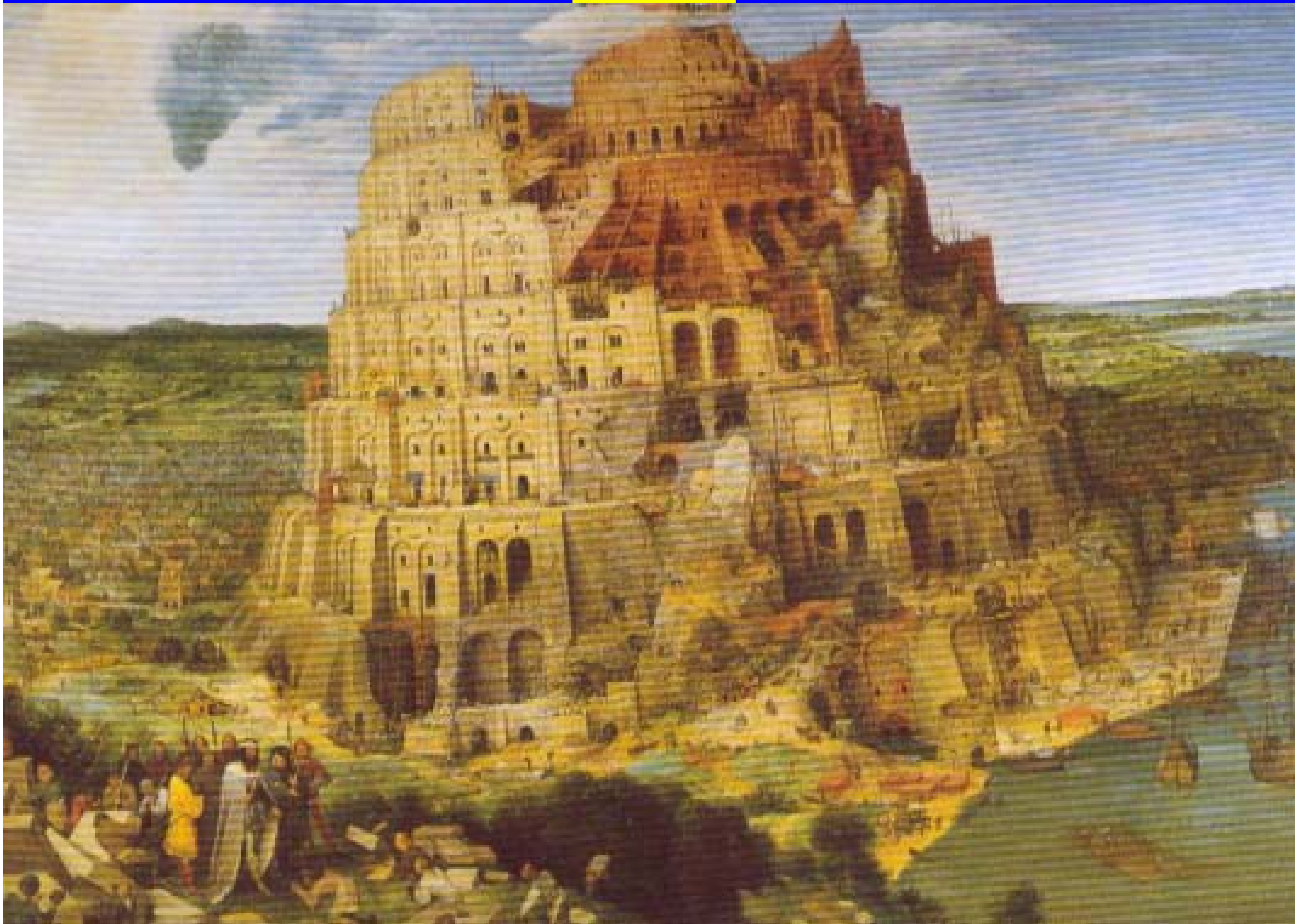
Use of an equation solver

- Scientists and practitioners have to speak to each other
- Using an equation solver makes equations as easy to read as a good novel!



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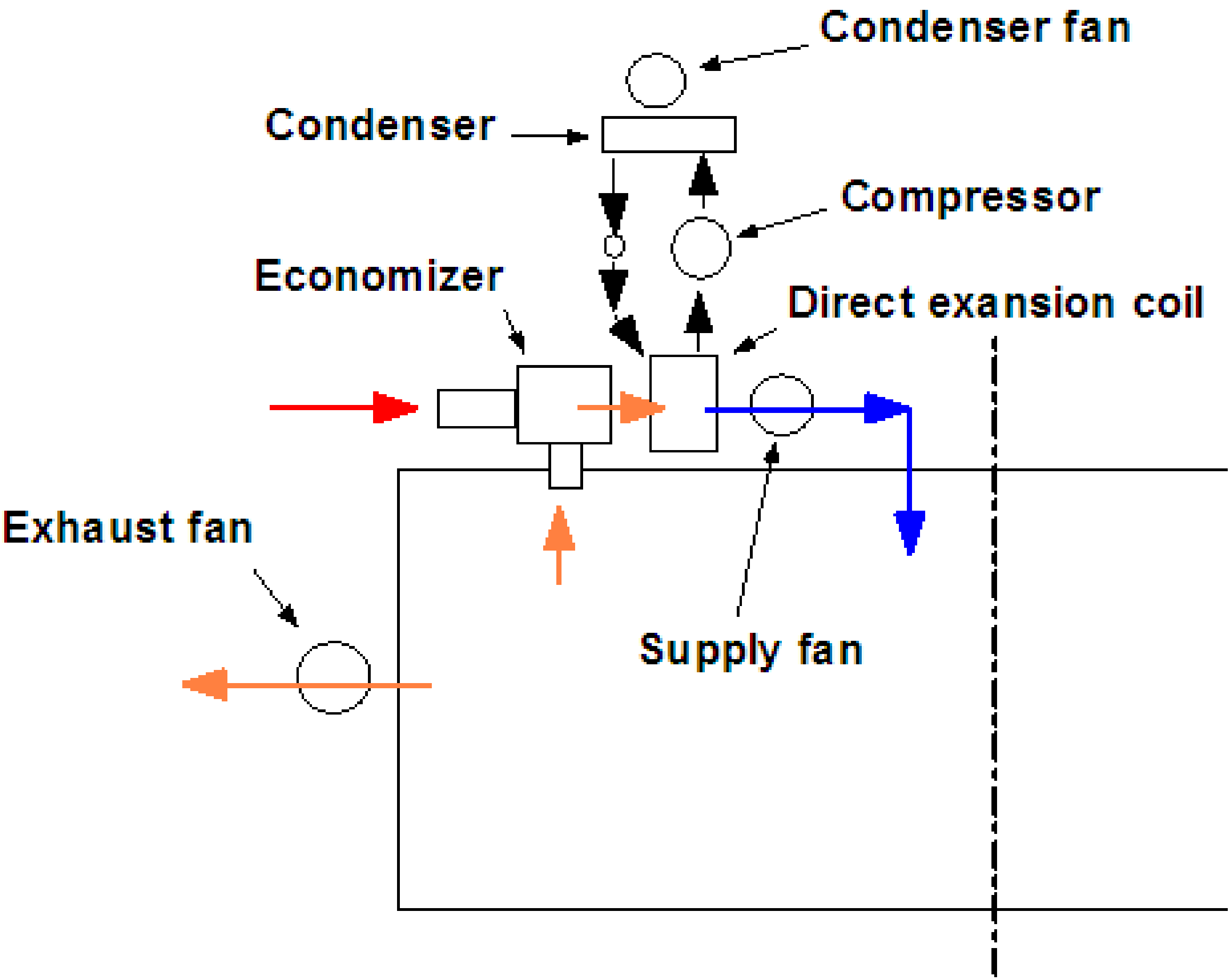
First example of System simulation: reversible air conditionner



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MODELING OF THE HVAC SYSTEM

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Reference model of the compressor:

- *Adaptation and tuning of a reference model*

  according to information available: manufacturer’s data and laboratory test results

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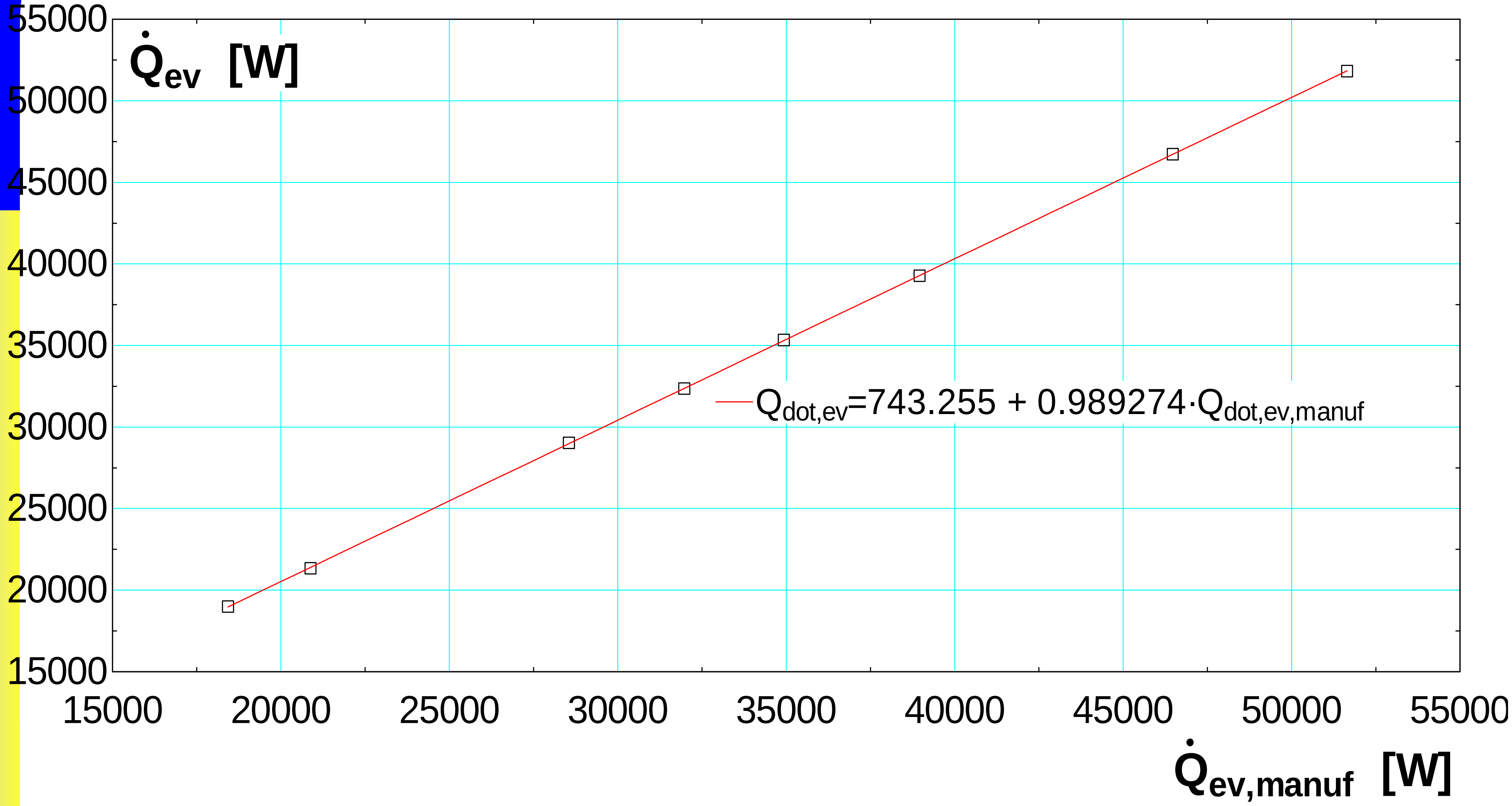
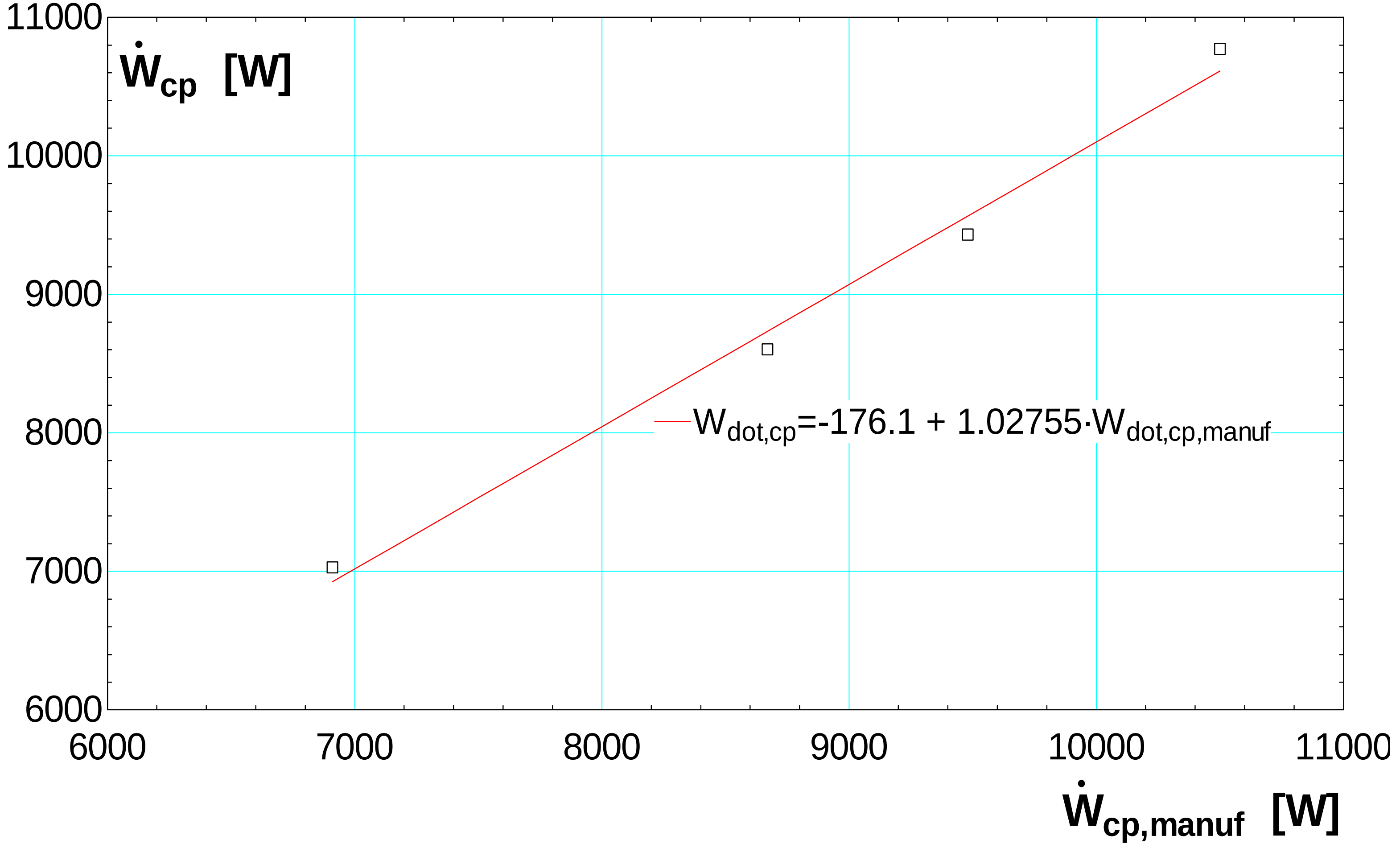


$\dot{Q}_{ev}$ [W]
55000
50000
45000
40000
35000
30000
25000
20000
15000
15000
20000
25000
30000
35000
40000
45000
50000
55000
$Q_{dot,ev}$=743.255 + 0.989274·$Q_{dot,ev,manuf}$
$\dot{Q}_{ev,manuf}$ [W]

Comparaison of simulated electrical



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Addition of a regenerator:

- modelled as a classical counter-flow heat exchanger

Part load:

- Unloading of 2 (on 4) cylinders
- Evaporator bypassing + liquid injection
- ON/OFF

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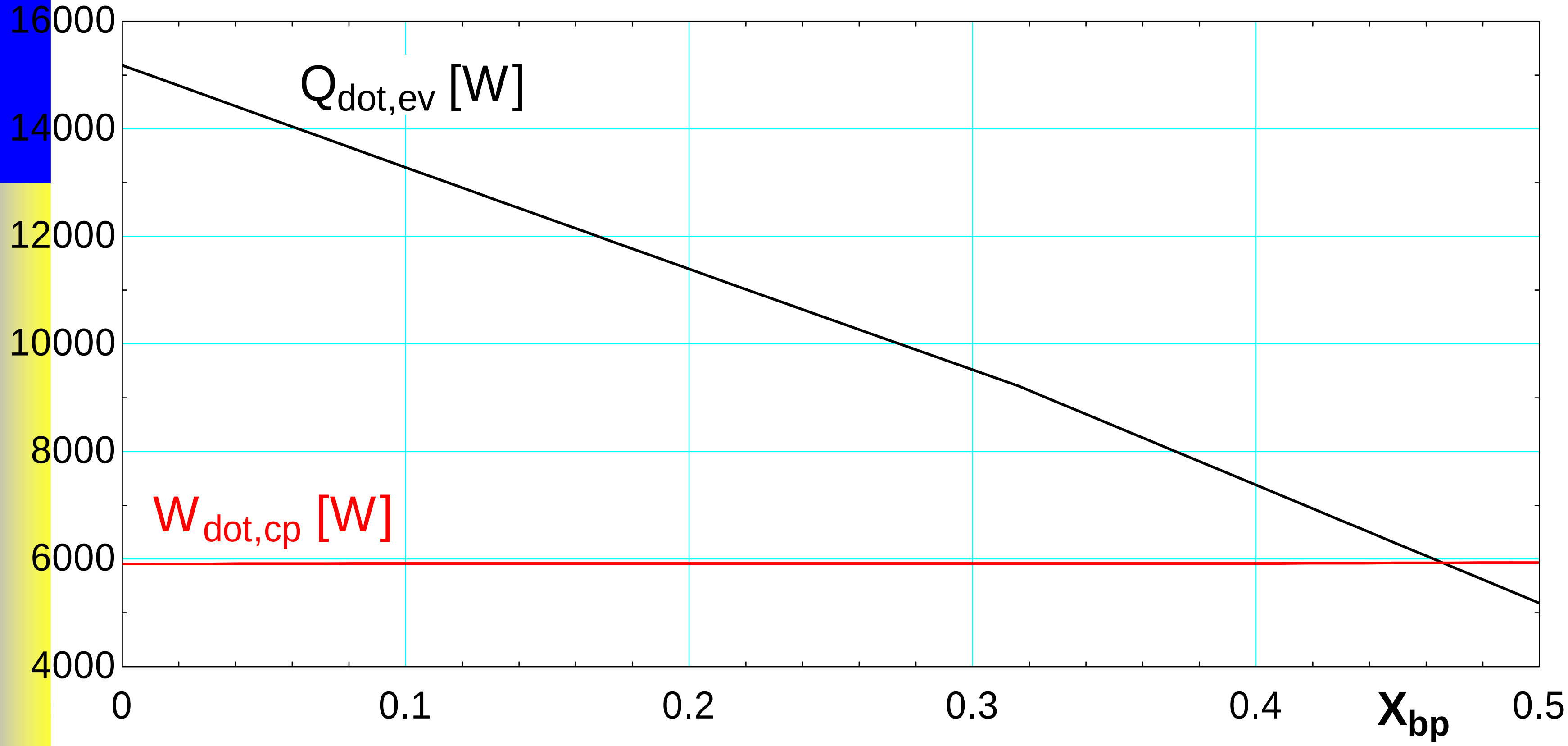

16000
14000
12000
10000
8000
6000
4000
0
0.1
0.2
0.3
0.4
0.5
$Q_{dot,ev}$ [W]
$W_{dot,cp}$ [W]
X_{bp}

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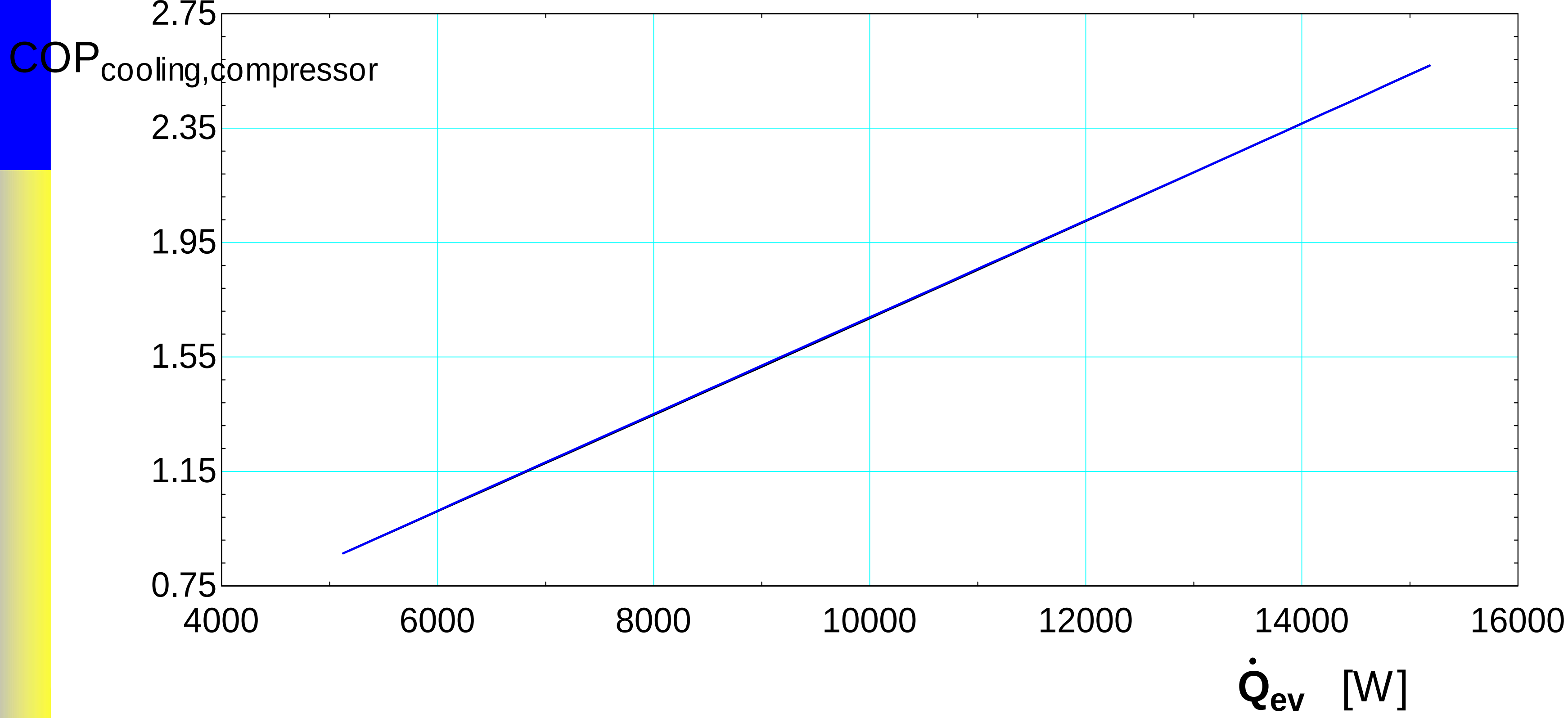
CO



$COP_{cooling,compressor}$
2.75
2.35
1.95
1.55
1.15
0.75
4000
6000
8000
10000
12000
14000
16000
$\dot{Q}_{ev}$ [W]

At the end, the by-pass control is:

- energy inefficient, but…
- safe for the compressor (if associated to liquid injection)
- easy to perform
- **and easy to simulate!**

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Simplified models of the compressor

- Reference model not robust enough for simulation of whole HVAC system
- Polynomial regressions are much more convenient
- Regressions established in two steps…

Refrigeration power as

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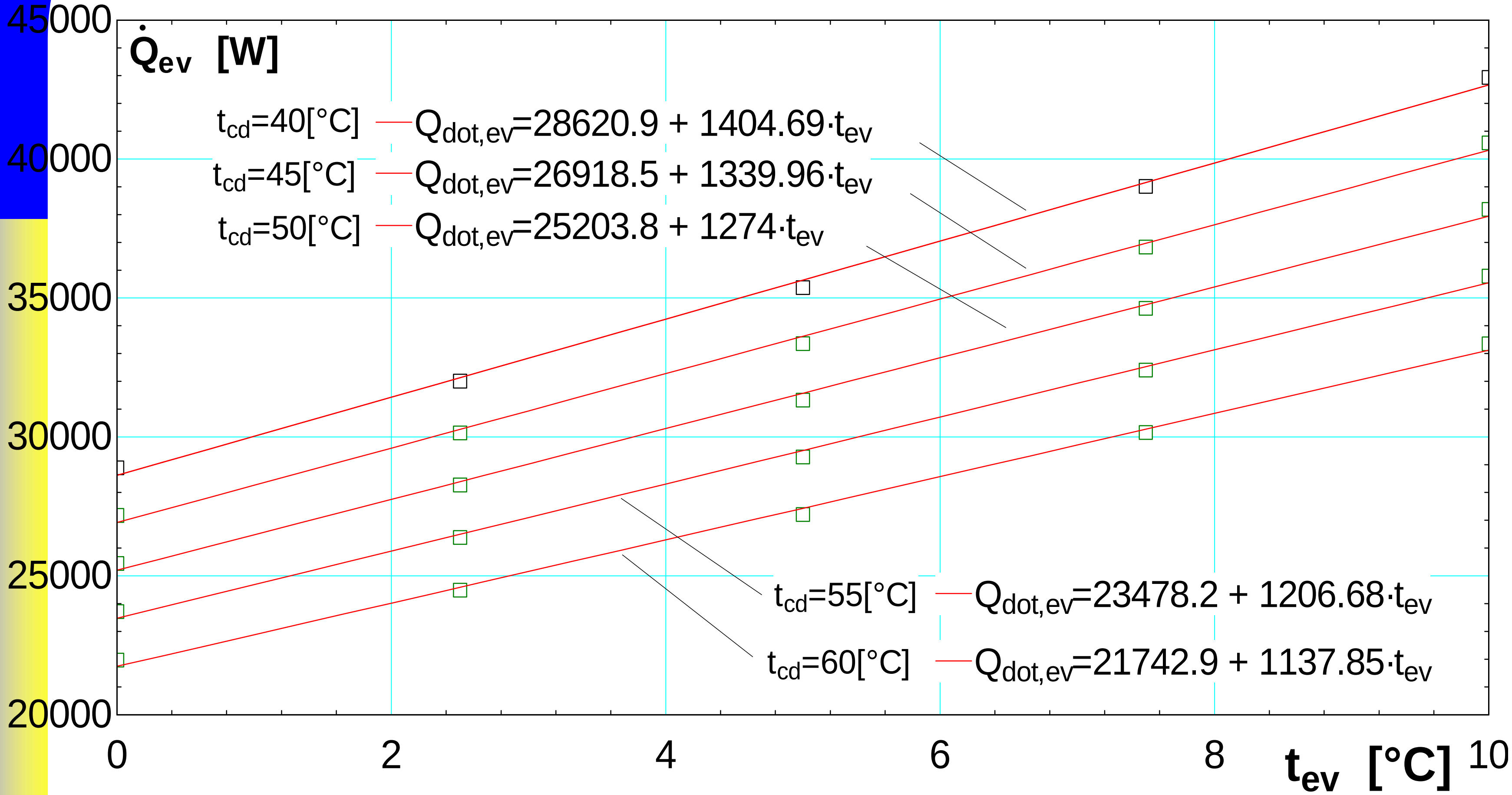

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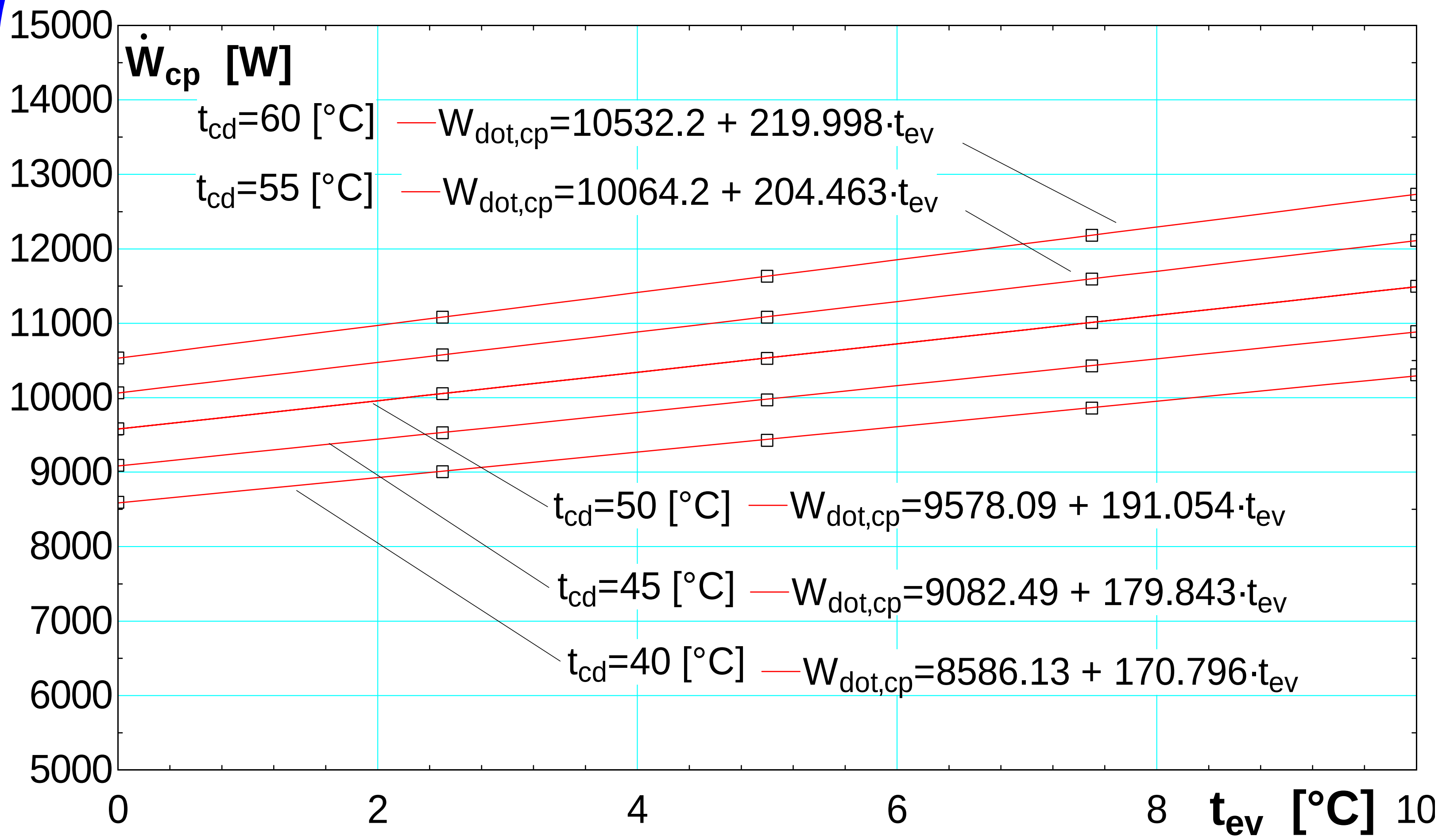
Electrical power as function



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Modelling of the condensing unit:

Air-cooled condenser with a two-speed fan;

3 *regimes* distinguished:

- high speed
- low speed
- no fan (free convection).

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- *3 fan regimes* associated to *3 compressor regimes* (4 cylinders, 2 cylinders and 2 cylinders + by-pass) into 9 possible combinations, i.e. ***9 models*****!**

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- Main *Outputs* of each model:

refrigeration and the electrical powers

- *Inputs:* evaporating and outdoor air temperatures
- *Parameters: 2* reference pressures of condenser fan control

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Imposing the cooling power:

- Quasi-static model built by combination of 2 (superior and inferior) “nearest” regimes

Reducing cooling power makes compressor passing through:

- cycling between 4 and 2 cylinders
- 2 cylinder with variable by-pass
- 2 cylinder, maximum by-pass and ON/OFF

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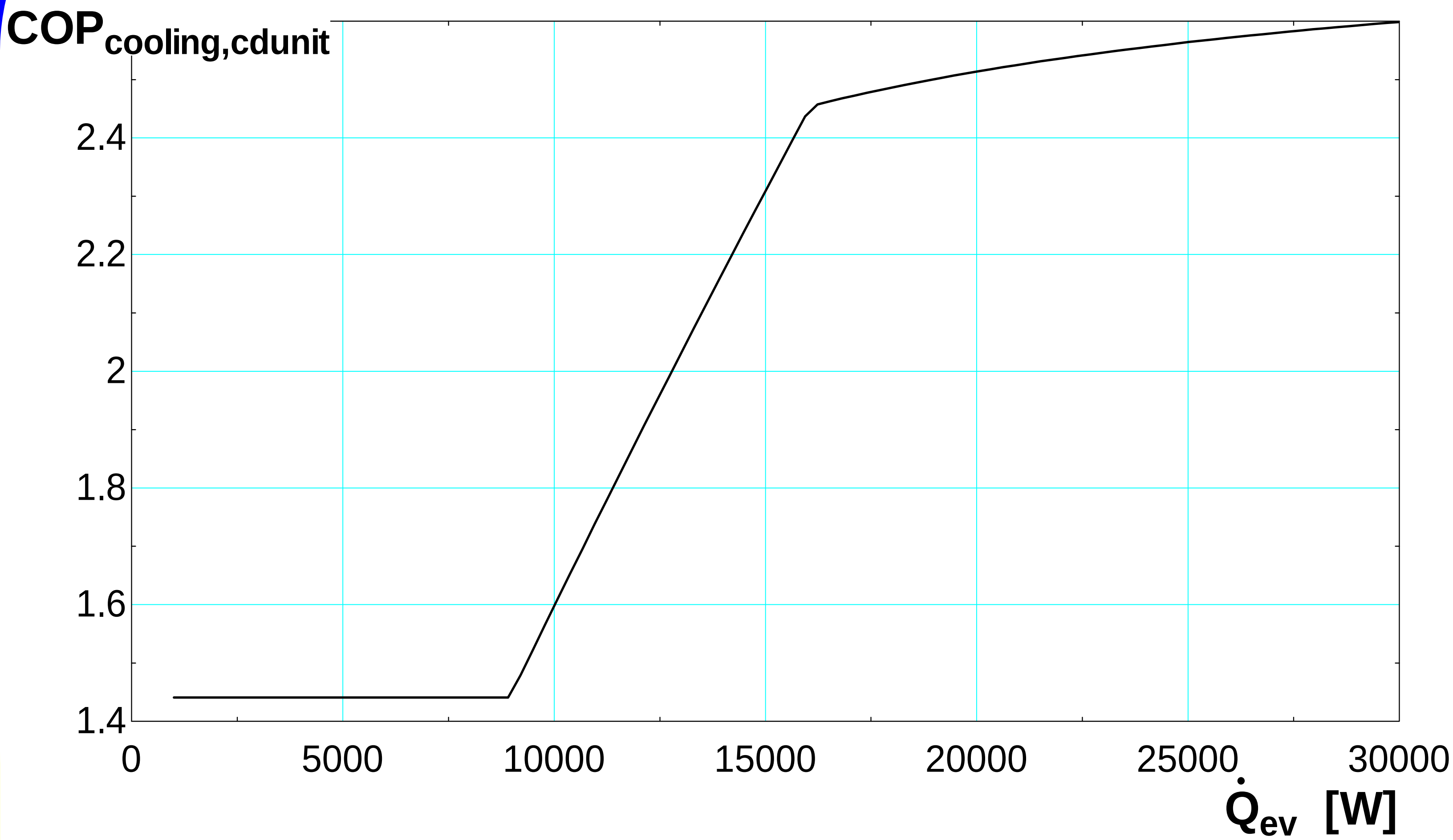
$COP_{cooling,cdunit}$
2.4
2.2
2
1.8
1.6
1.4
0
5000
10000
15000
20000
25000
30000
$\dot{Q}_{ev}$ [W]

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Coupling to the vehicle:

- Perfect control mode considered:

the building cooling demand imposes the cooling power

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Introduction the heat pumping mode:

- The evaporator becomes a condenser and reciprocally
- Thanks to reverting valve to adaptation of refrigerant circuit…

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3 different regimes to be considered on (outdoor) evaporator side:

- *Dry*
- *wet*
- *frosting*.

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Simulation and analysis

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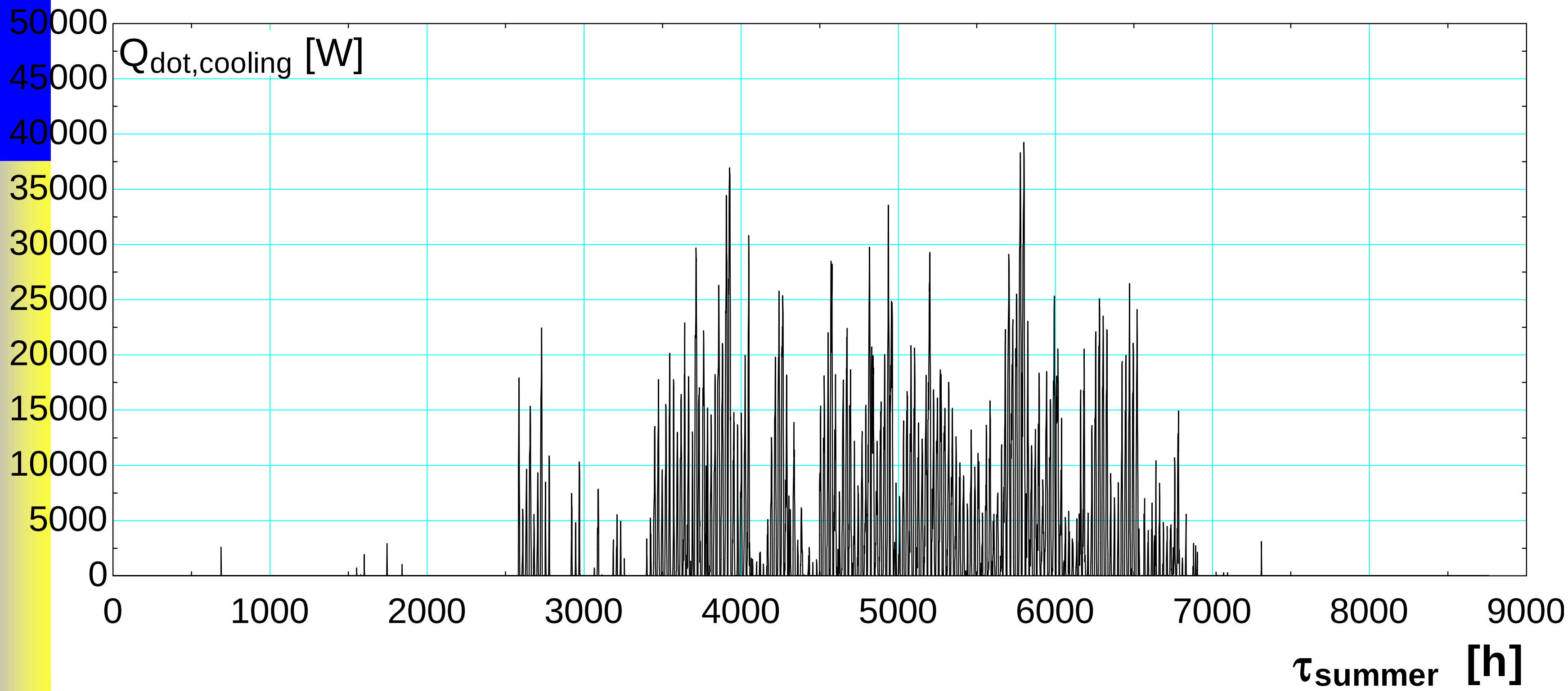
Cooling demand



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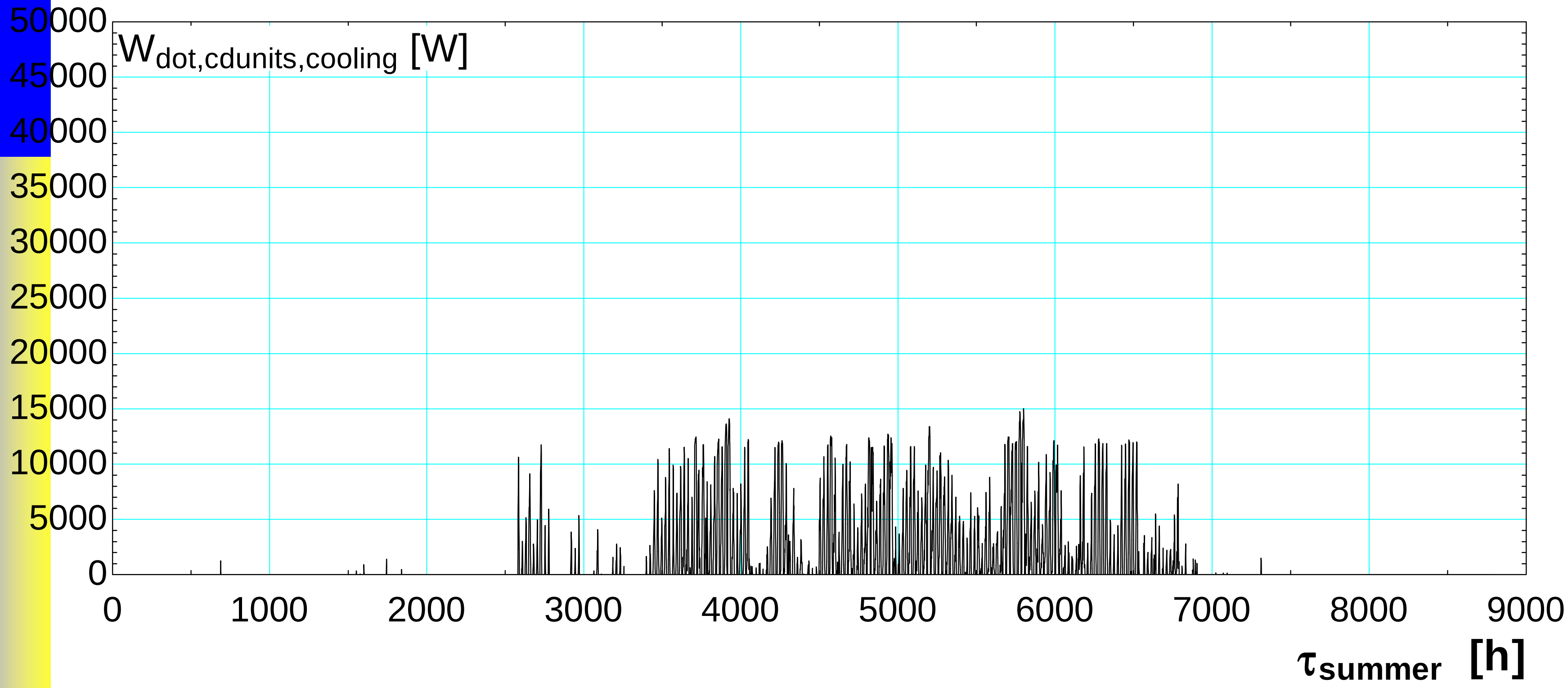
Consumption of the two condensing units of the vehicle in cooling regime



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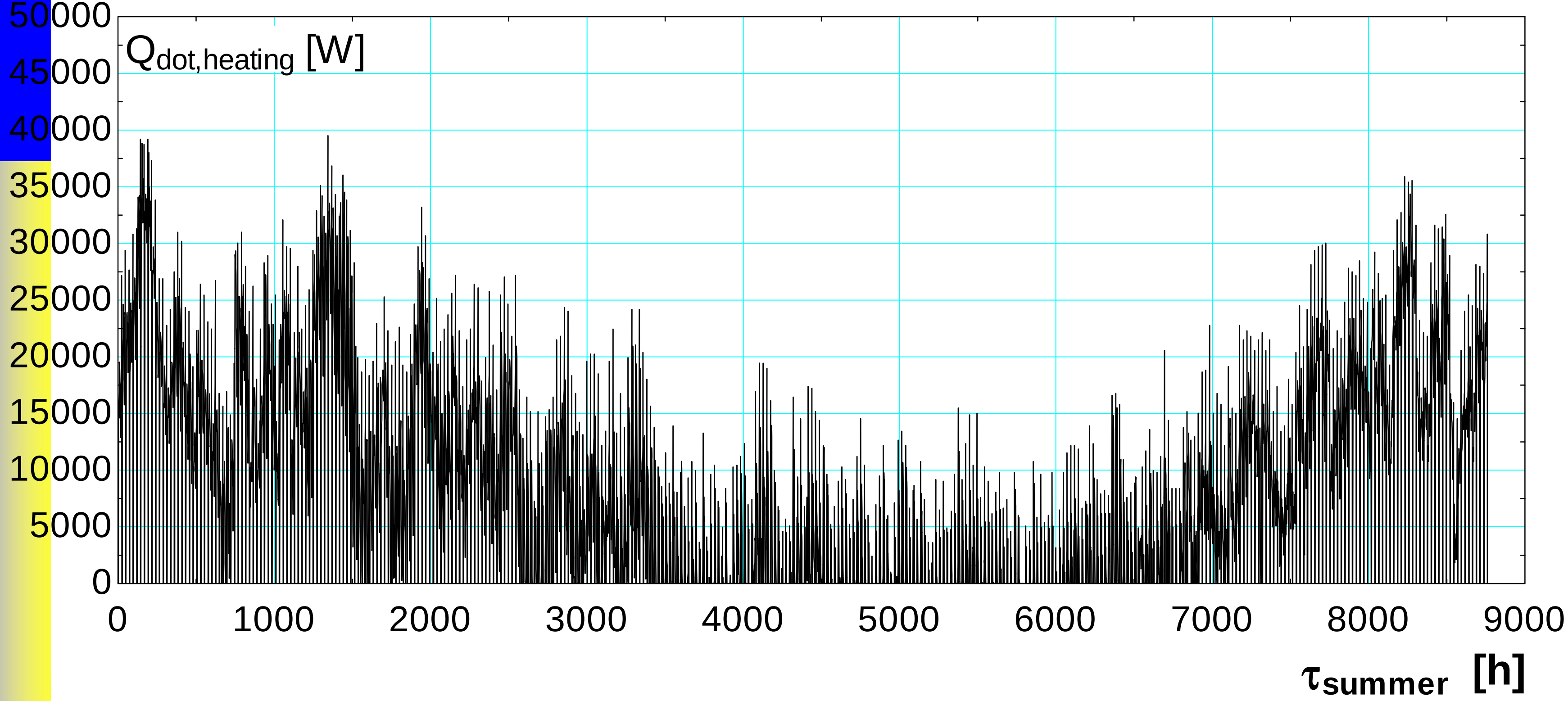
Heating demand



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different modes (by order of increasing efficiency… and complexity):

