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Are HVAC heating systems hidden house occupants? Is it possible to predict their behavior?

Ghent University, Gent, Belgium
Katarina Simic
27/10/2021

Prof Jelle Laverge
Prof Michel De Paepe

Smart solutions

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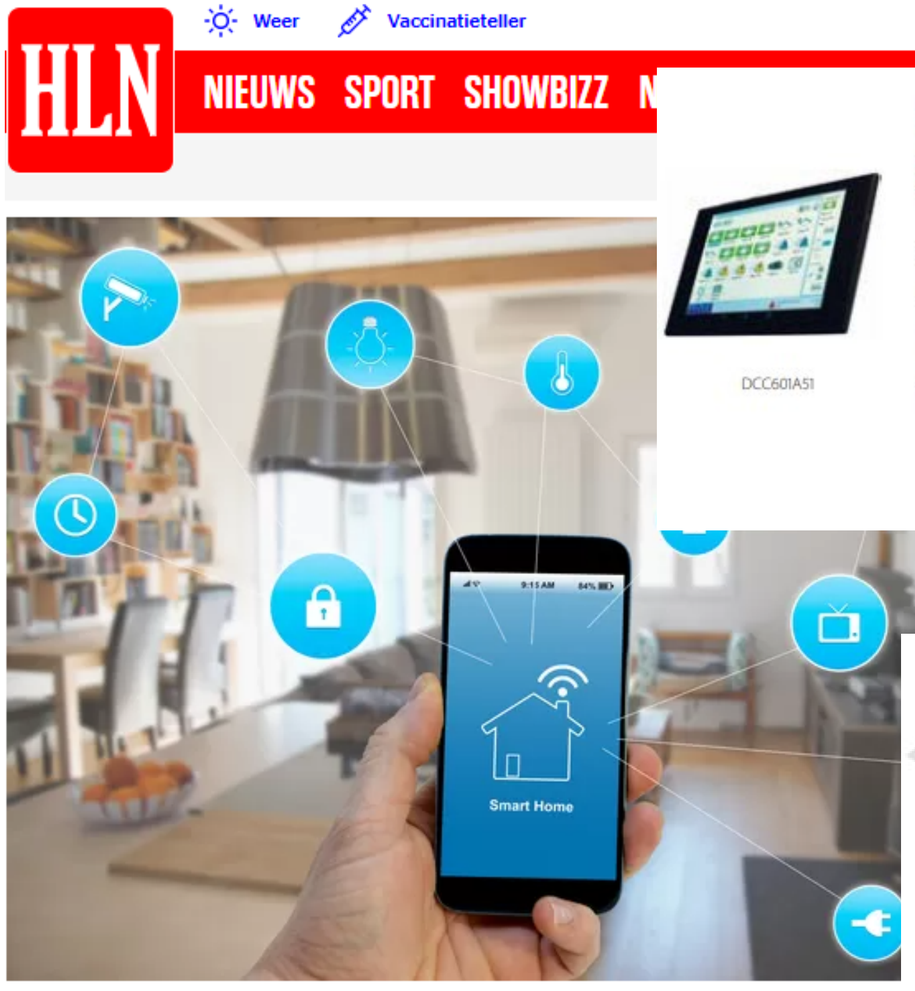
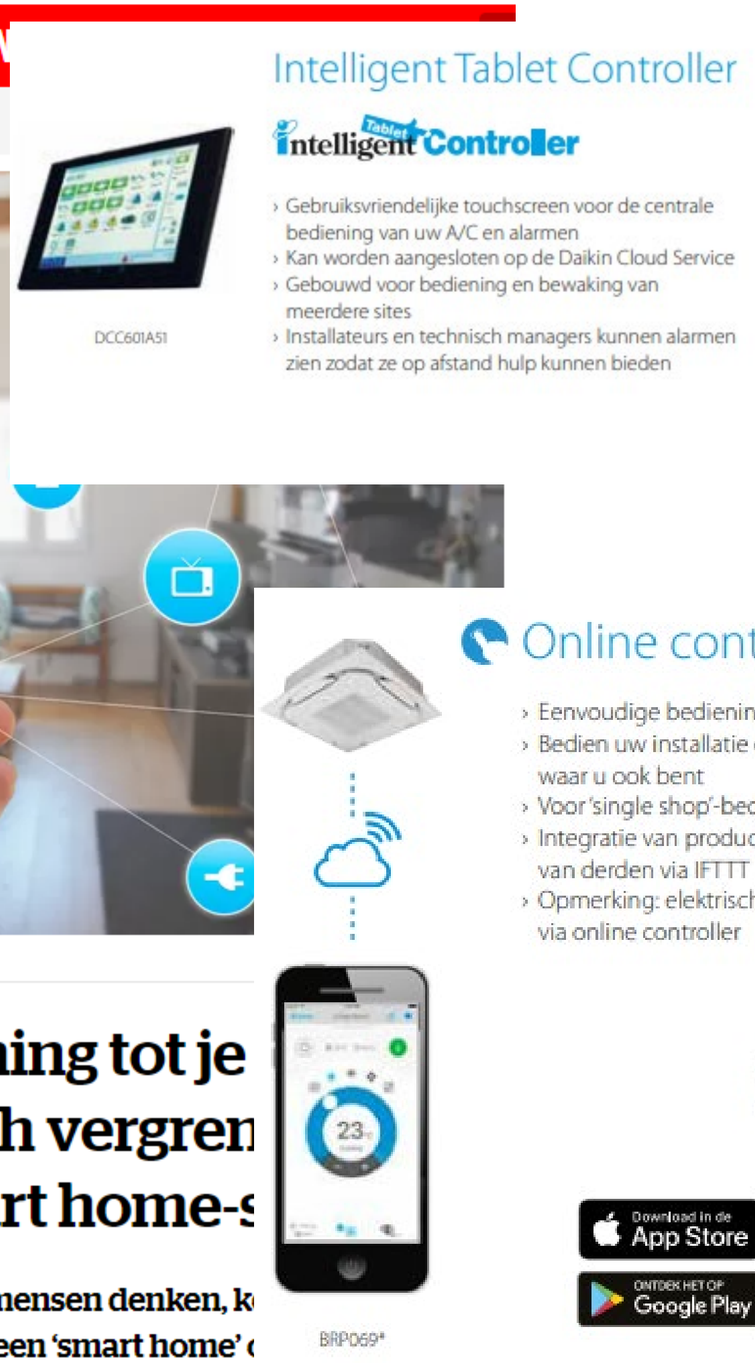