- Use of electrical resistances (no heat pumping)
- Heat pumping until a minimal outdoor air temperature of 5 °C (and use of electrical resistances below that limit)
- Heat pumping with minimum of contact temperature fixed at 0 °C (and boosting by electrical resistances)
- without temperature limit

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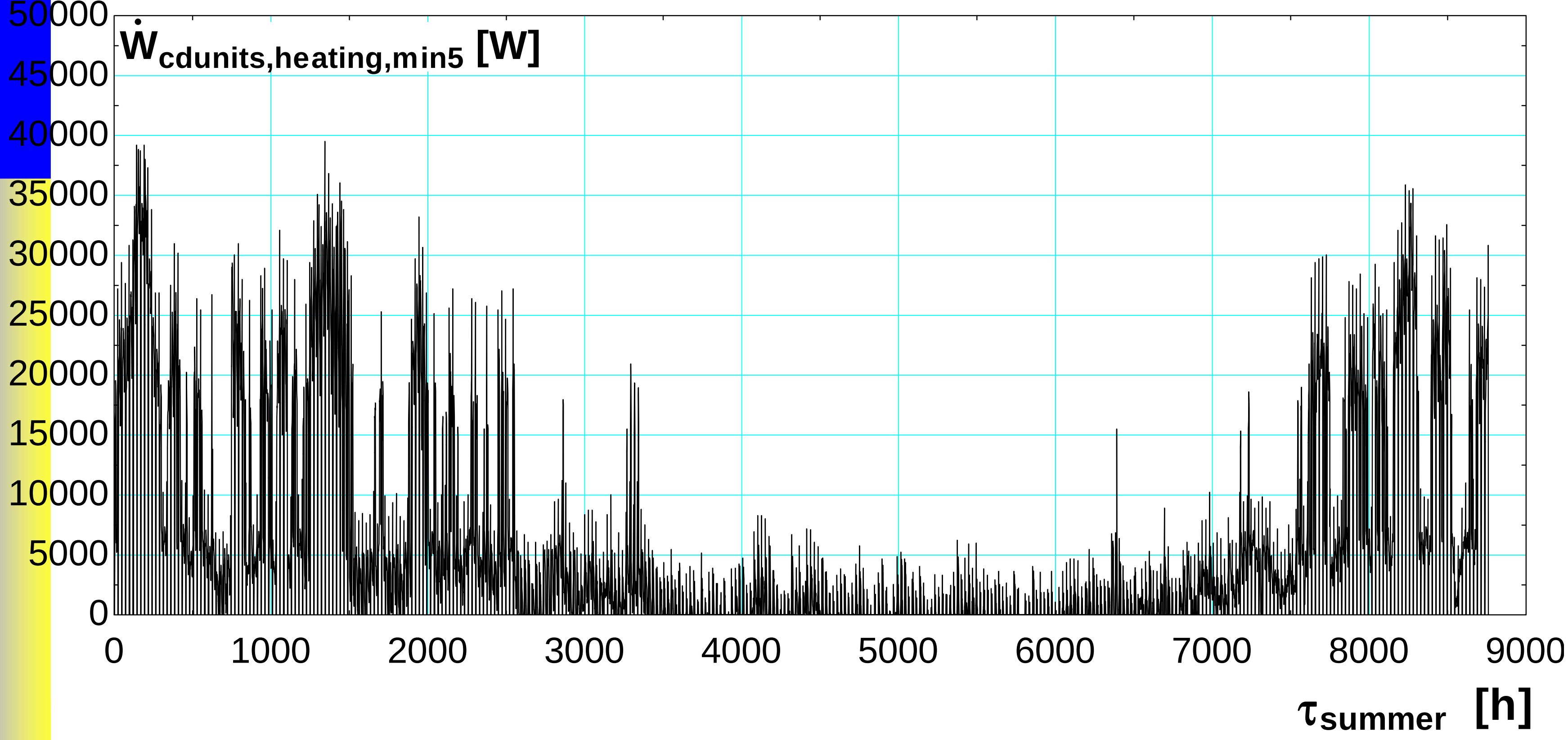
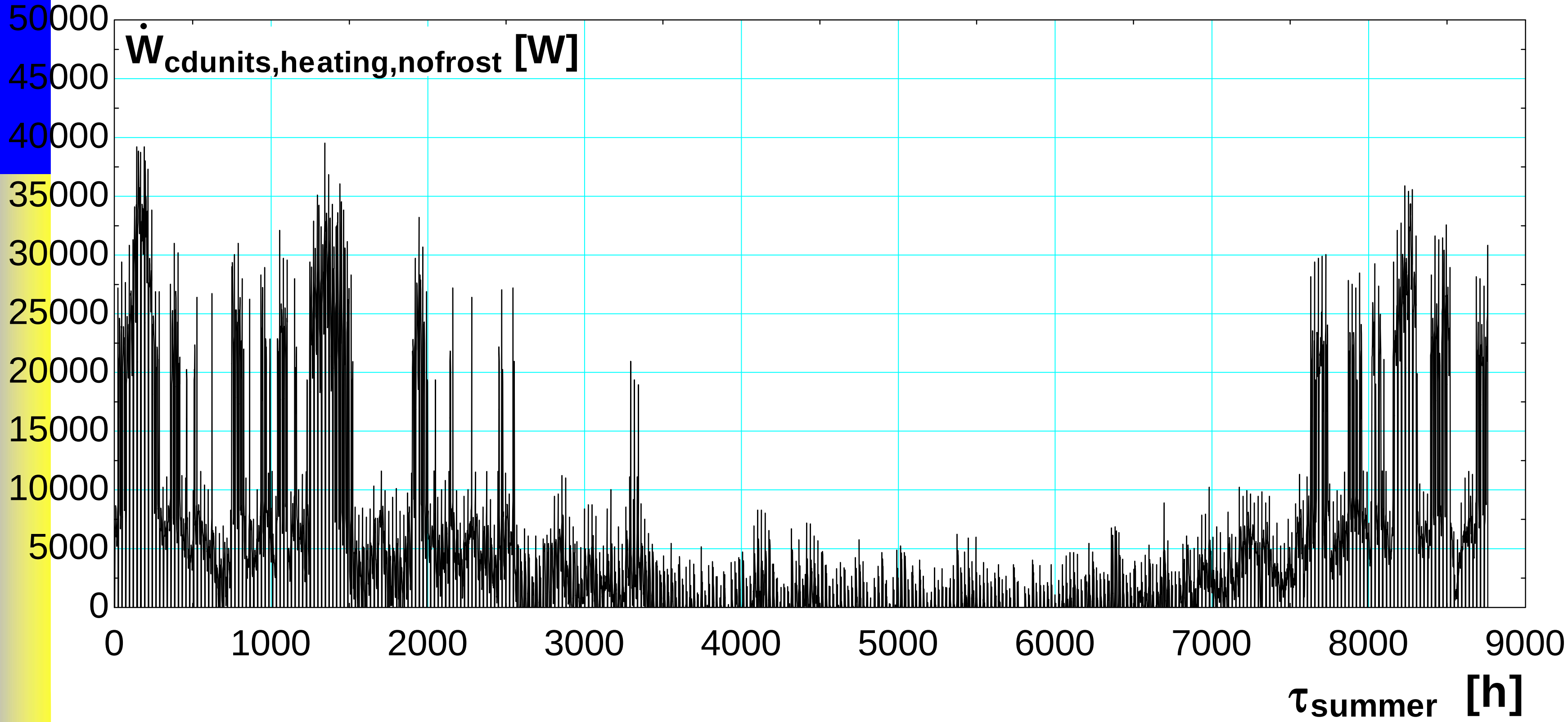
Consumption of the two condensing units and of the electrical resistances in second heating mode



Consumption of condensing units and electrical resistances in third heating mode



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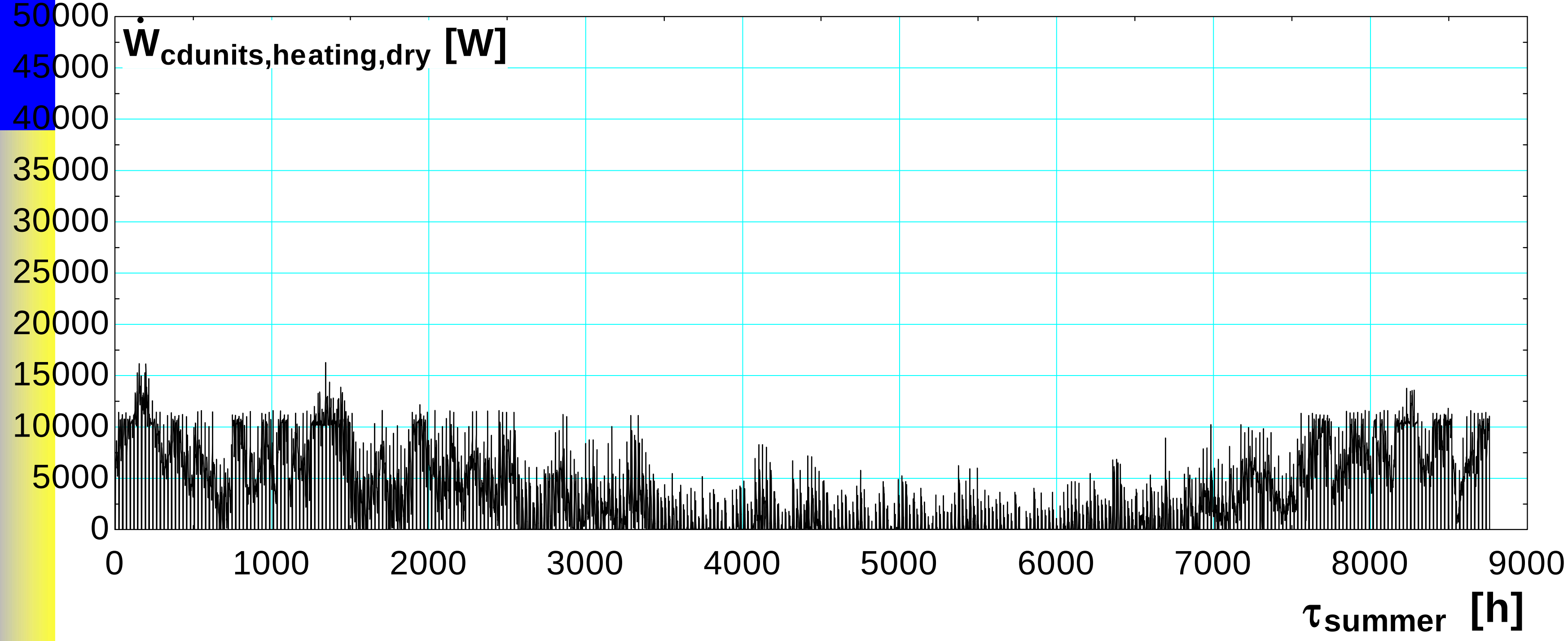
Consumption of condensing units and electrical resistances in fourth heating mode



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Main results:

- Yearly cooling and heating demands: 18 and 69 MWh
- Lighting: 11 MWh
- Supply and exhaust fans: 13 MWh
- Condensing units in cooling mode: 9.5 MWh
- Electrical resistances in the first heating mode: 69 MWh (equal to the heating demand)
- Condensing units and electrical resistances in second heating mode: 49.5 MWh
- Condensing units and electrical resistances in third heating mode: 43 MWh
- Condensing units in fourth heating mode: 28.5 MWh.

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Or, in other terms…

- Global consumption of the vehicle (except for its traction): 103 MWh per year
- 67 % of this consumption for heating with electrical resistances
- Possibility to save at least 19 % of the global consumption by using the condensing unit in simplest control mode
- 25 % with a little more “intelligent” control strategy (still without any defrosting risk)
- 39 % with frosting-defrosting control
- Saving representing 20 to 40 MWh, i.e. 20 to 40 % of global electricity consumption, traction not included…

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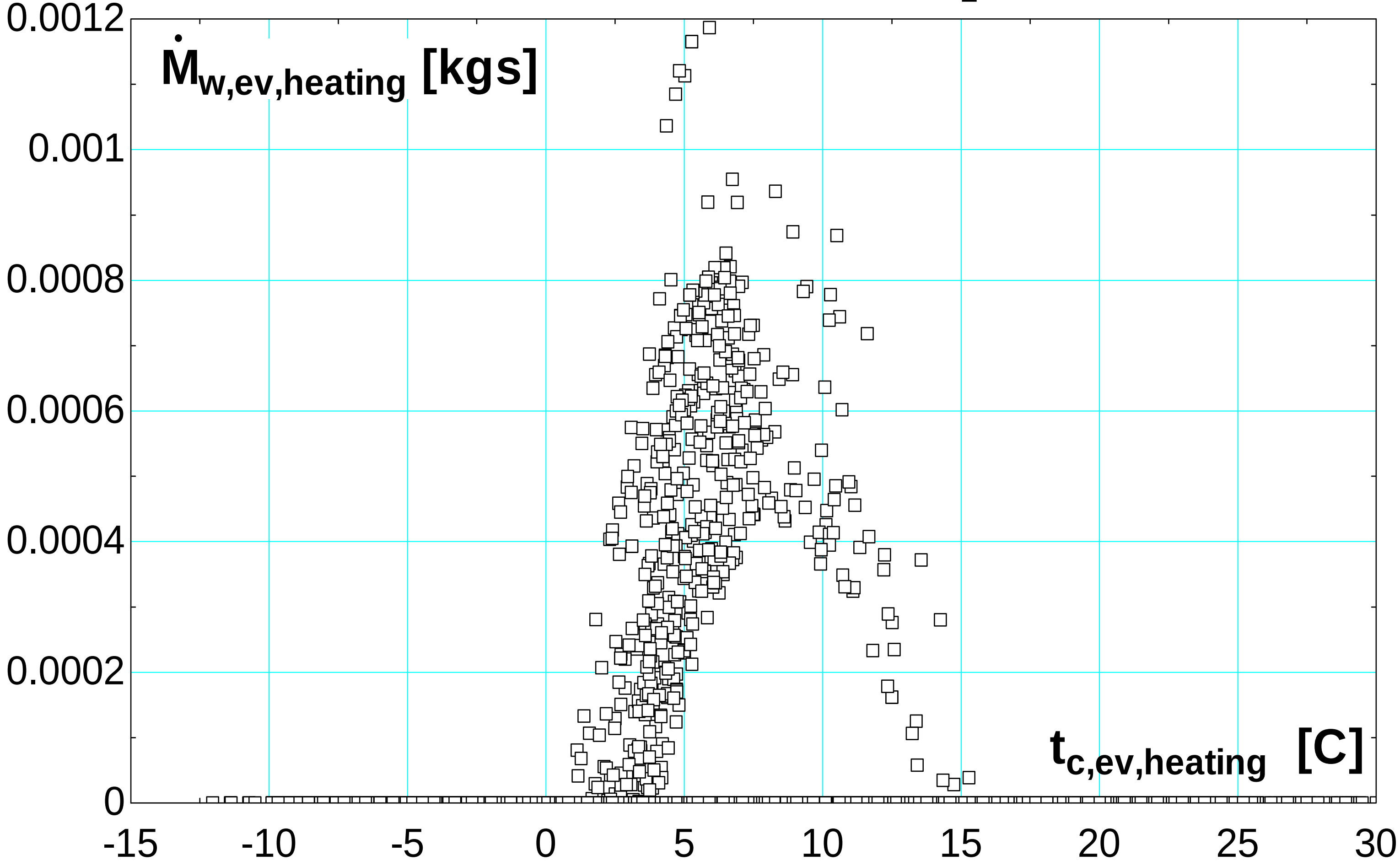
Moisture condensation on HP evaporators as function of the contact temperature:



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Second example of system simulation: ventilated frontage

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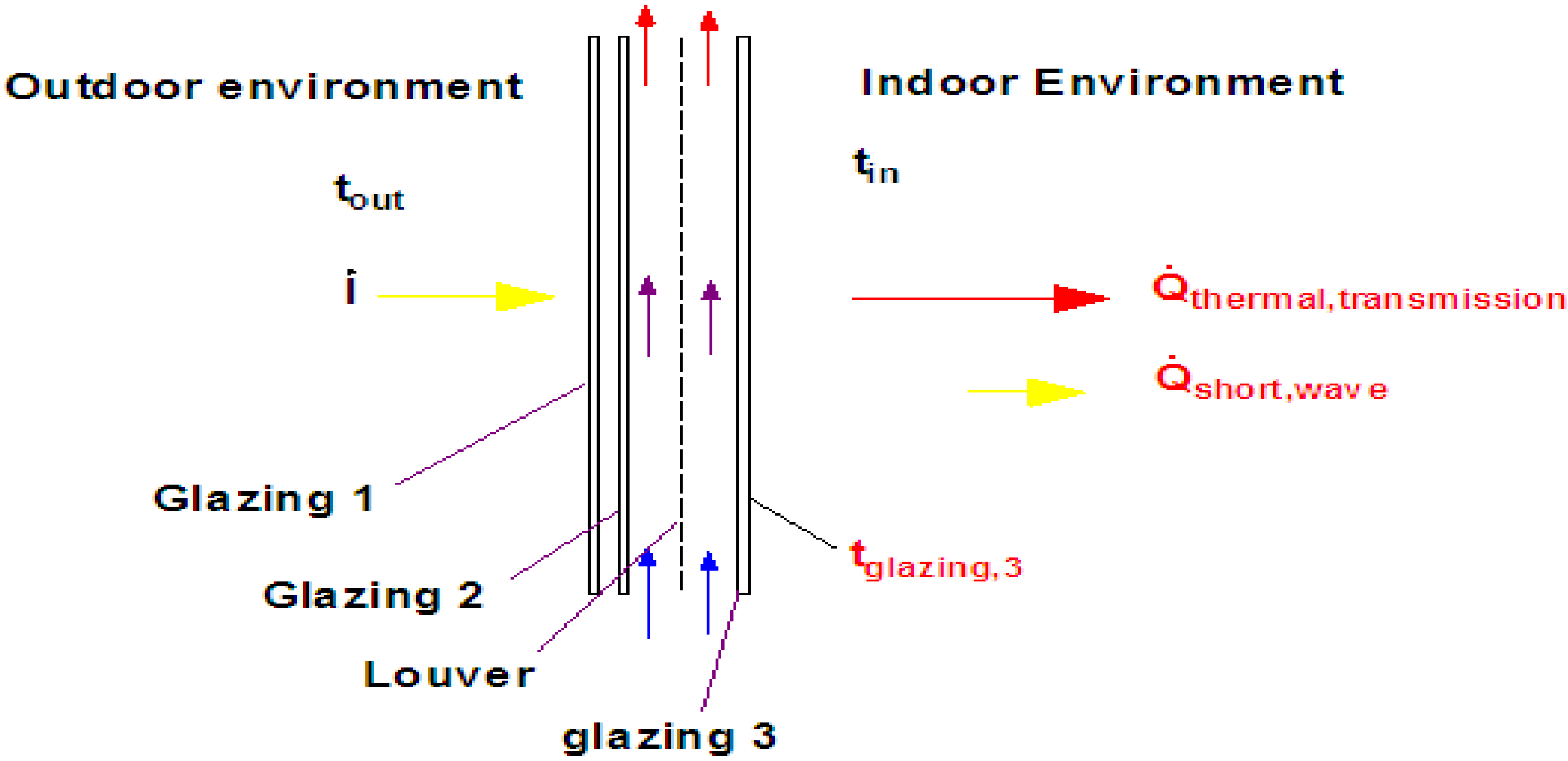

Figure 2: Structure of one module of the glazing subsystem

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Ventilated frontage with vertical slot in indoor glazing

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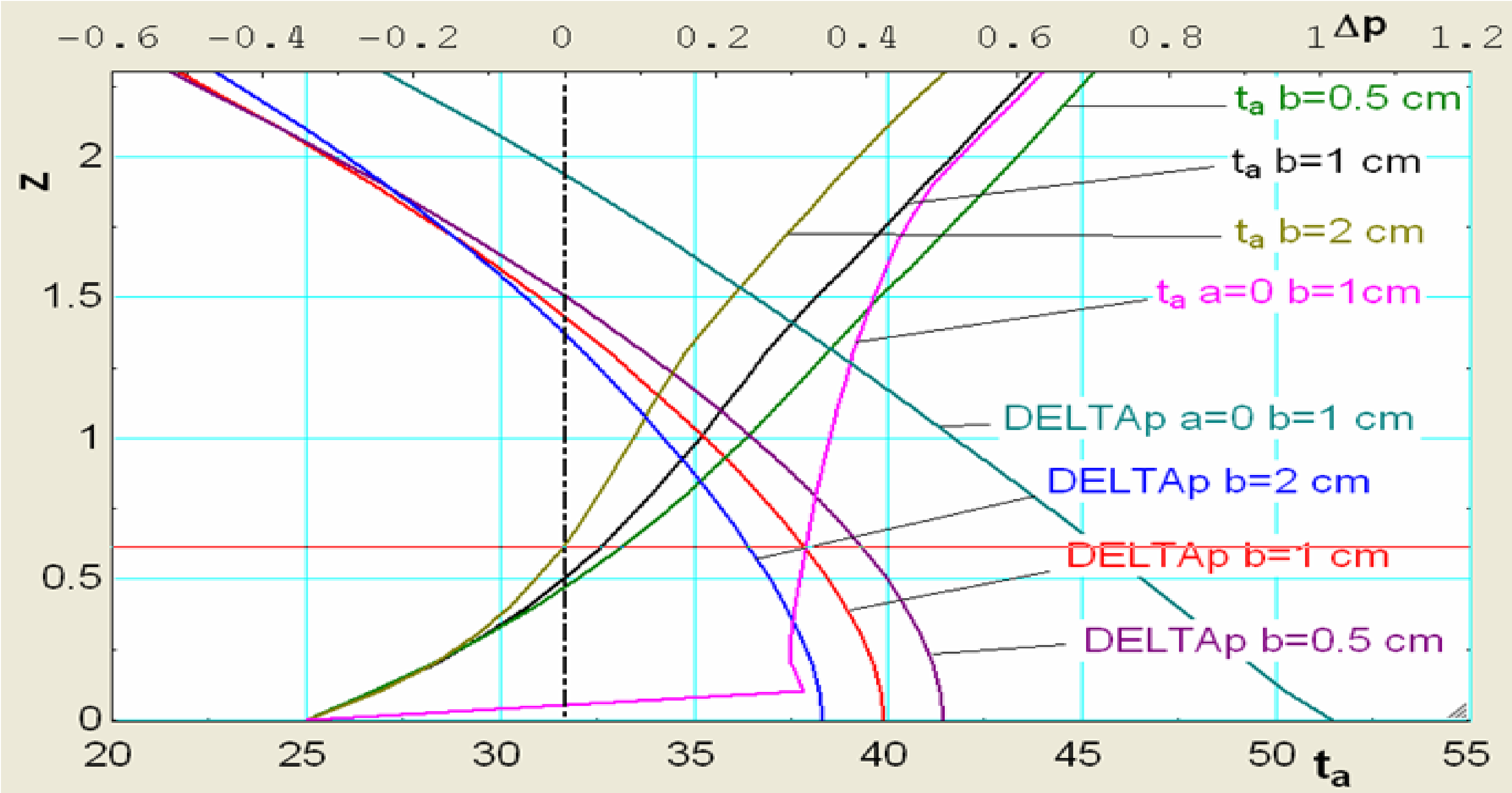

Figure 1: Profils verticaux de la température de l'air dans la cavité et de la dépression le long de la fente