© Getty Images/iStockphoto



Van slimme verwarming tot je voordeur automatisch vergren dit betaal je voor smart home-s

MULTIMEDIA **In tegenstelling tot wat veel mensen denken, k geen duizenden euro's om je woning tot een 'smart home' toveren. De kostprijs hangt immers af van hoe ver jij wil gaan in alles automatiseren. Onze techredacteur bekeek de mogelijkheden en de prijskaartjes van de meest gekozen slimme upgrades.**

Integrated & optimized modern systems

NEPBC

Smart Sensor Technology: Reducing HVAC Energy Use

BUILDINGS

5 FEB

By Adria Security Summit / 0 Comments / Uncategorized

SMART HVAC SYSTEMS ON CYBERSECURITY AND CONNECTION PROTOCOLS

ADRIA SECURITY SUMMIT CONFERENCE & EXHIBITION

vrt NWS

BEKIJK - Gloednieuwe woonwijk in Gent toont energielandschap van de toekomst

The Case for 'Smarter' HVAC Systems

smartspaces.

HVAC systems

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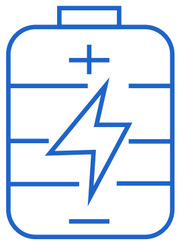
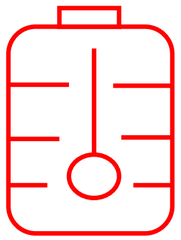
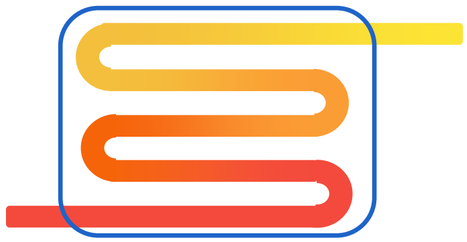


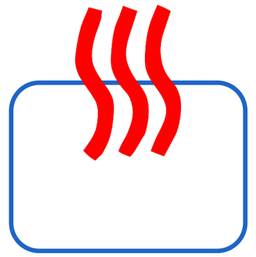
Electrical energy storages



Thermal energy storages

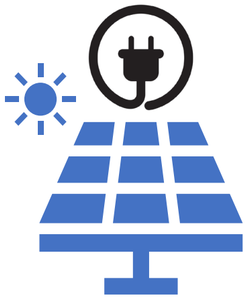


Underfloor heating

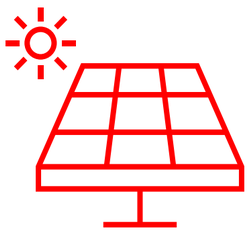


Radiator heating

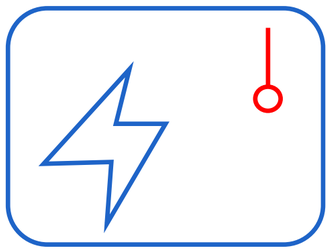
Domestic hot water



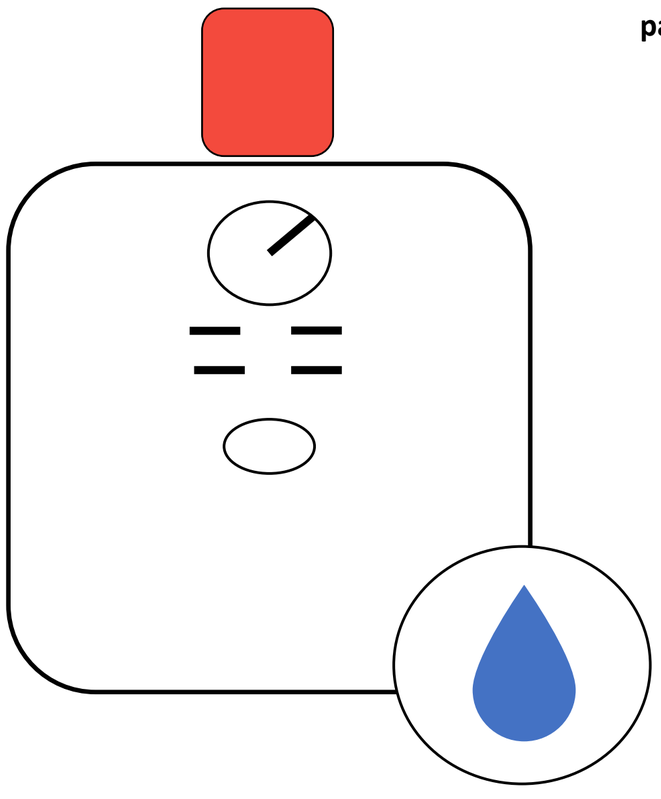
Photovoltaic panels



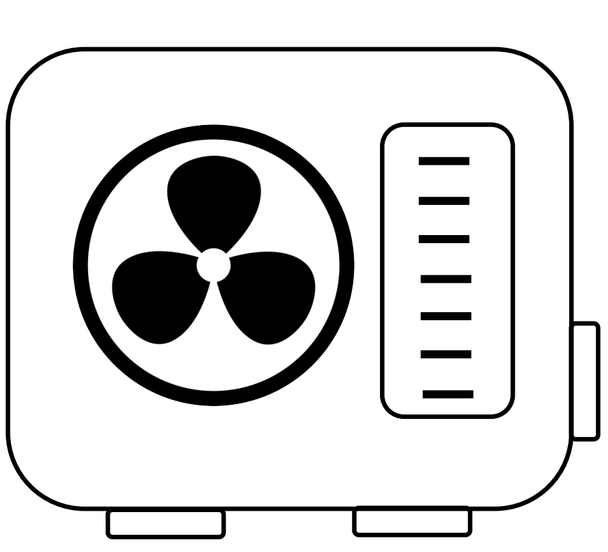
Solar thermal collectors



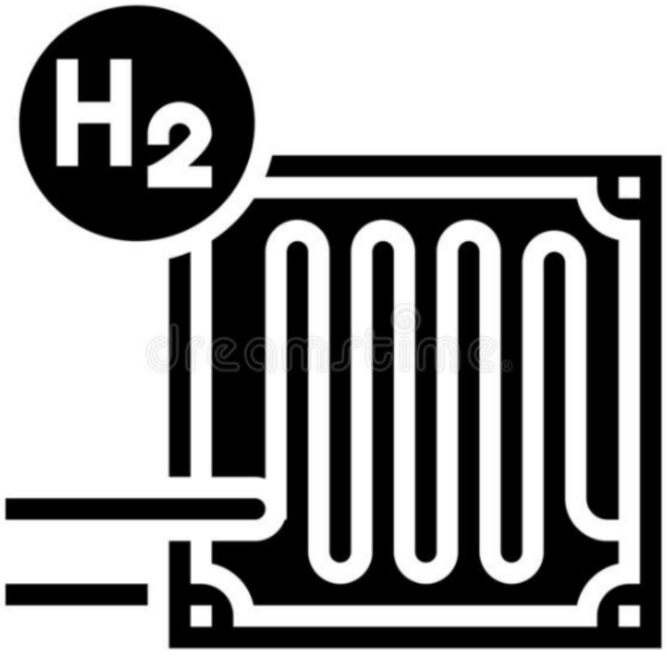
Electrical heating



Gas-Fired Boilers



Air-Water Heat Pumps



Fuel cells

Energy performance regulations

- ✓ **EPB**
- ✓ **EPBD**
- ✓ **ISO_EN**

Lack of Physical background

Parameter fitting

Limited number of data points

Oversimplified heat transfer correlations

Mismatch with the real energy use!