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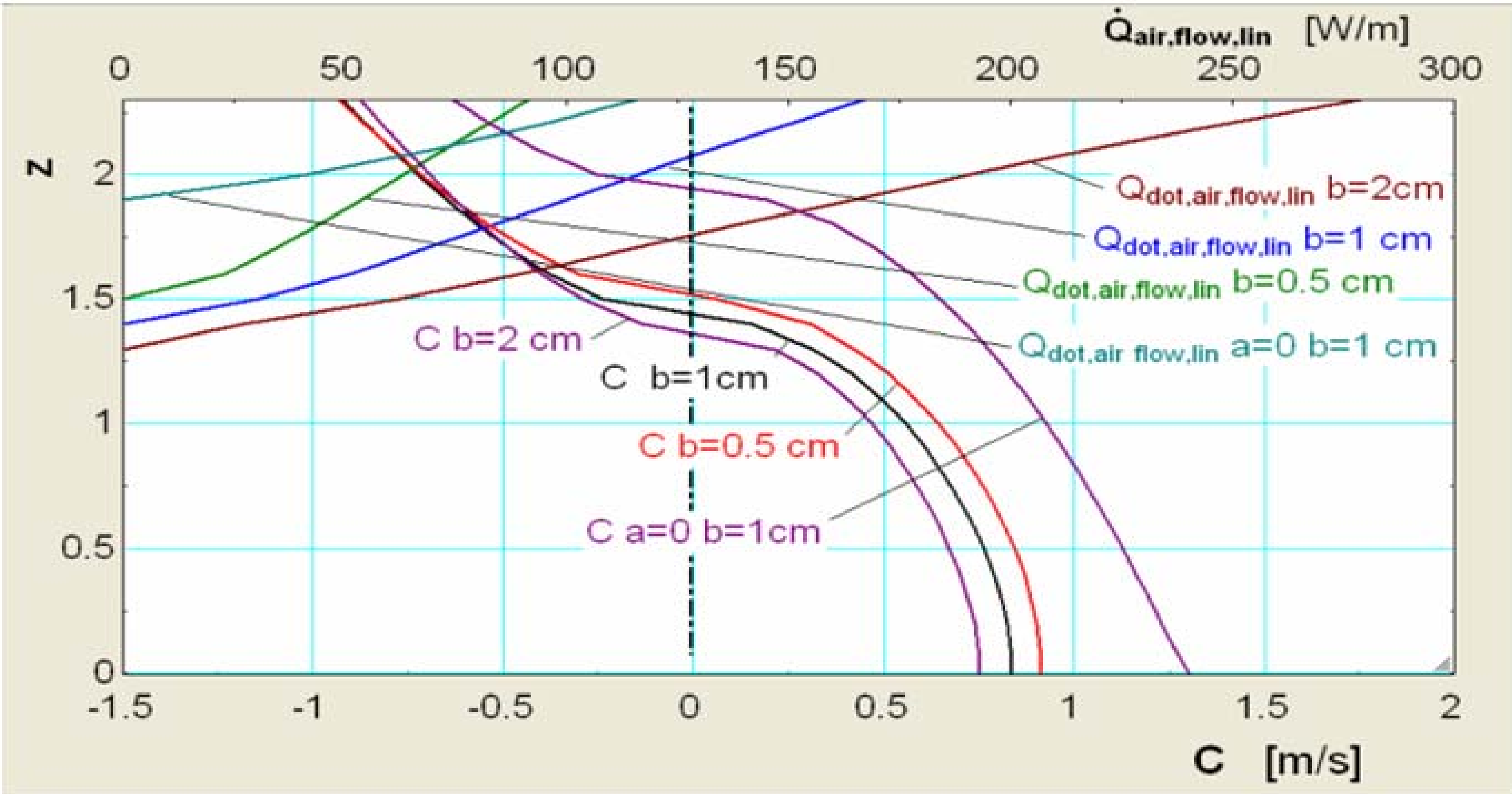

Figure 2: Profils verticaux de la vitesse de l'air tout au long de la fente et du débit d'enthalpie linéique qui s'en échappe (dans la partie supérieure)

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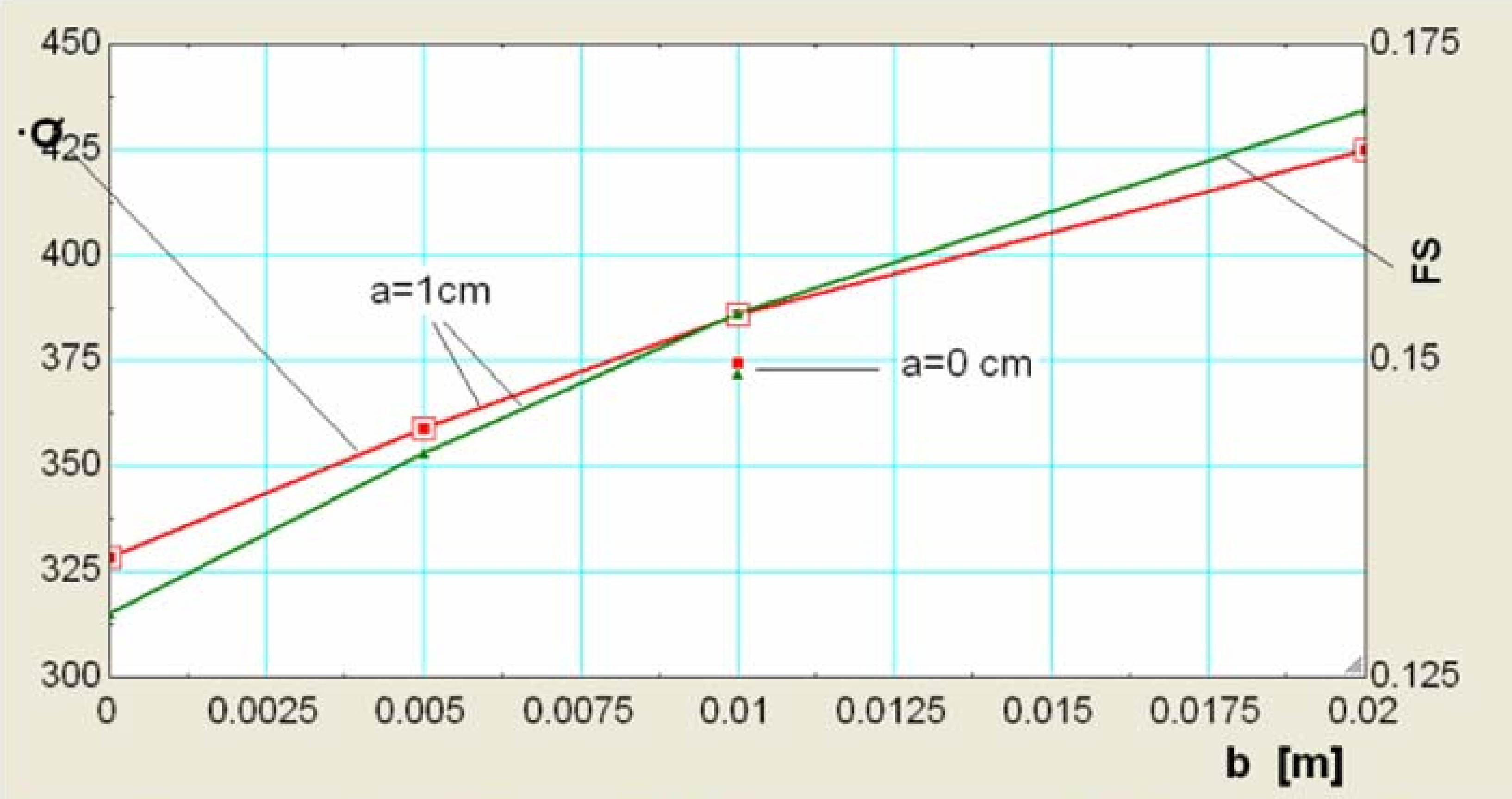

Figure 3: Gain de chaleur global occasionné par la façade et facteur solaire correspondant en fonction de la largeur (b) de la fente verticale

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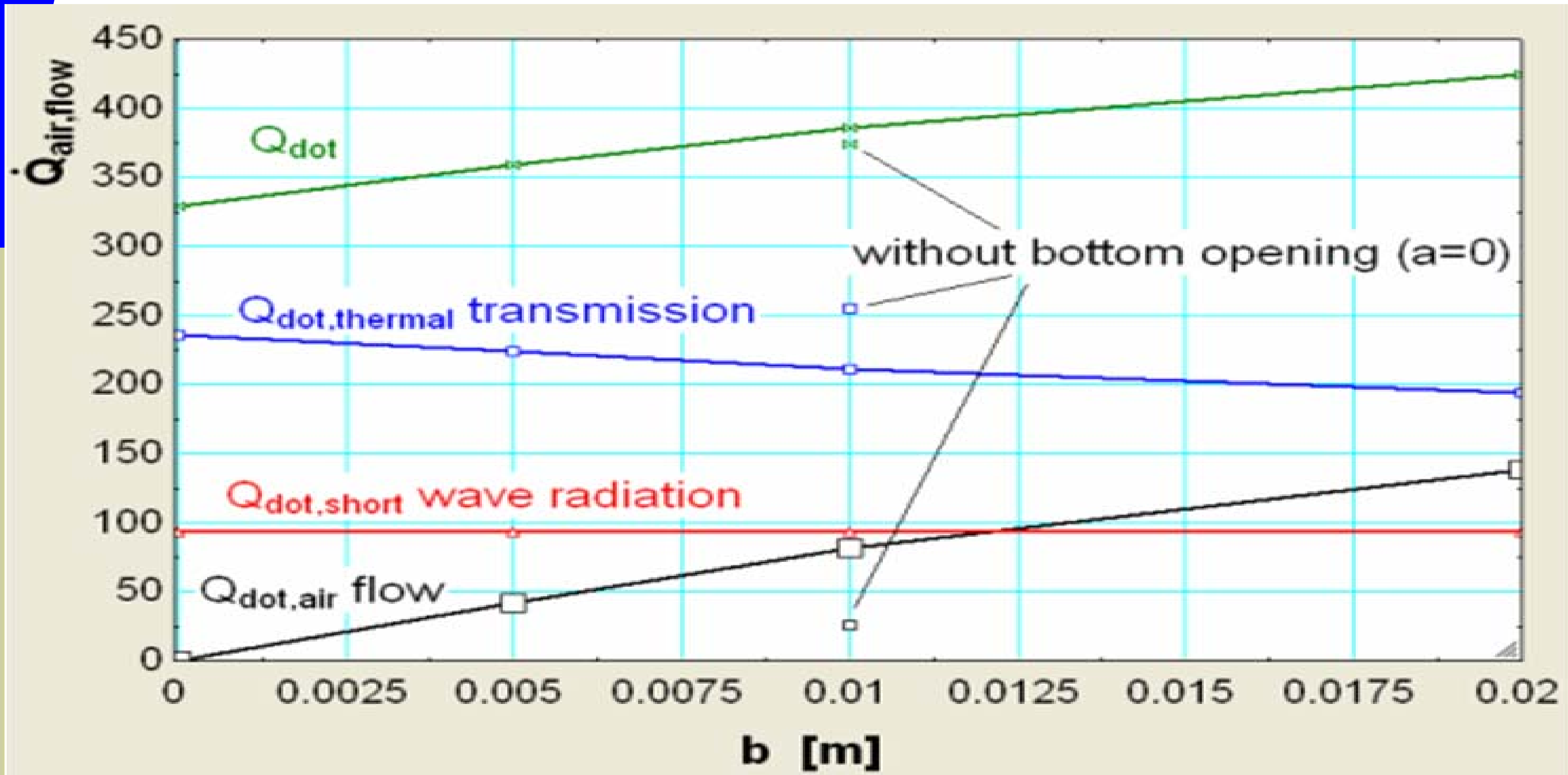

Figure 4: Débit d'enthalpie, flux radiatif de courte longueur d'onde, flux transmis et gain de chaleur global en fonction de la largeur de la fente

a [m]	b [m]	Δp_0 [Pa]	$\dot{Q}$ [W]	$\Delta Q_{dot,relatif}$ [-]	$\dot{Q}_{airflow}$ [W]	$\dot{Q}_{shortwave}$ [W]	$\dot{Q}_{thermaltransmission}$ [W]	FS [-]	$\Delta FS_{relatif}$ [-]
0.010	0.000	0.748	328.4	-0.000	0	92.74	235.7	0.130	-0.000
0.010	0.005	0.501	358.9	0.093	42.17	92.74	224	0.143	0.097
0.010	0.010	0.422	385.7	0.175	81.42	92.74	211.6	0.154	0.183
0.010	0.020	0.341	424.8	0.293	138.5	92.74	193.5	0.170	0.307
0.000	0.010	1.016	374.3	0.140	26.18	92.74	255.4	0.149	0.146

: Résultats globaux des différentes simulations

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Other example of ventilated frontage

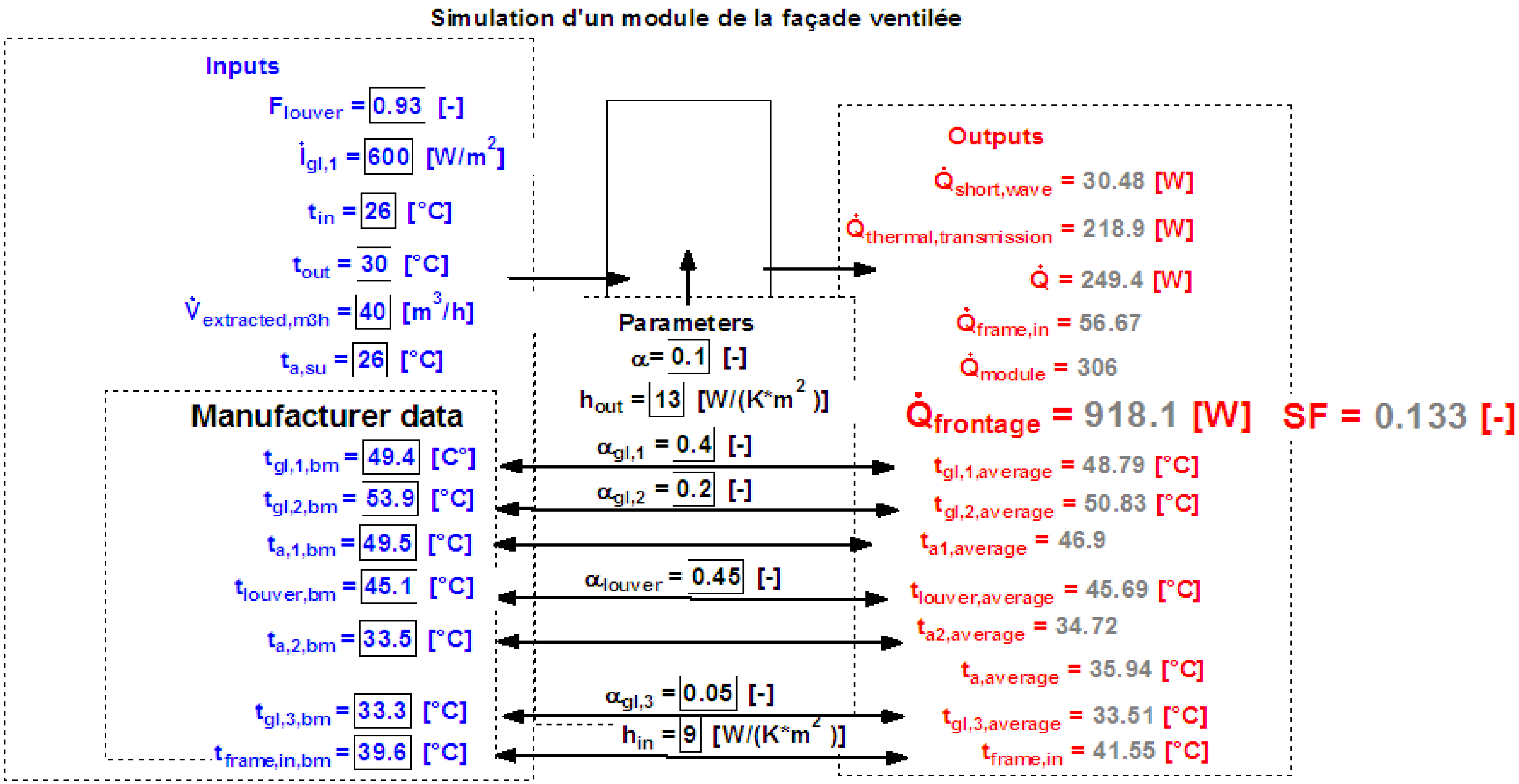

Figure 3: Tuning of the reference model with manufacturer data in nominal conditions

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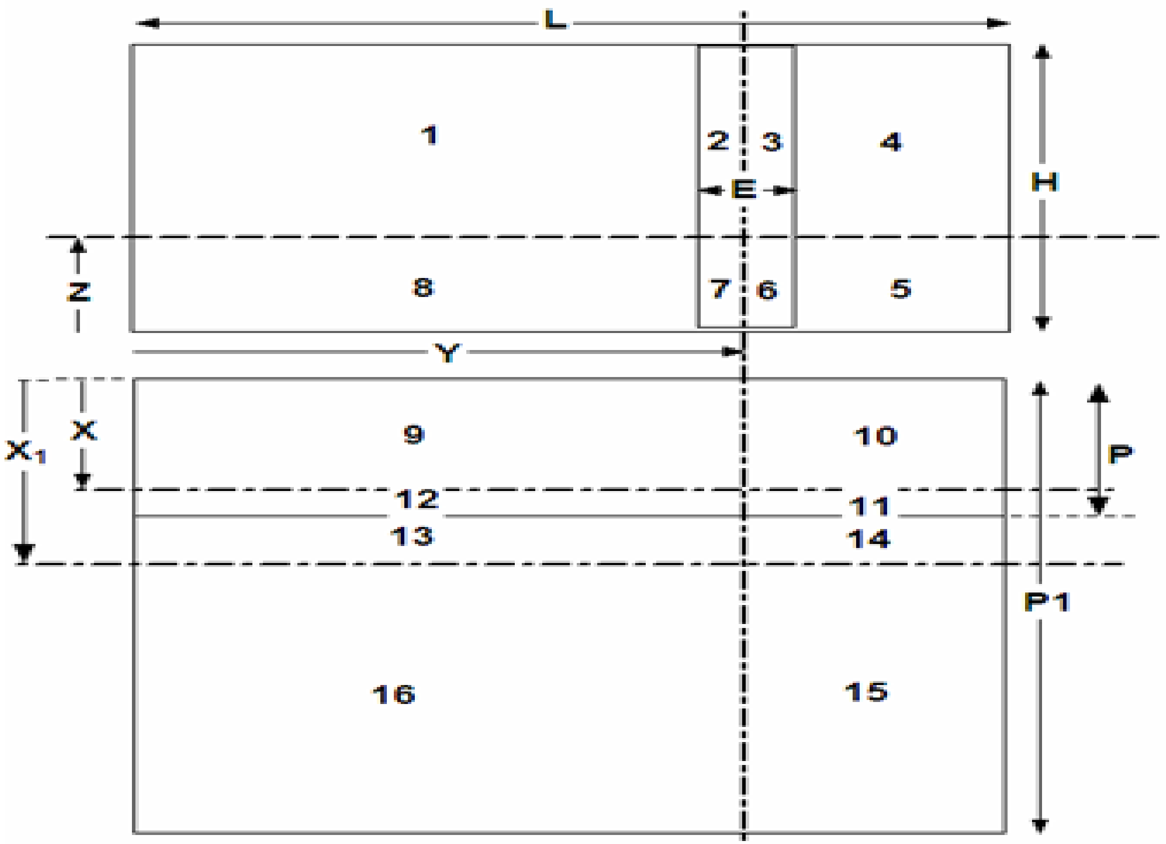

Figure 8: Subdivision of frontage and ceiling surfaces

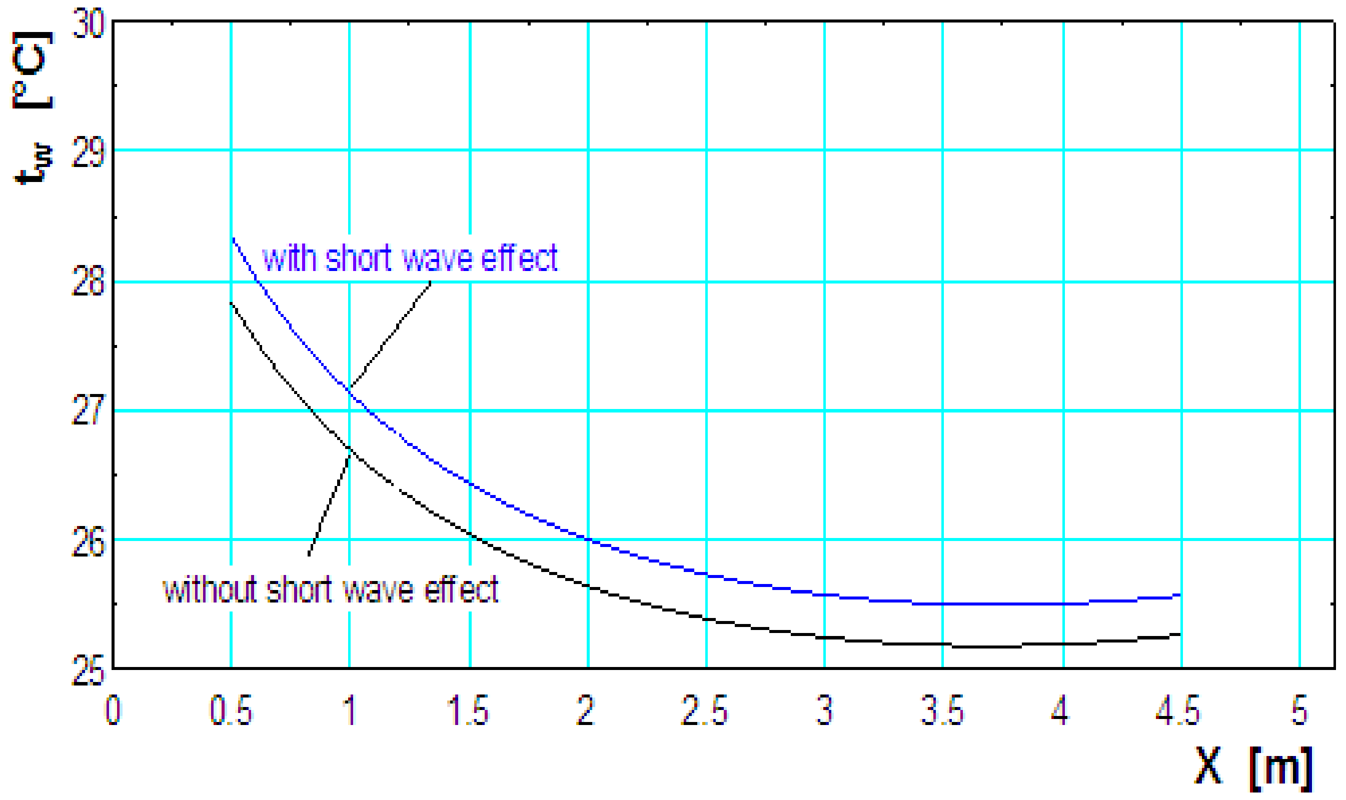

Figure 9: Mean radiant temperature with and without effect of sunshine

Global model

In the present study (with fixed outdoor conditions and fixed louver closing factor), the model can be reduced to a set of three linear regressions:

$$\dot{Q}_{frontage,fit} = 1520 - 12 \cdot t_{in}$$

$$t_{gl,3,average,fit} = 11.9 + 0.92 \cdot t_{in}$$

$$t_{frame,in,fit} = 32.8 + 0.51 \cdot t_{in}$$

The steady state balance of the room is expressed by the following equation :

$$\dot{Q}_{occ} + \dot{Q}_{light} + \dot{Q}_{appl} + \dot{Q}_{frontage} = \dot{H}_{vent} + \dot{Q}_{cc}$$