Energy performance regulations

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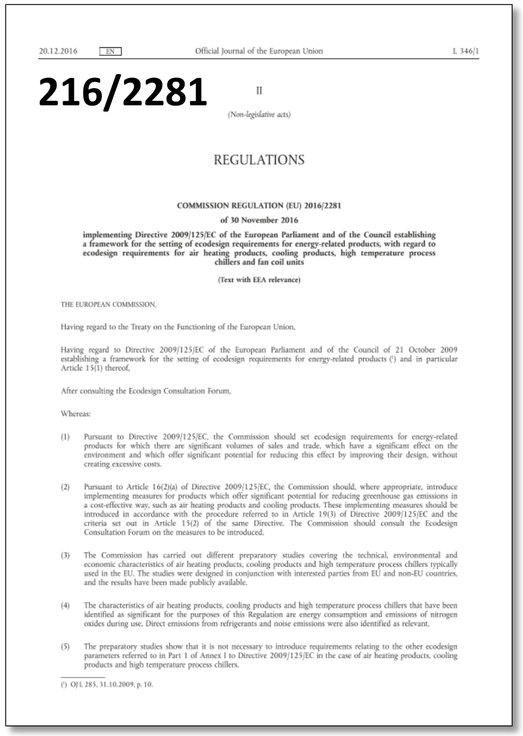
- ✓ EPB
- ✓ EPBD
- ✓ **Ecodesign**
- ✓ ISO_EN



20.12.2016 EN Official Journal of the European Union L 346/1

216/2281 II

(Non-legislative acts)

REGULATIONS

COMMISSION REGULATION (EU) 2016/2281

of 30 November 2016

implementing Directive 2009/125/EC of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for energy-related products, with regard to ecodesign requirements for air heating products, cooling products, high temperature process chillers and fan coil units

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products [1] and in particular Article 15(1) thereof,

After consulting the Ecodesign Consultation Forum,

Whereas:

(1) Pursuant to Directive 2009/125/EC, the Commission should set ecodesign requirements for energy-related products for which there are significant volumes of sales and trade, which have a significant effect on the environment and which offer significant potential for reducing this effect by improving their design, without creating excessive costs.

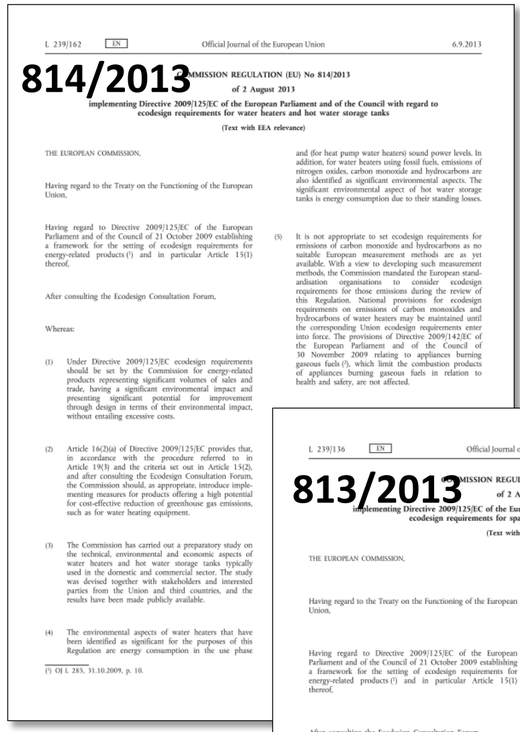
(2) Pursuant to Article 16(2)(a) of Directive 2009/125/EC, the Commission should, where appropriate, introduce implementing measures for products which offer significant potential for reducing greenhouse gas emissions in a cost-effective way, such as air heating products and cooling products. These implementing measures should be introduced in accordance with the procedure referred to in Article 19(3) of Directive 2009/125/EC and the criteria set out in Article 15(2) of the same Directive. The Commission should consult the Ecodesign Consultation Forum on the measures to be introduced.

(3) The Commission has carried out different preparatory studies covering the technical, environmental and economic characteristics of air heating products, cooling products and high temperature process chillers typically used in the EU. The studies were designed in conjunction with interested parties from EU and non-EU countries, and the results have been made publicly available.

(4) The characteristics of air heating products, cooling products and high temperature process chillers that have been identified as significant for the purposes of this Regulation are energy consumption and emissions of nitrogen oxides during use. Direct emissions from refrigerants and noise emissions were also identified as relevant.

(5) The preparatory studies show that it is not necessary to introduce requirements relating to the other ecodesign parameters referred to in Part 1 of Annex I to Directive 2009/125/EC in the case of air heating products, cooling products and high temperature process chillers.

[1] OJ L 285, 31.10.2009, p. 10.



L 239/162 EN Official Journal of the European Union 6.9.2013

814/2013 **COMMISSION REGULATION (EU) No 814/2013**

of 2 August 2013

implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water heaters and hot water storage tanks

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products [1] and in particular Article 15(1) thereof,

After consulting the Ecodesign Consultation Forum,

Whereas:

(1) Under Directive 2009/125/EC ecodesign requirements should be set by the Commission for energy-related products representing significant volumes of sales and trade, having a significant environmental impact and presenting significant potential for improvement through design in terms of their environmental impact, without entailing excessive costs.

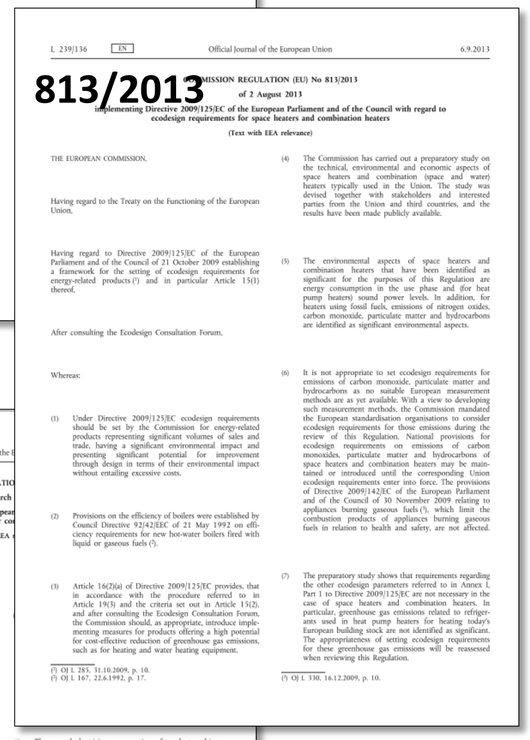
(2) Article 16(2)(a) of Directive 2009/125/EC provides that, in accordance with the procedure referred to in Article 19(3) and the criteria set out in Article 15(2), and after consulting the Ecodesign Consultation Forum, the Commission should, as appropriate, introduce implementing measures for products offering a high potential for cost-effective reduction of greenhouse gas emissions, such as for water heating equipment.

(3) The Commission has carried out a preparatory study on the technical, environmental and economic aspects of water heaters and hot water storage tanks typically used in the domestic and commercial sector. The study was devised together with stakeholders and interested parties from the Union and third countries, and the results have been made publicly available.

(4) The environmental aspects of water heaters that have been identified as significant for the purposes of this Regulation are energy consumption in the use phase and (for heat pump water heaters) sound power levels. In addition, for water heaters using fossil fuels, emissions of nitrogen oxides, carbon monoxide and hydrocarbons are also identified as significant environmental aspects. The significant environmental aspect of hot water storage tanks is energy consumption due to their standing losses.

(5) It is not appropriate to set ecodesign requirements for emissions of carbon monoxide and hydrocarbons as no suitable European measurement methods are as yet available. With a view to developing such measurement methods, the Commission mandated the European standardisation organisations to consider ecodesign requirements for those emissions during the review of this Regulation. National provisions for ecodesign requirements on emissions of carbon monoxides and hydrocarbons of water heaters may be maintained until the corresponding Union ecodesign requirements enter into force. The provisions of Directive 2009/142/EC of the European Parliament and of the Council of 30 November 2009 relating to appliances burning gaseous fuels [2], which limit the combustion products of appliances burning gaseous fuels in relation to health and safety, are not affected.

[1] OJ L 285, 31.10.2009, p. 10.



L 239/136 EN Official Journal of the European Union 6.9.2013

813/2013 **COMMISSION REGULATION (EU) No 813/2013**

of 2 August 2013

implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for space heaters and combination heaters

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products [1] and in particular Article 15(1) thereof,

After consulting the Ecodesign Consultation Forum,

Whereas:

(1) Under Directive 2009/125/EC ecodesign requirements should be set by the Commission for energy-related products representing significant volumes of sales and trade, having a significant environmental impact and presenting significant potential for improvement through design in terms of their environmental impact without entailing excessive costs.

(2) Provisions on the efficiency of boilers were established by Council Directive 92/42/EEC of 21 May 1992 on efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels [2].

(3) Article 16(2)(a) of Directive 2009/125/EC provides, that in accordance with the procedure referred to in Article 19(3) and the criteria set out in Article 15(2), and after consulting the Ecodesign Consultation Forum, the Commission should, as appropriate, introduce implementing measures for products offering a high potential for cost-effective reduction of greenhouse gas emissions, such as for heating and water heating equipment.