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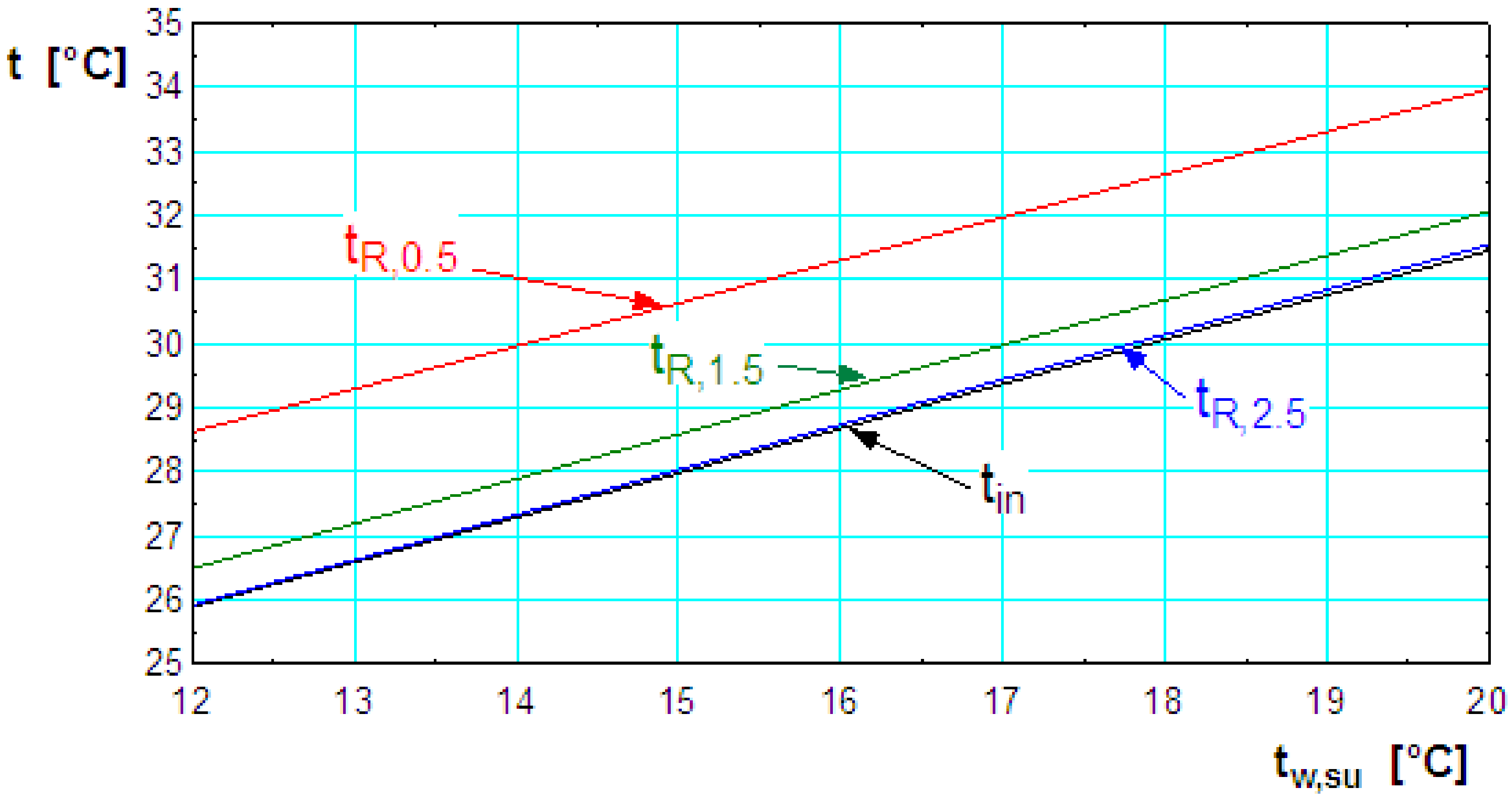

t [°C]
35
34
33
32
31
30
29
28
27
26
25
12
13
14
15
16
17
18
19
20
$t_{R,0.5}$
$t_{R,1.5}$
$t_{R,2.5}$
t_{in}
$t_{w,su}$ [°C]

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Other example

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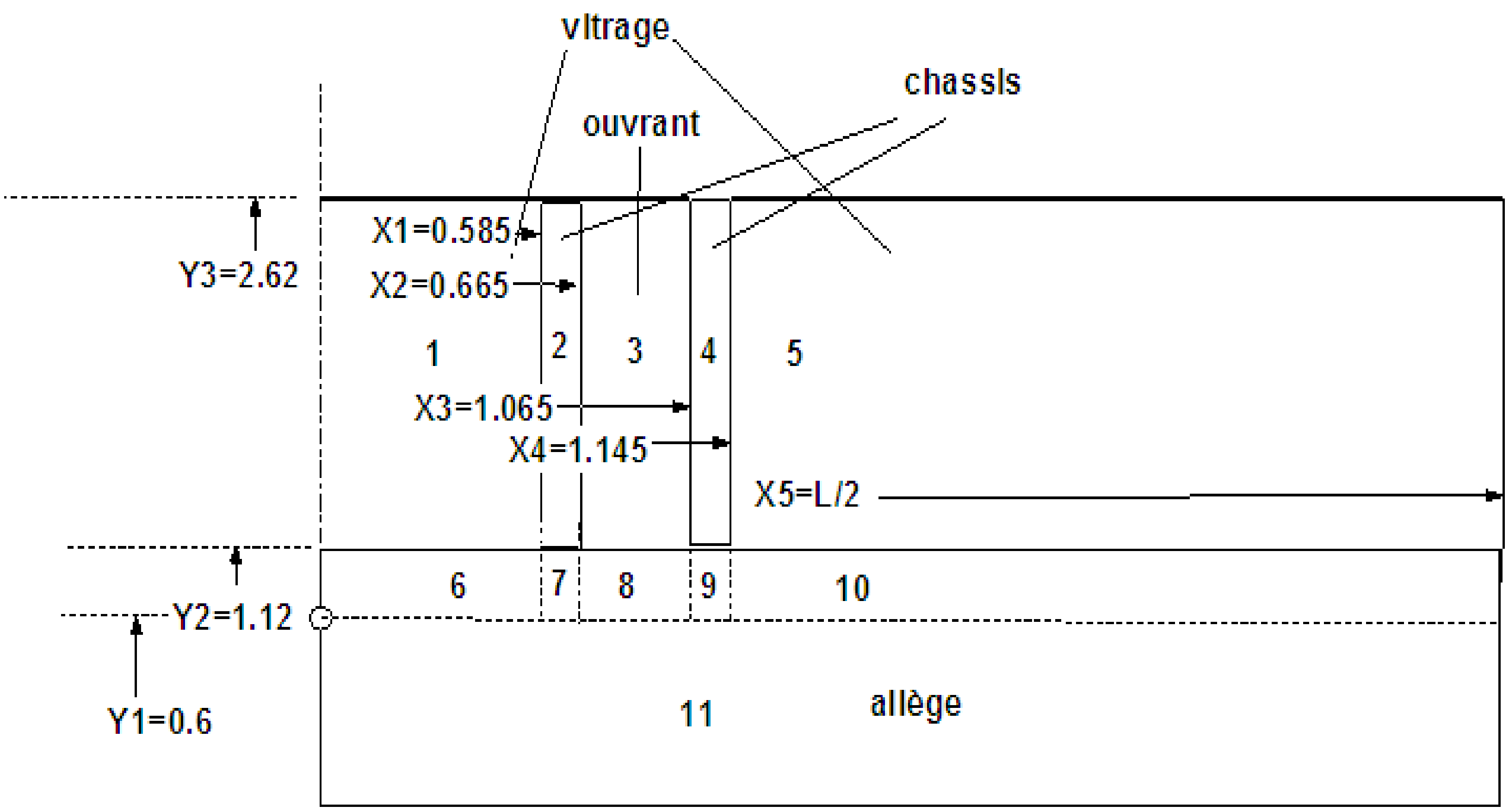

vitrage
chassis
ouvrant
X1=0.585
X2=0.665
Y3=2.62
1
2
3
4
5
X3=1.065
X4=1.145
X5=L/2
6
7
8
9
10
Y2=1.12
Y1=0.6
11
allège

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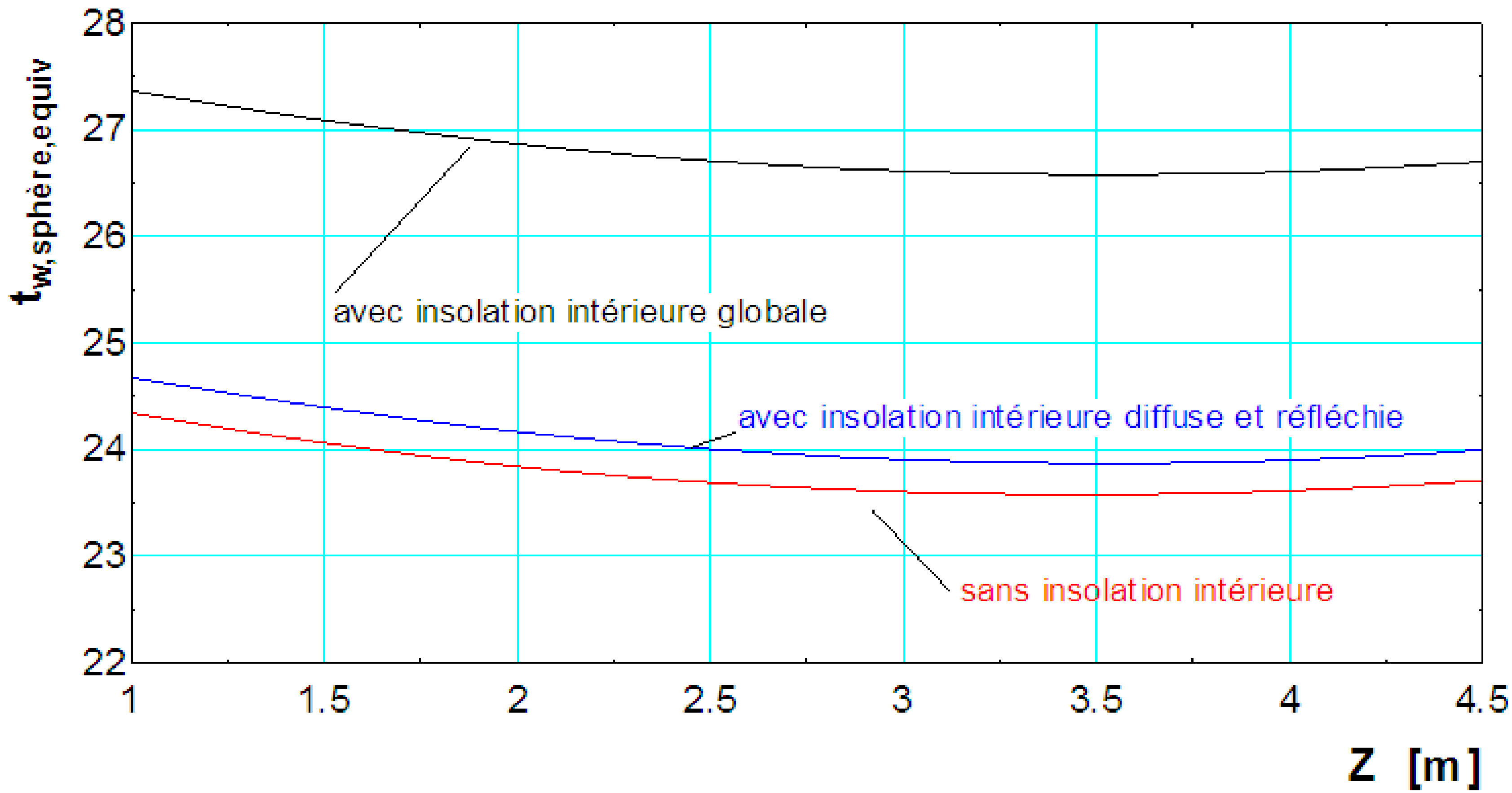

Figure 5: Température moyenne sphérique de rayonnement

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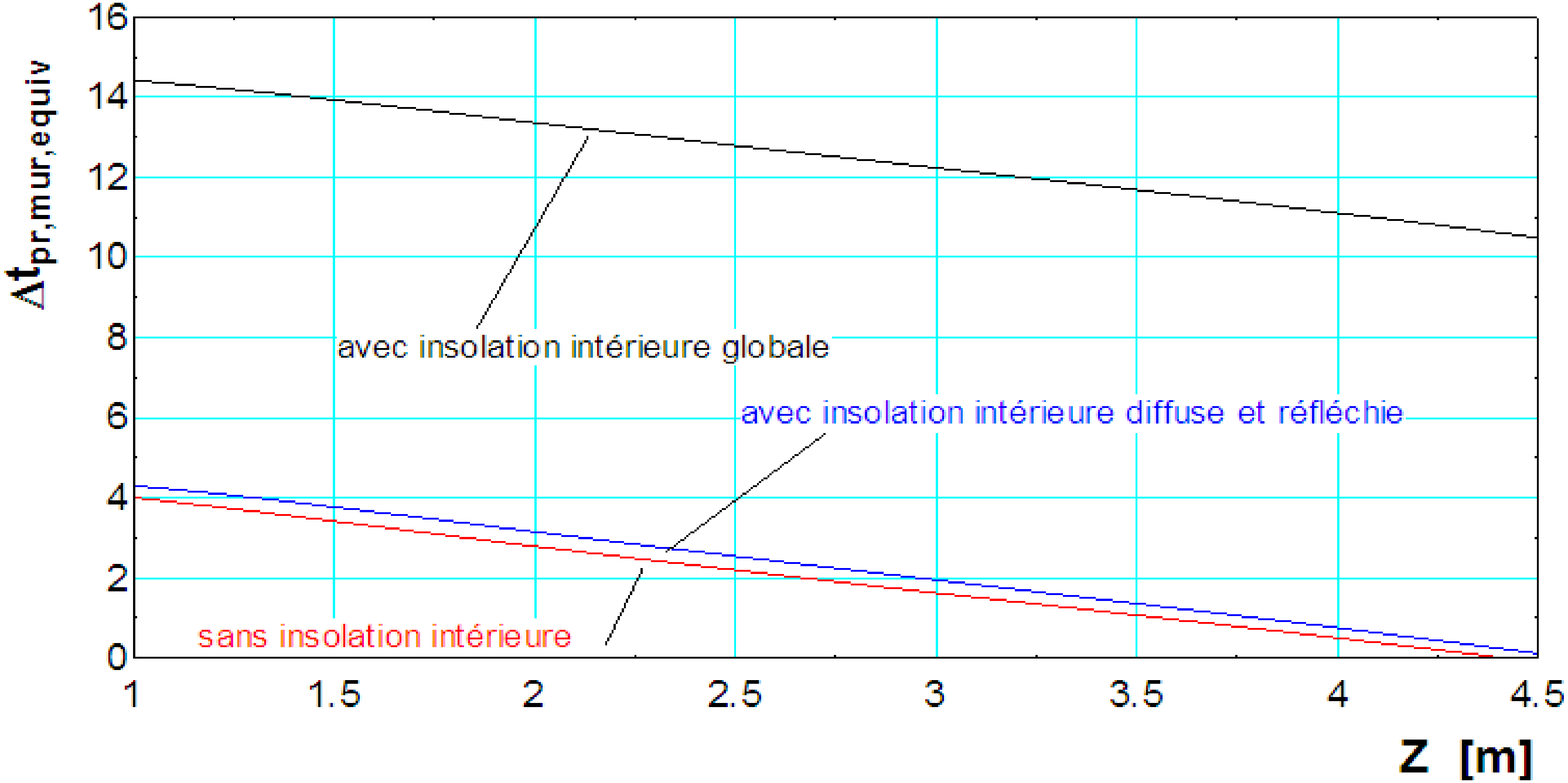

Figure 6: Asymétrie radiative « mur chaud »

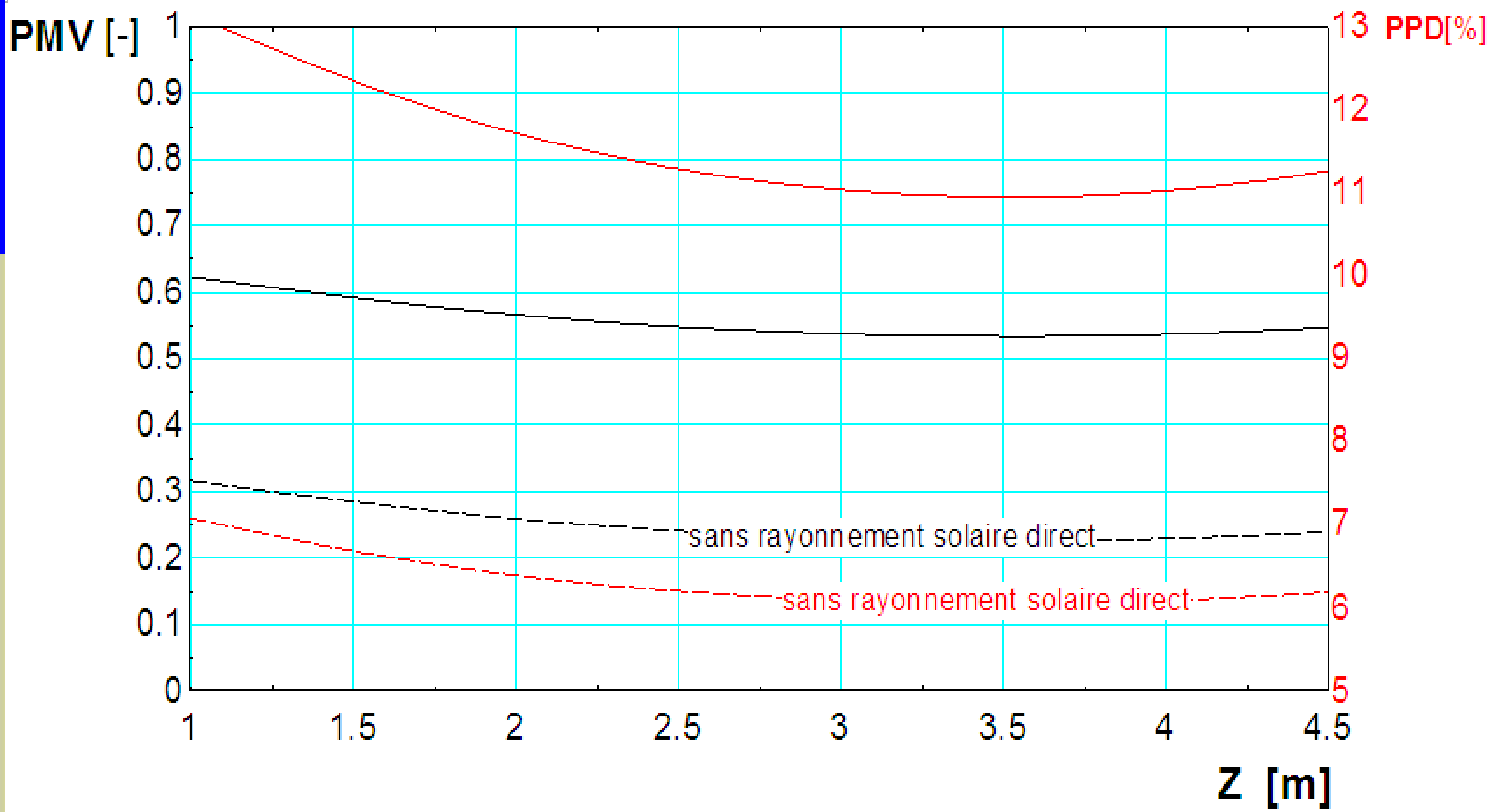

Figure 18b: Distributions des PMV et PPD dans la tour en été ; effet d'une protection de l'occupant contre l'insolation directe

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- The practical simulation tools are, until now, based on more or less simplified building models, in which some of the zones and some of the walls are “aggregated” into a few equivalent R-C-R circuits.

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- The “aggregation” is fully justified for early design and preliminary audit applications, but not in some other cases, as, for example, when having to analyse the performances of an existing building in order to identify the most attractive retrofitting potentials.

- A more realistic modelling of the building zones, of the external *and* internal partitions (walls, doors, windows…), of the inter-zone air flow rates and of all time schedules (occupancy, lighting, HVAC…) may be then required.

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- Such detailed building modelling might help a lot for a better understanding of actual energy consumptions and for a better prediction of the actual impact of new energy saving techniques

- It is, hopefully, also easy to perform with the equation solver, which is made available to all ATIC students…

First example: simulation of a dwelling

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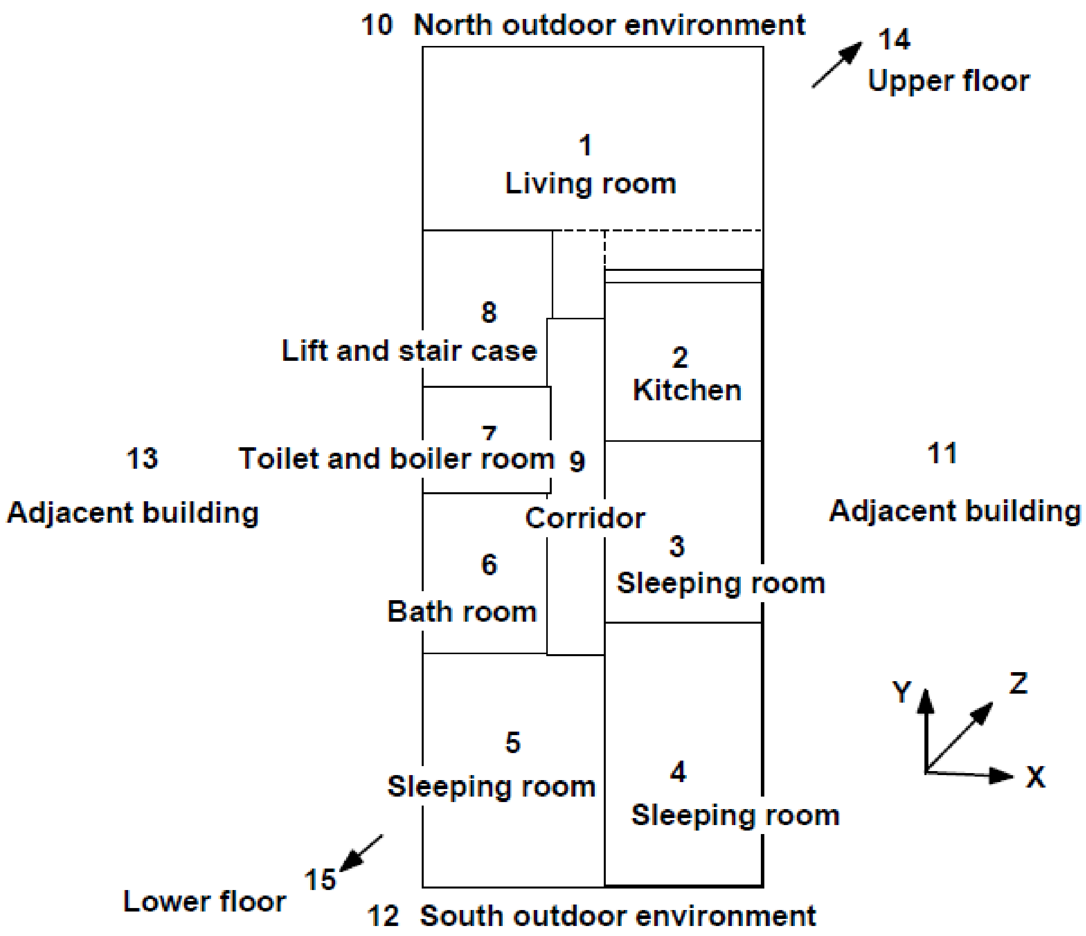
The dwelling subdivided in 9 zones



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ASSEMBLING OF THE SIMULATION MODEL

- **First step:** subdividing the building and its surroundings into different zones and identifying all *internal* and *external* walls.
- **Second step:** identifying the R and C components to be used to represent the internal and external zone “partitions”.
- **Third step:** interconnecting all the R-C-R circuits and establishing the energy balances of all nodes.