(4) The Commission has carried out a preparatory study on the technical, environmental and economic aspects of space heaters and combination (space and water) heaters typically used in the Union. The study was devised together with stakeholders and interested parties from the Union and third countries, and the results have been made publicly available.

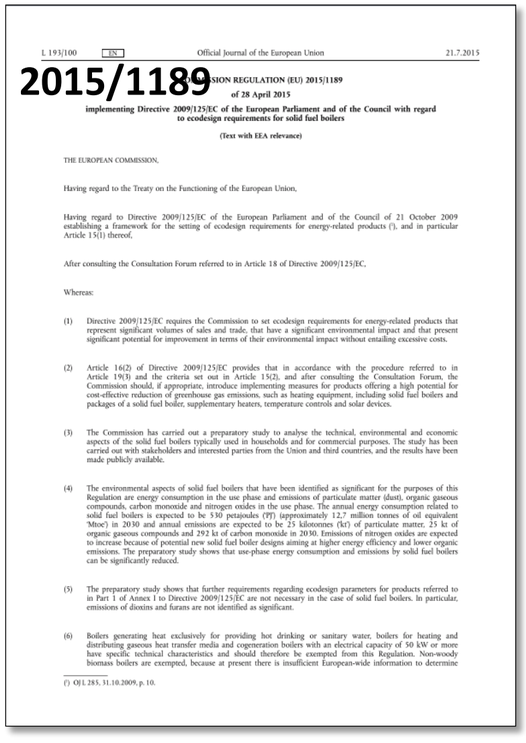
(5) The environmental aspects of space heaters and combination heaters that have been identified as significant for the purposes of this Regulation are energy consumption in the use phase and (for heat pump heaters) sound power levels. In addition, for heaters using fossil fuels, emissions of nitrogen oxides, carbon monoxide, particulate matter and hydrocarbons are identified as significant environmental aspects.

(6) It is not appropriate to set ecodesign requirements for emissions of carbon monoxide, particulate matter and hydrocarbons as no suitable European measurement methods are as yet available. With a view to developing such measurement methods, the Commission mandated the European standardisation organisations to consider ecodesign requirements for those emissions during the review of this Regulation. National provisions for ecodesign requirements on emissions of carbon monoxides, particulate matter and hydrocarbons of space heaters and combination heaters may be maintained or introduced until the corresponding Union ecodesign requirements enter into force. The provisions of Directive 2009/142/EC of the European Parliament and of the Council of 30 November 2009 relating to appliances burning gaseous fuels [3], which limit the combustion products of appliances burning gaseous fuels in relation to health and safety, are not affected.

(7) The preparatory study shows that requirements regarding the other ecodesign parameters referred to in Annex I, Part 1 to Directive 2009/125/EC are not necessary in the case of space heaters and combination heaters, In particular, greenhouse gas emissions related to refrigerants used in heat pump heaters for heating today's European building stock are not identified as significant. The appropriateness of setting ecodesign requirements for these greenhouse gas emissions will be reassessed when reviewing this Regulation.

[1] OJ L 285, 31.10.2009, p. 10.

[3] OJ L 330, 16.12.2009, p. 10.



L 193/100 EN Official Journal of the European Union 21.7.2015

2015/1189 **COMMISSION REGULATION (EU) 2015/1189**

of 28 April 2015

implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for solid fuel boilers

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products [1], and in particular Article 15(1) thereof,

After consulting the Consultation Forum referred to in Article 18 of Directive 2009/125/EC,

Whereas:

(1) Directive 2009/125/EC requires the Commission to set ecodesign requirements for energy-related products that represent significant volumes of sales and trade, that have a significant environmental impact and that present significant potential for improvement in terms of their environmental impact without entailing excessive costs.

(2) Article 16(2) of Directive 2009/125/EC provides that in accordance with the procedure referred to in Article 19(3) and the criteria set out in Article 15(2), and after consulting the Consultation Forum, the Commission should, if appropriate, introduce implementing measures for products offering a high potential for cost-effective reduction of greenhouse gas emissions, such as heating equipment, including solid fuel boilers and packages of a solid fuel boiler, supplementary heaters, temperature controls and solar devices.