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- The equations are repeated and adapted, step by step, with help of the classical “copy”, “past”, “find” and “replace” functions for all walls and all zones.

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Room 1 (living room):

Thermal balance:

$$\dot{Q}_{occ,sensible,1} + \dot{W}_{lighting,1} + \dot{W}_{appliances,1} + \dot{Q}_{heating,1} + \dot{Q}_{sun,1} + \dot{H}_{vent,1} - \dot{Q}_{1,2} - \dot{Q}_{1,wall,1,8} - \dot{Q}_{1,9} - \dot{Q}_{1,10} - \dot{Q}_{1,wall,1,11} - \dot{Q}_{1,wall,1,13} - \dot{Q}_{1,wall,1,14} - \dot{Q}_{1,wall,1,15} = \dot{Q}_{storage,1}$$

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Internal heat gains due to occupancy, lighting and appliances:

$$\dot{Q}_{occ,sensible,1} = f_{occ,1} \cdot \dot{Q}_{occ,sensible,1,max}$$

Occupancy schedule:

$$f_{occ,1} = \textbf{Interpolate1}\left[\text{'occupancy}_{hour}\text{', 'hour', 'f}_{occ,1}\text{' , 'hour'} = hour_{per}\right]$$

$$\dot{Q}_{occ,sensible,1,max} = 150 \quad [W]$$

$$\dot{W}_{lighting,1} = f_{occ,1} \cdot \dot{W}_{lighting,1,max}$$

$$\dot{W}_{lighting,1,max} = 200 \quad [W]$$

$$\dot{W}_{appliances,1} = f_{occ,1} \cdot \dot{W}_{appliances,1,max}$$

$$\dot{W}_{appliances,1,max} = 100 \quad [W]$$

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Heating control (supposed to be proportional):

$$\dot{Q}_{heating,1} = f_{heating,1} \cdot X_{heating,1} \cdot \dot{Q}_{heating,fl,1}$$

Heating schedule:

$$f_{heating,1} = \textbf{Interpolate1}\left[\text{'occupancy}_{hour}\text{', 'hour', 'f}_{heating,1}\text{' , 'hour' = hour}_{per}\right]$$

Control law:

$$X_{heating,1} = \textbf{Min}\left[1 , \textbf{Max}\left(0 , C_{heating,control,1} \cdot \left[t_{heating,set,1} - t_1\right]\right)\right]$$

$\dot{Q}_{heating,fl,1}$ = 4000 [W]

$C_{heating,control,1}$ = 1 [C^{-1}]

Control set point:

$t_{heating,set,1}$ = 20 [C]

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Solar heat gain through the window:

$$\dot{Q}_{sun,1} = I_{North} \cdot A_{1,10} \cdot S_{window}$$

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Ventilation:

$$\dot{H}_{vent,1} = \dot{C}_1 \cdot [t_{su,1} - t_{ex,1}]$$

$$\dot{C}_1 = \dot{M}_{ex,1} \cdot c_p$$

$$c_p = 1020 \quad [J/kg\text{-}C]$$

$$t_{su,1} = t_{10}$$

(hypothetical air circulation)

$$t_{ex,1} = t_1$$

(perfect mixing hypothesis)

Transmission through the walls:

Light partition between zones 1 and 2:

$$\dot{Q}_{1,2} = A_{1,2} \cdot U_{partition} \cdot [t_1 - t_2]$$

(if partition closed)

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Each heavy wall is, in first approximation simulated here as a first order R-C-R branch:

Wall 1-8:

Heat transfer from zone 1 to wall thermal mass:

$$\dot{Q}_{1,wall,1,8} = A_{1,8} \cdot U_{1,wall,1,8} \cdot \delta t_{1,wall,1,8}$$

$$U_{1,wall,1,8} = 2 \cdot U_{wall,in}$$

(in first approximation)

$$\delta t_{1,wall,1,8} = t_1 - t_{wall,1,8}$$

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Heat transfer from zone 8 to wall thermal mass:

$$\dot{Q}_{8,wall,1,8} = A_{1,8} \cdot U_{8,wall,1,8} \cdot \delta t_{8,wall,1,8}$$

$$U_{8,wall,1,8} = U_{1,wall,1,8}$$

$$\delta t_{8,wall,1,8} = t_8 - t_{wall,1,8}$$

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Wall heat balance:

$$\dot{Q}_{1,wall,1,8} + \dot{Q}_{8,wall,1,8} = \dot{Q}_{storage,wall,1,8}$$

Energy storage in wall thermal mass:

$$Q_{storage,wall,1,8} = \int_{\tau_1}^{\tau_2} [\, \dot{Q}_{storage,wall,1,8} \,] \, d\tau$$

$$Q_{storage,wall,1,8} = A_{1,8} \cdot C\backslash A_{wall,in} \cdot \Delta t_{wall,1,8}$$

$$\Delta t_{wall,1,8} = t_{wall,1,8} - t_{wall,1,8,1}$$

Initial temperature (hypothetical):

$$t_{wall,1,8,1} = 20 \quad [C]$$

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Wall 1-10 (North window):

$$\dot{Q}_{1,10} = A_{1,10} \cdot U_{window} \cdot \left[t_1 - t_{10,equiv} \right]$$

- The heavy walls connecting zone 1 to adjacent zones 11, 12, 13 14 and 15 are simulated in the same way as the wall 1-8…

Indoor thermal storage:

$$Q_{storage,1} = \int_{\tau_1}^{\tau_2} [\dot{Q}_{storage,1}] \, d\tau$$

$$Q_{storage,1} = C_1 \cdot \Delta t_1$$

The indoor (fictitious) thermal mass corresponds to the air thermal mass multiplied by a majoration factor:

$$C_1 = F_{thermalmass} \cdot V_1 \cdot \rho \cdot c_p$$

$$F_{thermalmass} = 5 \quad [-]$$

$$\Delta t_1 = t_1 - t_{1,1}$$

$$t_{1,1} = 20 \quad [C]$$

- Various hypotheses can be made on the temperature of the stair case.
- For example, it can be assumed that this temperature is, at least, 5 C higher than the outdoor temperature and never lower than 5 C:

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Hypothetical temperature in the stair case:

$$t_8 = \mathbf{Max}\left[\, t_{8,min} \,,\ t_{out} + \Delta t_{8,out} \,\right] \quad [C]$$

$$t_{8,min} = 5 \quad [C]$$

$$\Delta t_{8,out} = 5 \quad [C]$$

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- The outdoor environmental temperature is supposed to take the effect of long wave sky radiation into account (the sky is usually colder than the air, depending on sky clarity):

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Outdoor air temperature:

$$t_{10} = t_{out}$$

Sky radiation effect:

$$t_{10,equiv} = t_{10} - \varepsilon \cdot F_{IR,sky} \cdot \frac{IR_{sky}}{h_{out}}$$

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Emissivity:

$\varepsilon = 0.9 \quad [-]$

Sky view factor:

$F_{IR,sky} = 0.5 \quad [-]$

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$$IR_{sky} = IR_{sky,min} + IR_{sky,max} \cdot s \backslash s_{cs}$$

$$IR_{sky,min} = 45 \quad [W/m^2]$$

$$IR_{sky,max} = 100 \quad [W/m^2]$$

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- Various hypotheses can also be done on the temperatures of the other adjacent zones, depending mainly on the occupancy rate or the surrounding apartments:

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Hypothetical temperatures of the surrounding internal zones:

$t_{11} = t_1$

$t_{13} = t_8$

$t_{14} = t_8$

$t_{15} = t_1$

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- The thermal balances of the other 7 internal zones are established in the same way…

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All power and energy consumptions can be defined as follows:

Heating power:

$$\dot{Q}_{heating} = \dot{Q}_{heating,1} + \dot{Q}_{heating,2} + \dot{Q}_{heating,5} + \dot{Q}_{heating,6}$$

Heating energy:

$$Q_{heating} = \int_{\tau_1}^{\tau_2} [\dot{Q}_{heating}]\, d\tau$$

$$Q_{heating,kWh} = \frac{Q_{heating}}{W\backslash kW \cdot s\backslash h}$$

$W\backslash kW = 1000$ [W/kW]

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Lighting power:

$$\dot{W}_{lighting} = \dot{W}_{lighting,1} + \dot{W}_{lighting,2} + \dot{W}_{lighting,5} + \dot{W}_{lighting,6}$$

Lighting energy:

$$W_{lighting} = \int_{\tau_1}^{\tau_2} \left[\dot{W}_{lighting} \right] d\tau$$

$$W_{lighting,kWh} = \frac{W_{lighting}}{W\backslash kW \cdot s\backslash h}$$

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Hot water power:

$$\dot{Q}_{hot,water} = \dot{M}_{hot,water} \cdot c_{water} \cdot [t_{hot,water} - t_{distribution}]$$

$$\dot{M}_{hot,water} = \frac{\dot{M}_{hot,water,day}}{s\backslash h \cdot hour\backslash day}$$

$$\dot{M}_{hot,water,day} = 80 \quad [kg]$$

$$c_{water} = 4187 \quad [J/kg\text{-}C]$$

$$t_{hot,water} = 70 \quad [C]$$

$$t_{distribution} = 10 \quad [C]$$

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Hot water energy:

$$Q_{hot,water} = \int_{\tau_1}^{\tau_2} \left[\dot{Q}_{hot,water} \right] d\tau$$

$$Q_{hot,water,kWh} = \frac{Q_{hot,water}}{W\backslash kW \cdot s\backslash h}$$

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And, as all consumptions are in the same energy form (electricity), they may be added together:

Total energy:

$$W_{total,kWh} = Q_{heating,kWh} + W_{lighting,kWh} + W_{appliances,kWh} + Q_{hot,water,kWh}$$

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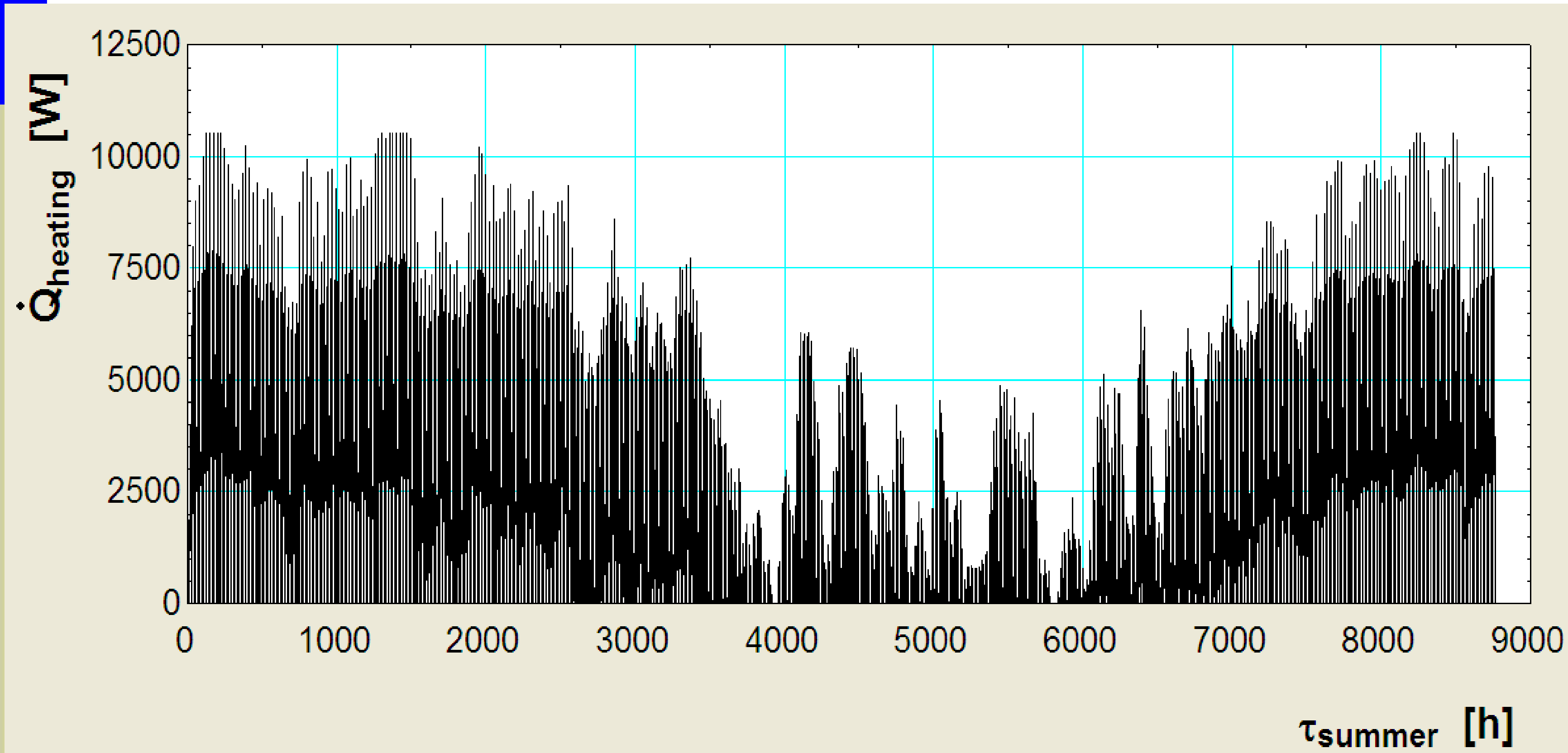
FIRST SIMULATION RESULTS: INFLUENCE OF OCCUPANCY RATES

- The possible influences of both (surrounding and internal) occupancy rates are here observed by simulation on a reference year.

Total heating demand when the dwelling is fully occupied and the adjacent four dwellings unoccupied



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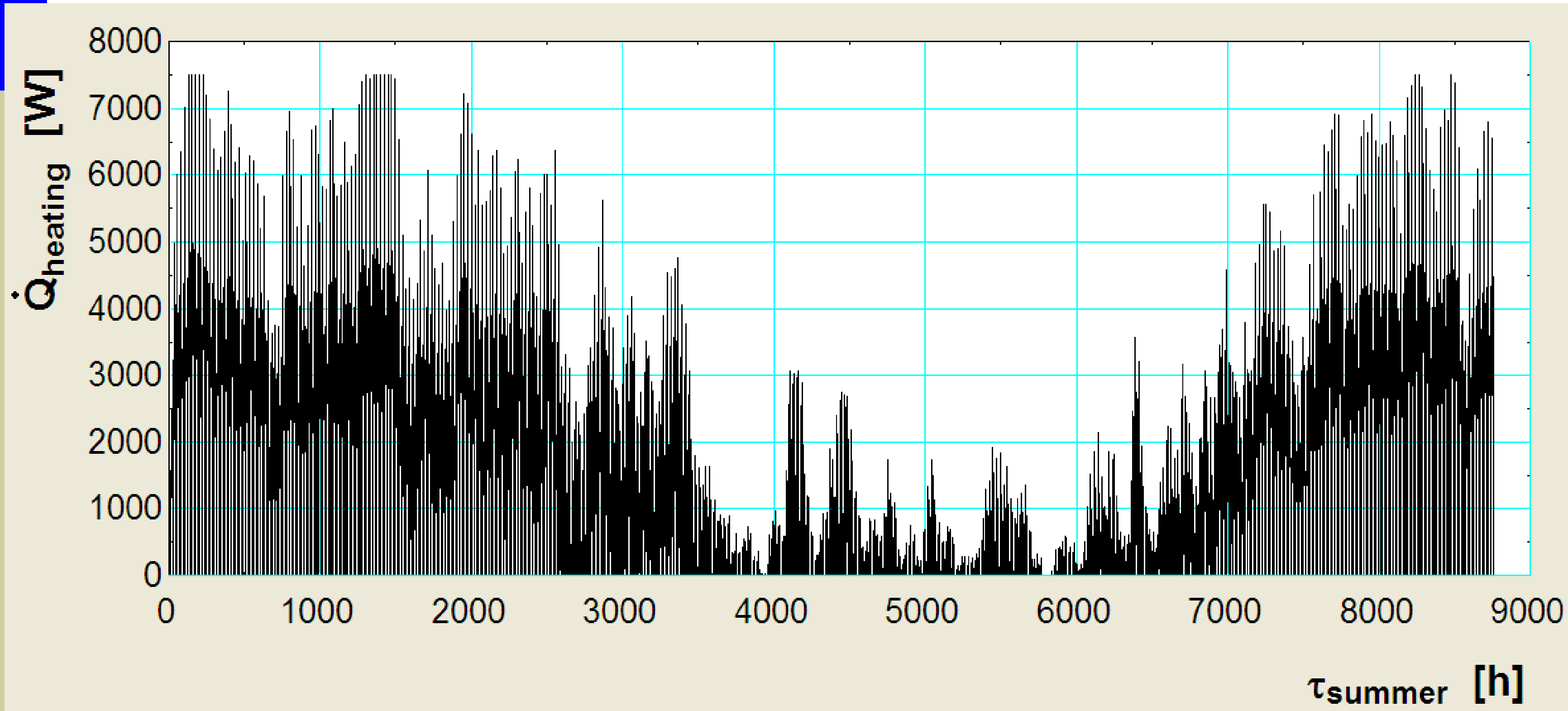
Total heating demand when the dwelling is partially occupied and the adjacent four dwellings unoccupied



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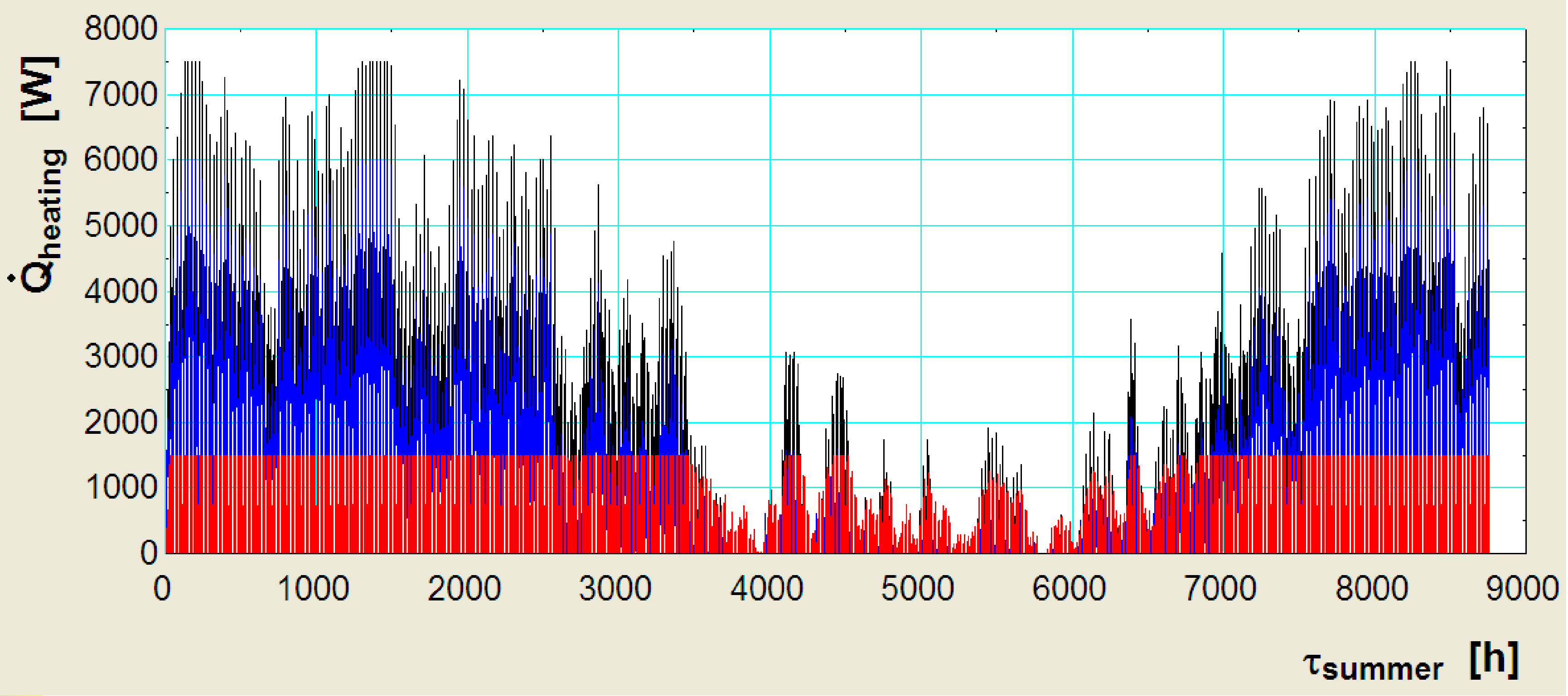
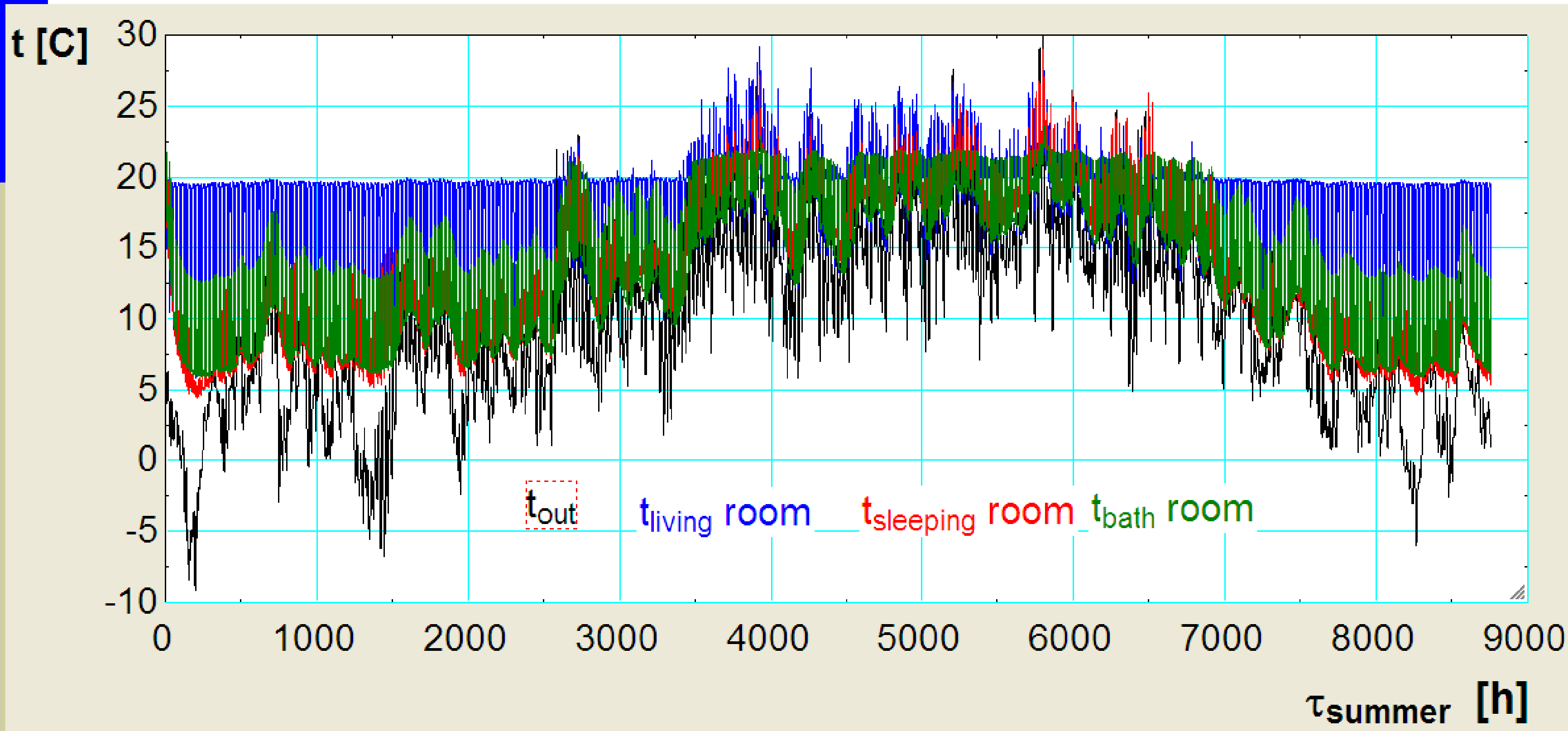
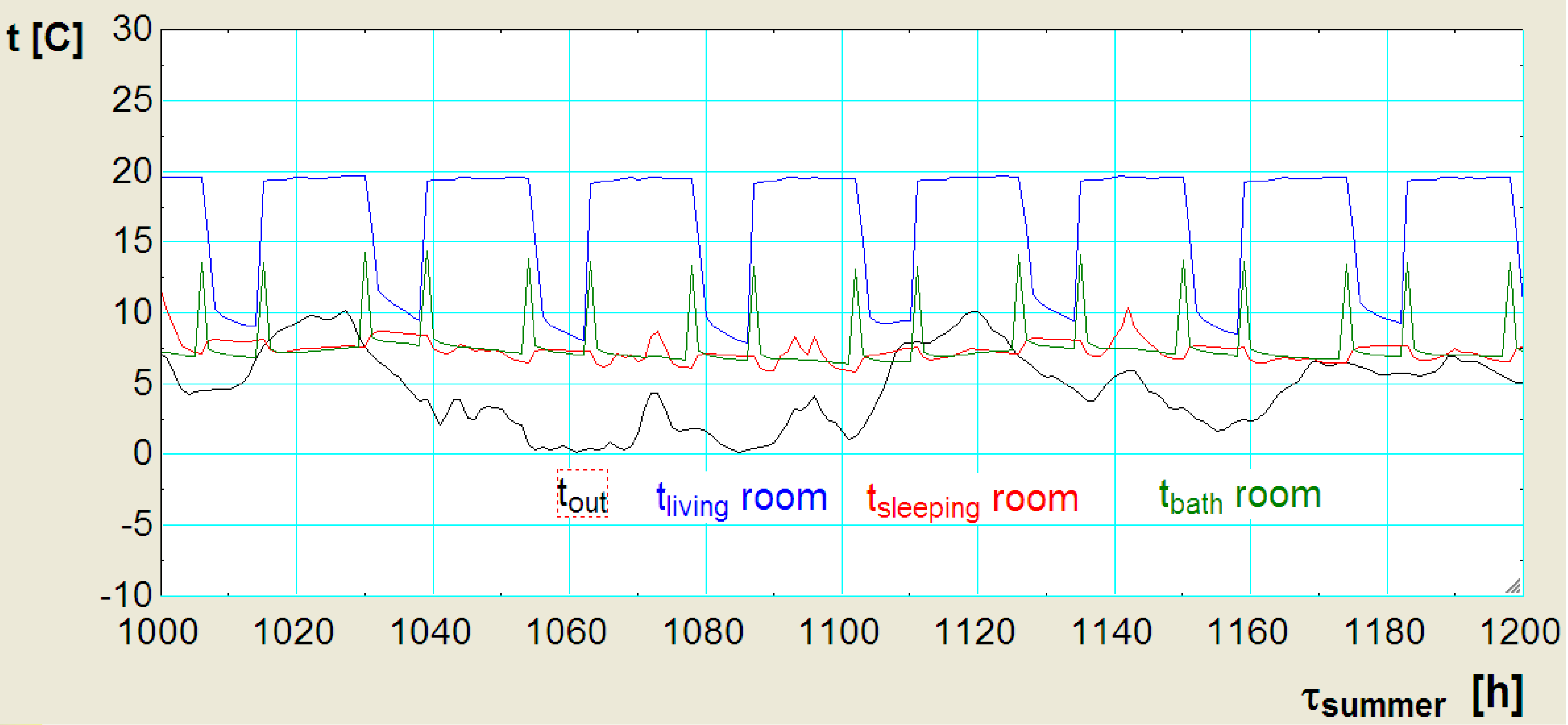
Heating demands of the whole dwelling (in black), of the living room (in blue) and of the bath room (in red)



Outdoor and indoor temperatures in the conditions

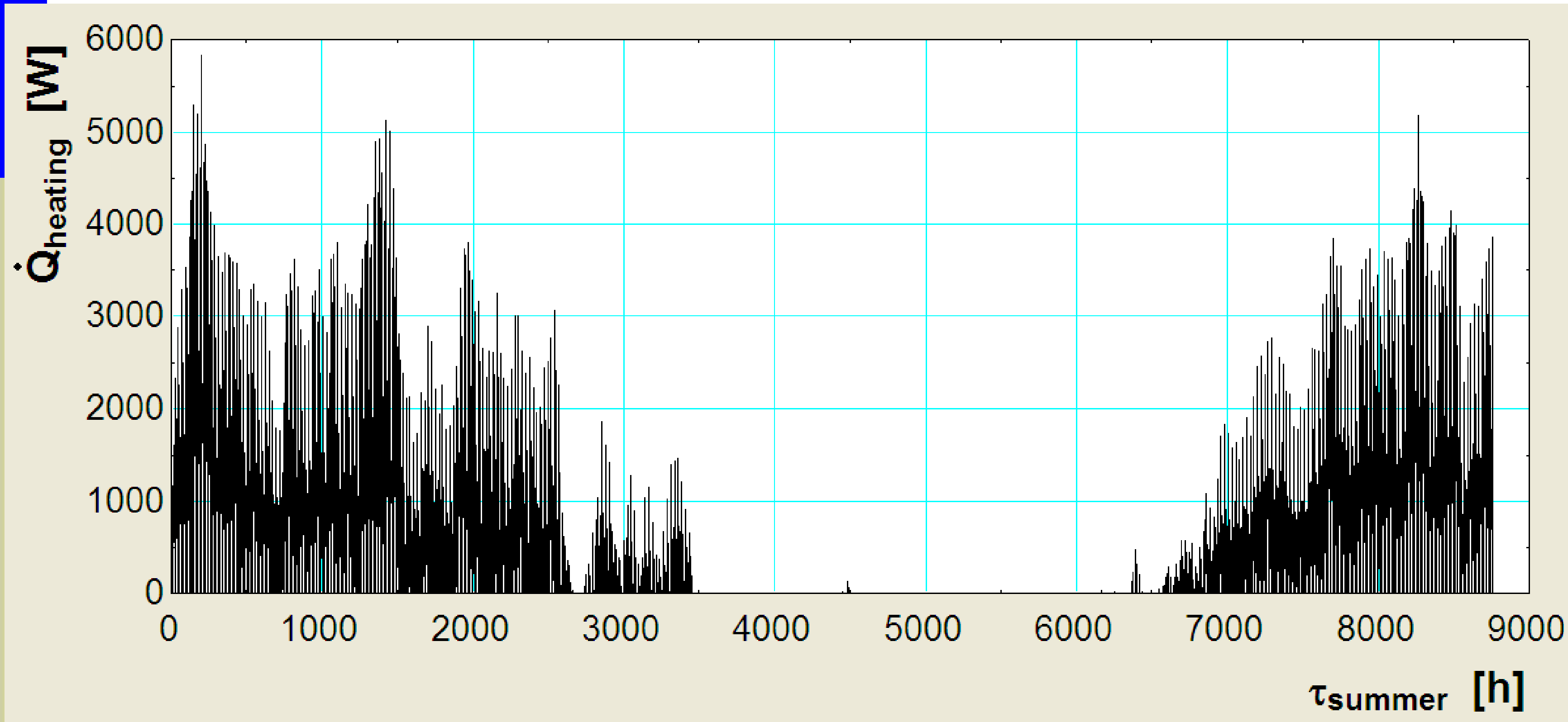


Zoom

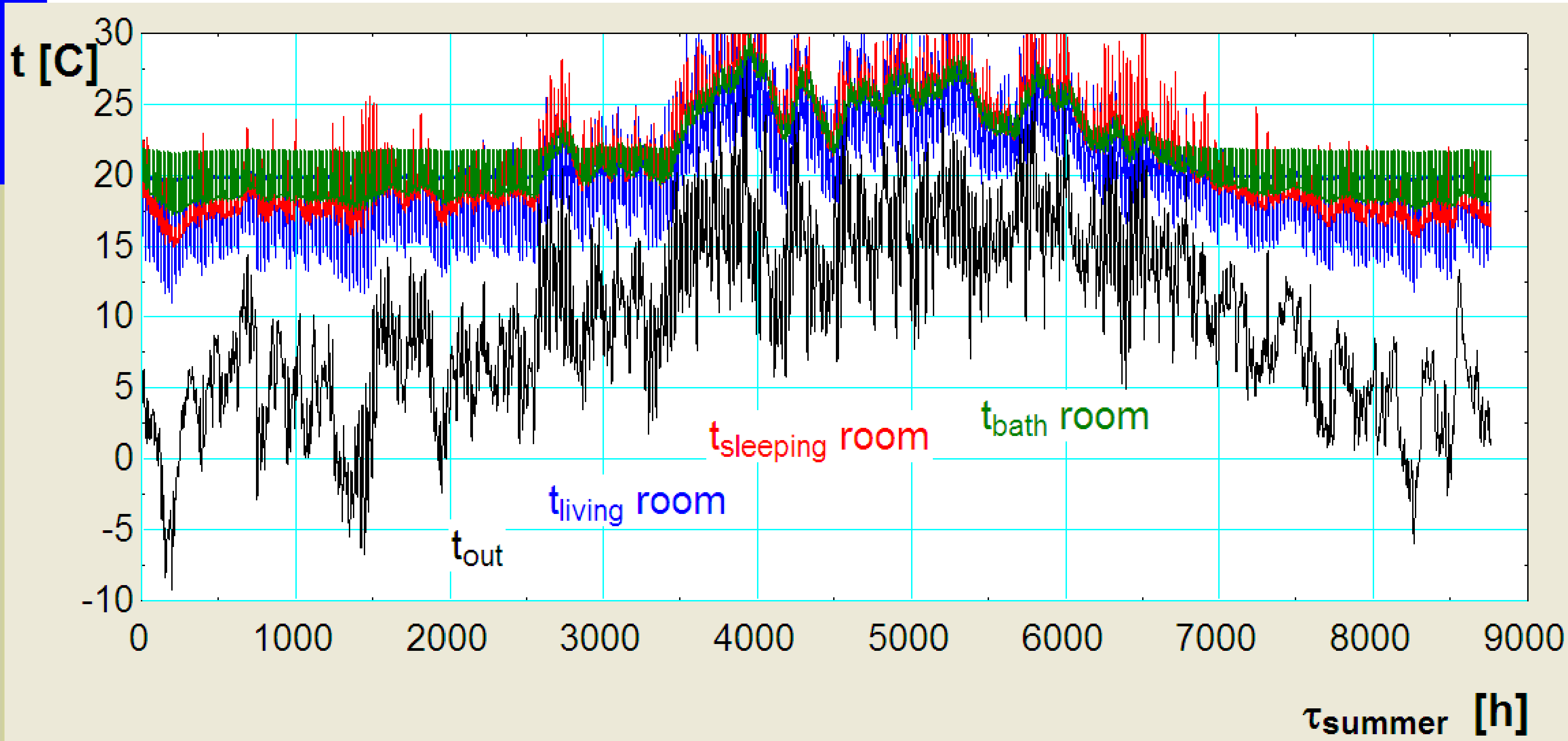


t [C]
30
25
20
15
10
5
0
-5
-10
1000
1020
1040
1060
1080
1100
1120
1140
1160
1180
1200
t_{out}
t_{living} room
$t_{sleeping}$ room
t_{bath} room
τ_{summer} [h]

Total heating demand when the dwelling is fully occupied and also the four adjacent dwellings

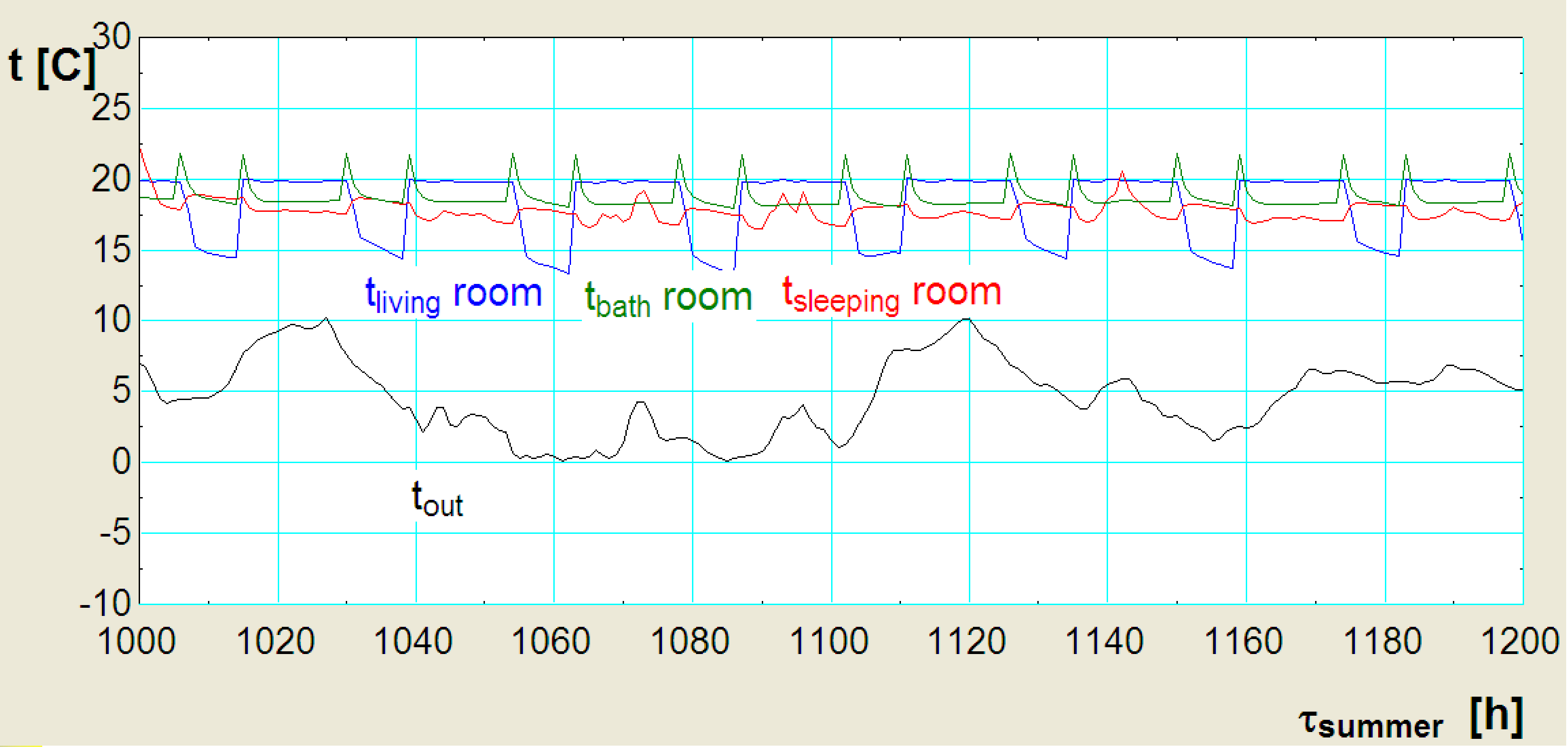


Outdoor and indoor temperatures



ATIC

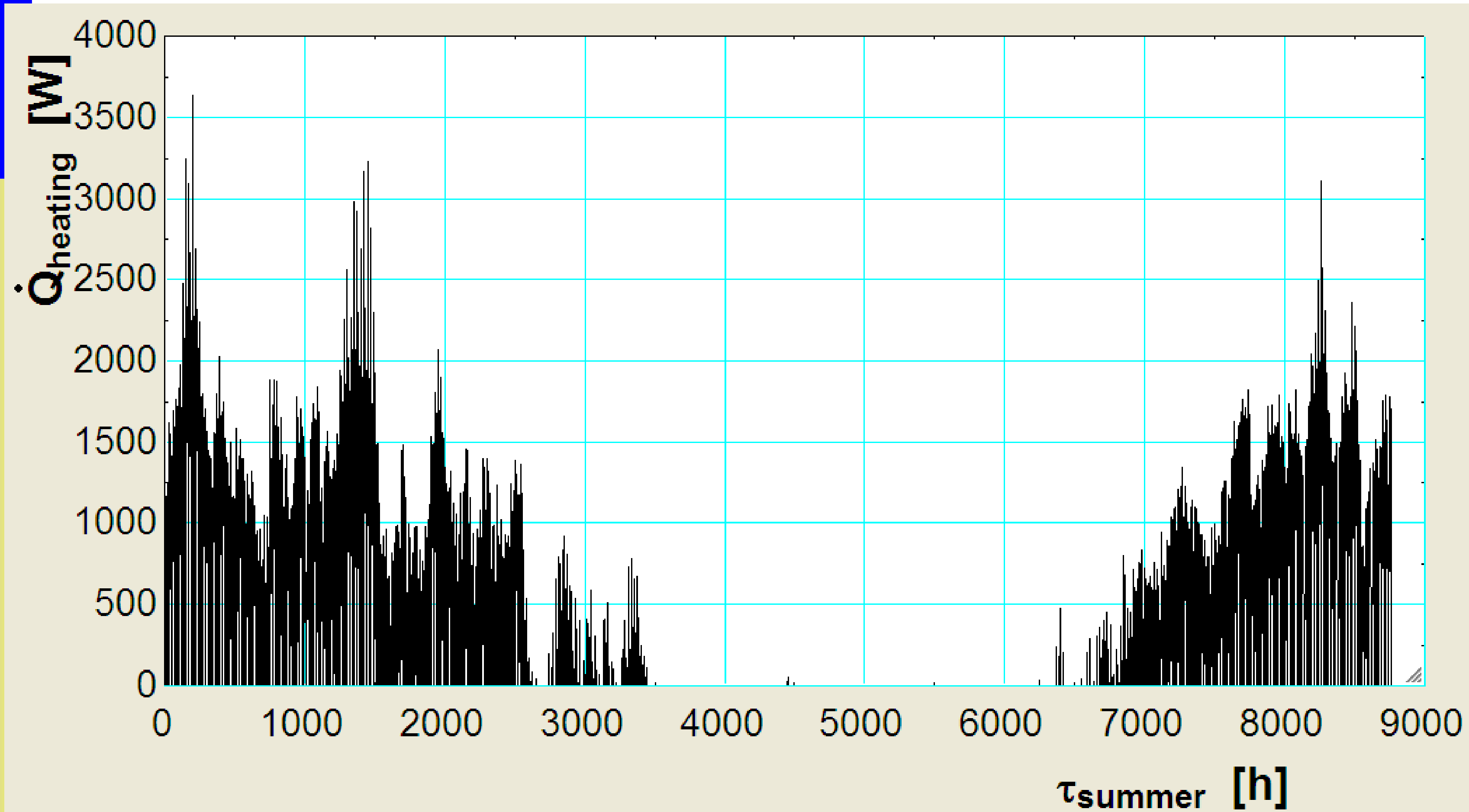
Zoom



t [C]
30
25
20
15
10
5
0
-5
-10
1000
1020
1040
1060
1080
1100
1120
1140
1160
1180
1200
t_{living} room
t_{bath} room
$t_{sleeping}$ room
t_{out}
τ_{summer} [h]

ATIC

Total heating demand of the dwelling partially occupied and the four adjacent dwellings occupied



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Synthesis of simulation results

Dwelling [-]	Surrounding [-]	$Q_{hot,water}$ [kWh]	$Q_{heating}$ [kWh]	$W_{Appliances,kWh}$ [kWh]	$W_{lighting,kWh}$ [kWh]	$W_{total,kWh}$ [kWh]
0.33	0	2038	10104	5475	1978	19595
0.33	0.25	2038	7864	5475	1978	17355
0.33	0.5	2038	5215	5475	1978	14706
0.33	0.75	2038	4611	5475	1978	14102
0.33	1	2038	3767	5475	1978	13235
0.66	0.25	2038	8720	5475	2635	18868
1	0	2038	12027	5475	3292	22832
1	0.25	2038	9535	5475	3292	20340
1	0.5	2038	10800	5475	3292	21605
1	0.75	2038	4524	5475	3292	18889
1	1	2038	4524	5475	3292	15329

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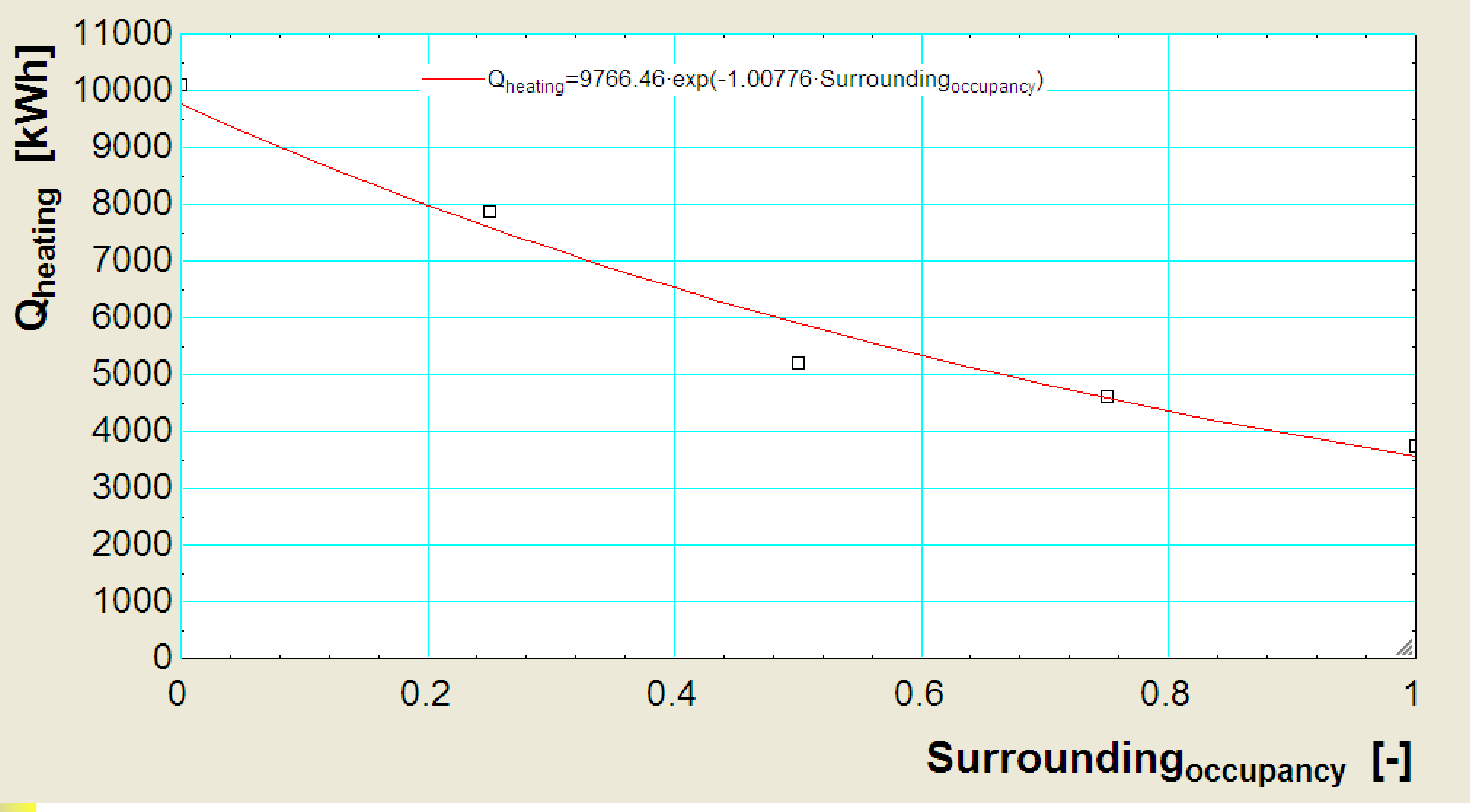
Influence of surrounding occupancy rate on heating demand