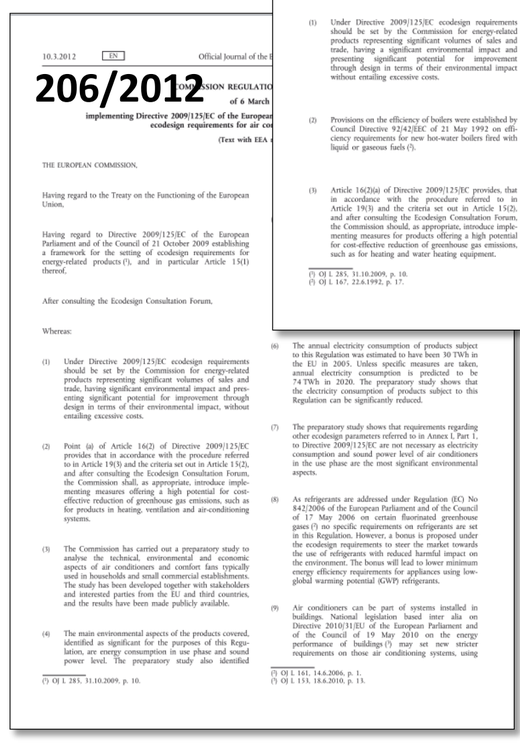
(3) The Commission has carried out a preparatory study to analyse the technical, environmental and economic aspects of the solid fuel boilers typically used in households and for commercial purposes. The study has been carried out with stakeholders and interested parties from the Union and third countries, and the results have been made publicly available.

(4) The environmental aspects of solid fuel boilers that have been identified as significant for the purposes of this Regulation are energy consumption in the use phase and emissions of particulate matter (dust), organic gaseous compounds, carbon monoxide and nitrogen oxides in the use phase. The annual energy consumption related to solid fuel boilers is expected to be 530 petajoules (PJ) (approximately 12,7 million tonnes of oil equivalent 'Mtoe') in 2030 and annual emissions are expected to be 25 kilotonnes (kt) of particulate matter, 25 kt of organic gaseous compounds and 292 kt of carbon monoxide in 2030. Emissions of nitrogen oxides are expected to increase because of potential new solid fuel boiler designs aiming at higher energy efficiency and lower organic emissions. The preparatory study shows that use-phase energy consumption and emissions by solid fuel boilers can be significantly reduced.

(5) The preparatory study shows that further requirements regarding ecodesign parameters for products referred to in Part 1 of Annex I to Directive 2009/125/EC are not necessary in the case of solid fuel boilers. In particular, emissions of dioxins and furans are not identified as significant.

(6) Boilers generating heat exclusively for providing hot drinking or sanitary water, boilers for heating and distributing gaseous heat transfer media and cogeneration boilers with an electrical capacity of 50 kW or more have specific technical characteristics and should therefore be exempted from this Regulation. Non-woody biomass boilers are exempted, because at present there is insufficient European-wide information to determine

[1] OJ L 285, 31.10.2009, p. 10.



10.3.2012 EN Official Journal of the E

206/2012 **COMMISSION REGULATIO**

of 6 March

implementing Directive 2009/125/EC of the European ecodesign requirements for air co

(Text with EEA

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products [1], and in particular Article 15(1) thereof,

After consulting the Ecodesign Consultation Forum,

Whereas:

(1) Under Directive 2009/125/EC ecodesign requirements should be set by the Commission for energy-related products representing significant volumes of sales and trade, having significant environmental impact and presenting significant potential for improvement through design in terms of their environmental impact, without entailing excessive costs.

(2) Point (a) of Article 16(2) of Directive 2009/125/EC provides that in accordance with the procedure referred to in Article 19(3) and the criteria set out in Article 15(2), and after consulting the Ecodesign Consultation Forum, the Commission shall, as appropriate, introduce implementing measures offering a high potential for cost-effective reduction of greenhouse gas emissions, such as for products in heating, ventilation and air-conditioning systems.

(3) The Commission has carried out a preparatory study to analyse the technical, environmental and economic aspects of air conditioners and comfort fans typically used in households and small commercial establishments. The study has been developed together with stakeholders and interested parties from the EU and third countries, and the results have been made publicly available.

(4) The main environmental aspects of the products covered, identified as significant for the purposes of this Regulation, are energy consumption in use phase and sound power level. The preparatory study also identified

[1] OJ L 285, 31.10.2009, p. 10.

(6) The annual electricity consumption of products subject to this Regulation was estimated to have been 30 TWh in the EU in 2005. Unless specific measures are taken, annual electricity consumption is predicted to be 74 TWh in 2020. The preparatory study shows that the electricity consumption of products subject to this Regulation can be significantly reduced.

(7) The preparatory study shows that requirements regarding other ecodesign parameters referred to in Annex I, Part 1, to Directive 2009/125/EC are not necessary as electricity consumption and sound power level of air conditioners in the use phase are the most significant environmental aspects.

(8) As refrigerants are addressed under Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases [1] no specific requirements on refrigerants are set in this Regulation. However, a bonus is proposed under the ecodesign requirements to steer the market towards the use of refrigerants with reduced harmful impact on the environment. The bonus will lead to lower minimum energy efficiency requirements for appliances using low-global warming potential (GWP) refrigerants.