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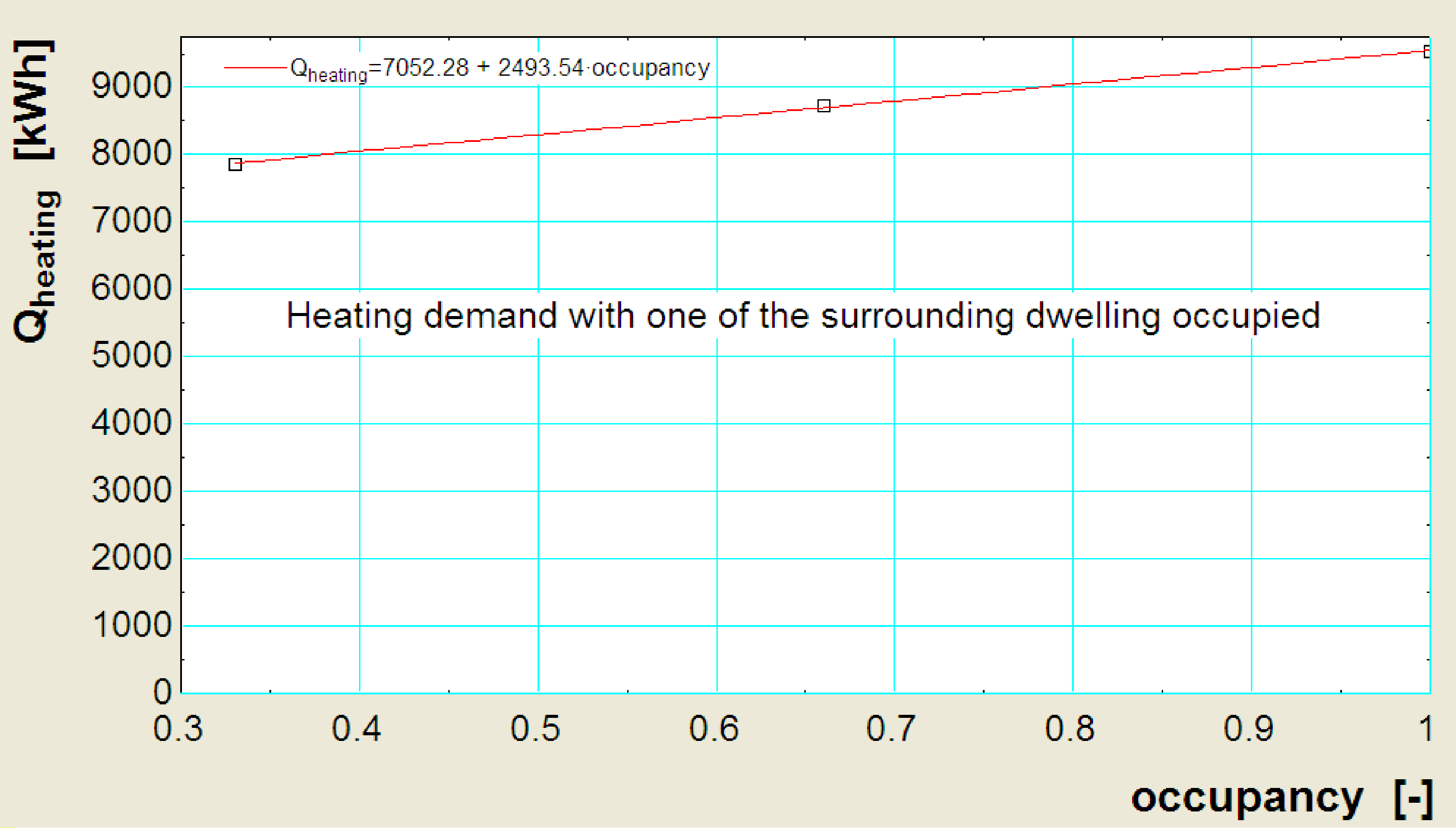
Influence of dwelling occupancy on heating demand



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- These regressions established on simulation results are no more than a provocation
- Building “signatures” more interesting when established on shorter time bases
- Both internal and external occupancy rates are varying a lot all along the year!

- Question: which is the shorter time basis on which such signature can be established?
- One month? One week? One day? One hour?

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Other example:

- **Transformation of an old building**
- **(Still unusual) pre-study performed to support initial choices**
- **Fully readable equations**
- **Large flexibility**
- **Executable files**
- **Any architectural change easy to introduce**

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First step

- Subdividing the building into different zones
- Identifying all *internal* and *external* walls
- In the example considered: 14 zones and 81 walls…

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Second step

- Identification of all R and C components
- Identification of ventilation capacity flow rates and of internal heat gains
- Solution to be *copied and pasted* in the (third step) simulation model.

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. *Third Step*

- Interconnection of all R-C-R circuits and energy balances of all nodes
- In the example considered: 1558 equations: 1495 algebraic and 63 integral
- NB: equations repeated and adapted, step by step, with help of “copy”, “past”, “find” and “replace” functions…

- Some zones heated and cooled by some terminal units (radiators, fan coils, ceiling…)
- Each heating/cooling unit run according to some (hourly, daily, weekly and seasonal) schedules
- Supposed-to-be proportional control…

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- Global balance established on the “central” node (indoor environment) of each zone
- Fictitious air thermal mass associated to this node
- Fans consumptions taken into account
- First approach *as if* each zone had separate HVAC system with constant performances
- Global consumptions easy to calculate

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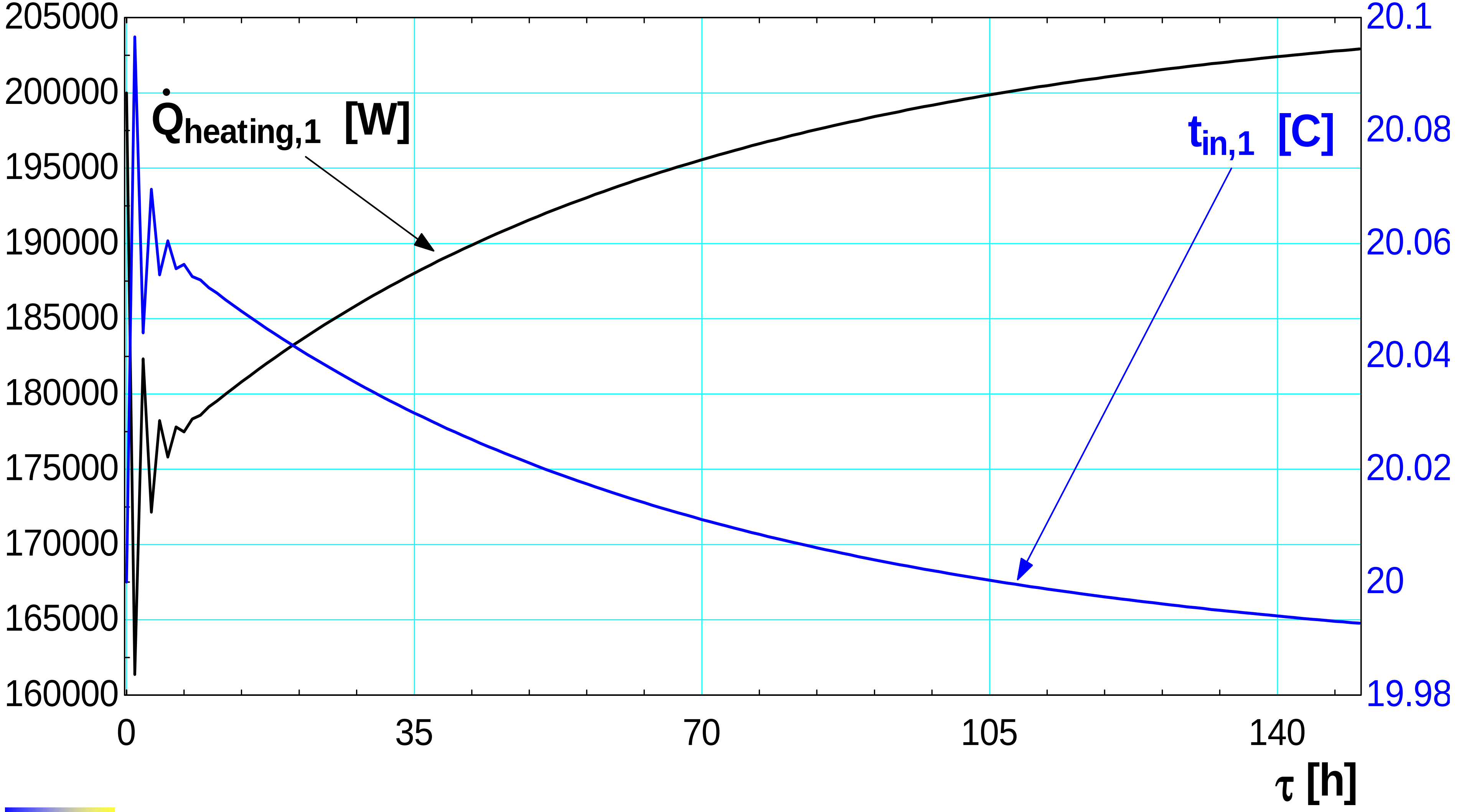
HEATING DEMAND IN NOMINAL CONDITIONS

- Nominal (sizing) heat losses are calculated with the same simulation model, by imposing some reference conditions:
- no sunshine,
- no internal “free” heat,
- constant outdoor temperature
- constant indoor set point



205000
200000
195000
190000
185000
180000
175000
170000
165000
160000
$\dot{Q}_{heating,1}$ [W]
$t_{in,1}$ [C]
20.1
20.08
20.06
20.04
20.02
20
19.98
0
35
70
105
140
τ [h]

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SIMULATION

- Example: building equipped with cooling system, preventing the indoor temperature of over-passing 25 C during occupancy periods

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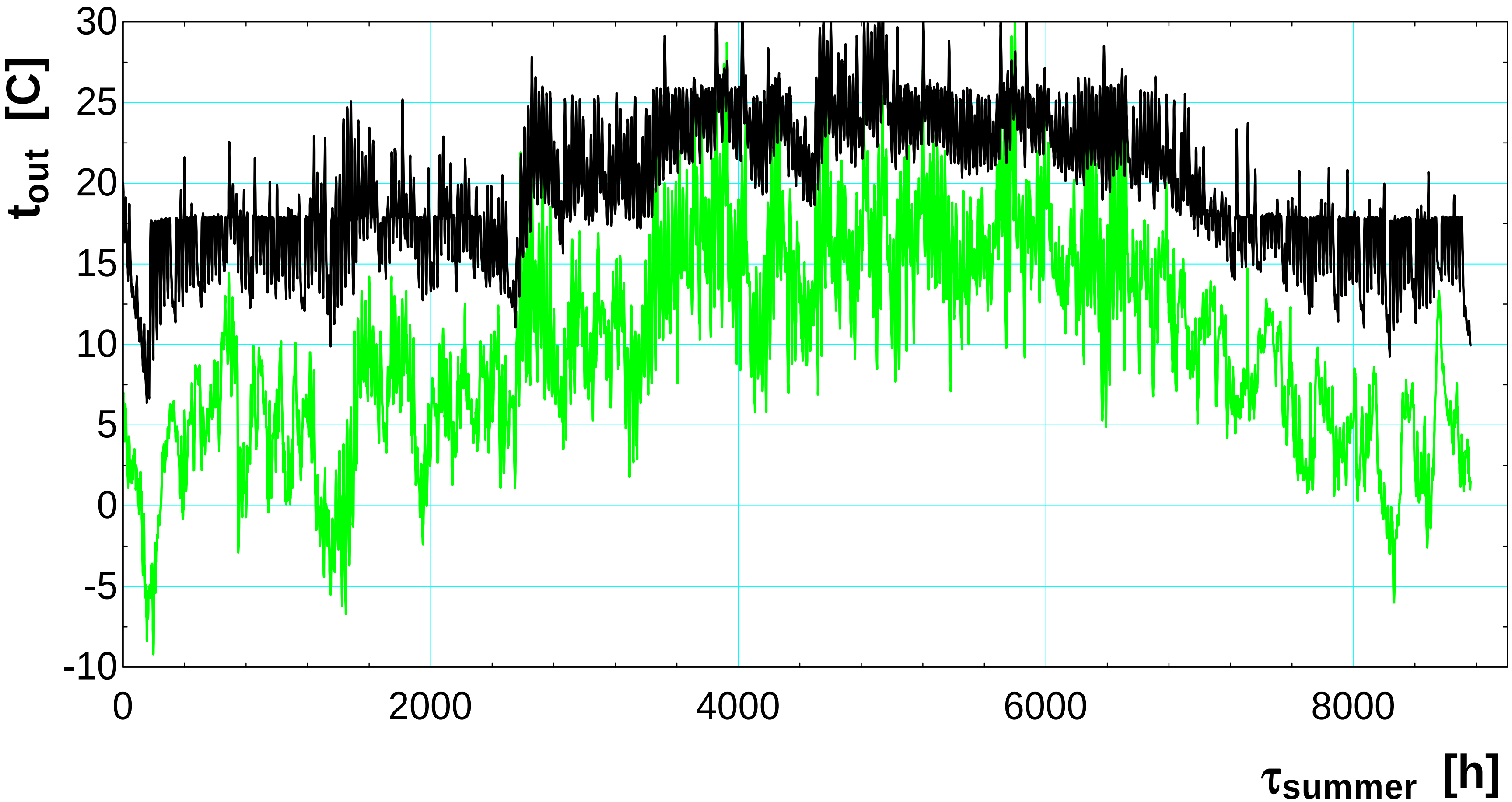
Outdoor (green) and indoor (black) temperatures of zone 1



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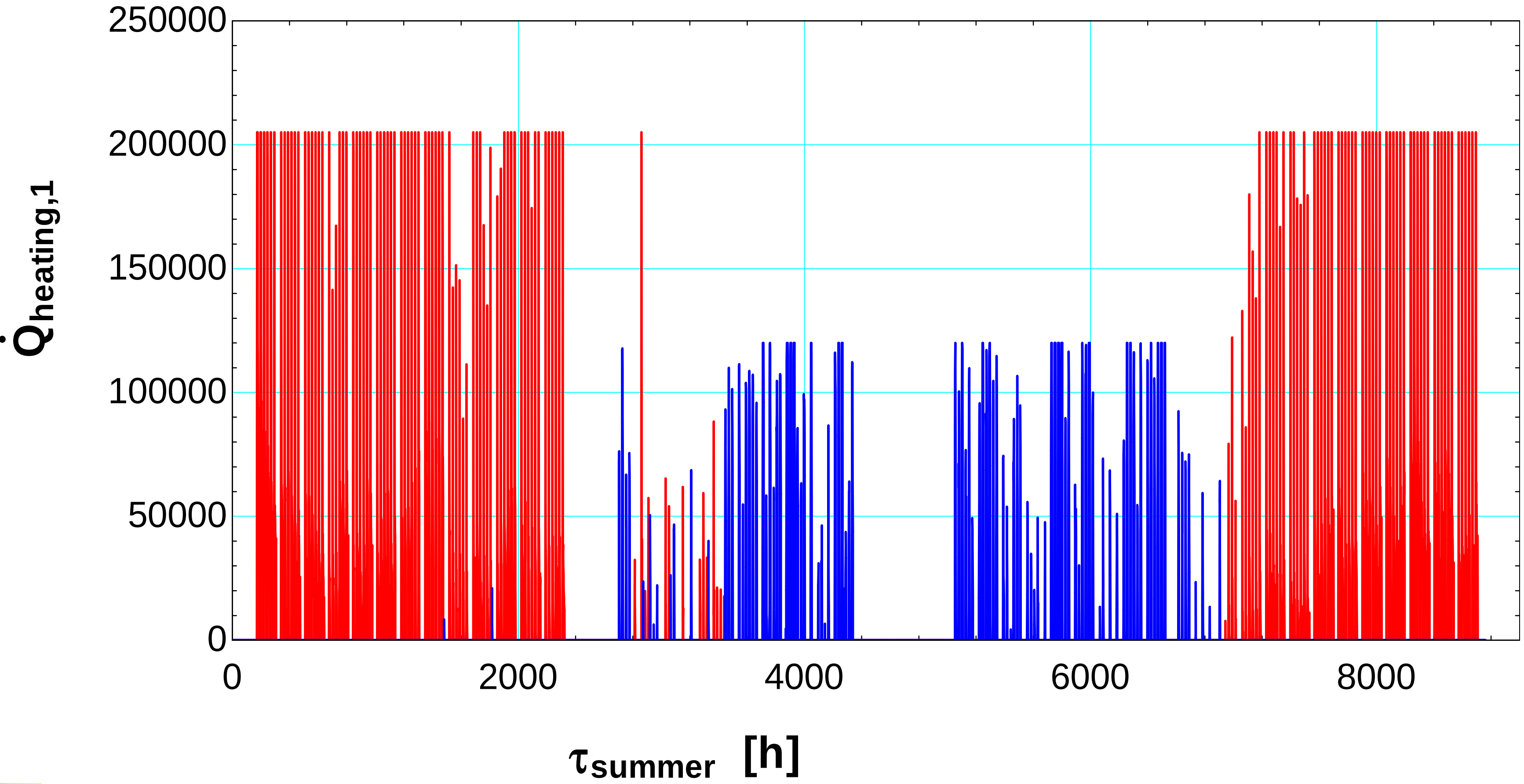
Heating (red) and cooling (blue) demands



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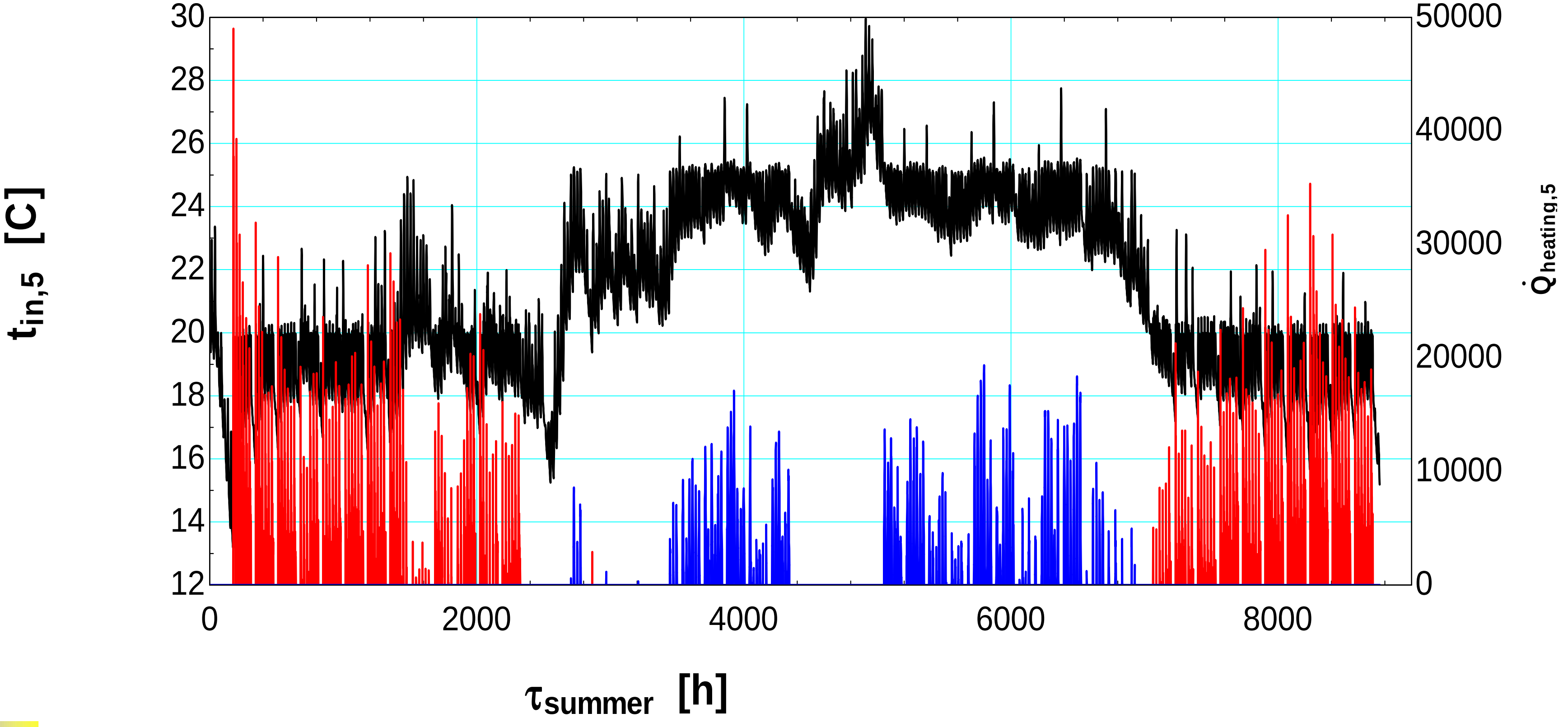
Indoor temperature (black), heating (red) and cooling (blue) demands of zone 5



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ANALYSIS

- Case considered:

- building over-insulated

- occupancy and ventilation flow rates limited

to 20 % of their nominal values

- no ventilation heat recovery

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Main terms of yearly energy consumptions

- Heating: 213 651 kWh (fuel)
- Lighting: 151 479 kWh (electricity)
- Cooling: 27 412 kWh (electricity)

NB: all terms *not* converted into primary energy!

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Corresponding running costs:

- Lighting: 21 813 €
- Heating: 11 538 €
- Cooling: 3 947 €

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- Lighting is dominant term, for primary energy as well for running costs
- Cooling is much less important…

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Going further with comparative simulations shows that, *in this case*…

- Over-insulation is not cost effective
- The heating demand is dominated by ventilation
- First priority: minimizing lighting
- Second priority: controlling mechanical ventilation as function of actual occupancy
- Ventilation heat recovery *not* cost effective

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In *this* case also…

- Mechanical cooling actually welcome in order to eliminate significant overheating periods
- Global energy consumptions and running costs not significantly increased
- Even more attractive if reversible heat pump system…

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CONCLUSIONS

- Multi-zone simulation is easy with help of equation solver
- Fairly detailed and transparent analyses
- Identification of best energy savings opportunities
- Lighting may represent a very significant part of the energy consumptions and of the running costs.
- “Passive” techniques of reducing the energy demands should be carefully considered *before* looking for more sophisticate (and more expensive) “active” techniques…