(9) Air conditioners can be part of systems installed in buildings, National legislation based inter alia on Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings [2] may set new stricter requirements on those air conditioning systems, using

[1] OJ L 161, 14.6.2006, p. 1.
[2] OJ L 153, 18.6.2010, p. 13.

The research question

- **Do the available data contain the necessary information for better understanding and predicting the performance of most common Belgian heat generation appliances?**

Is the available information enough?

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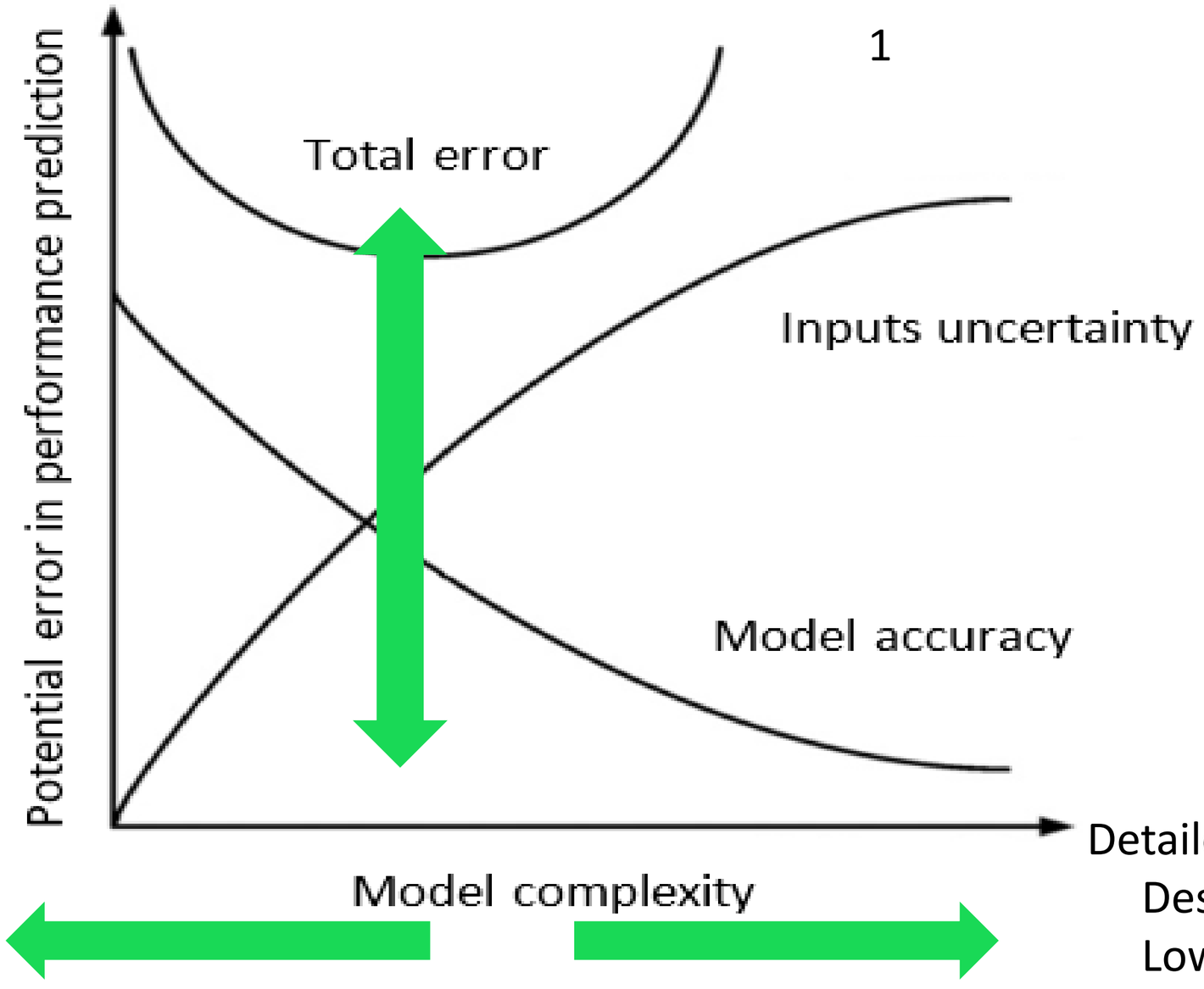
- ✓ Scientific literature, state of the art



Less complex, data based:
Reusability possible
Myriad of assumptions

Detailed, case specific:
Design data based
Low reusability

[1]M. Trcka and J. L. M. Hensen, “Overview of HVAC system simulation,” *Autom. Constr.*, vol. 19, pp. 93–99, 2010.

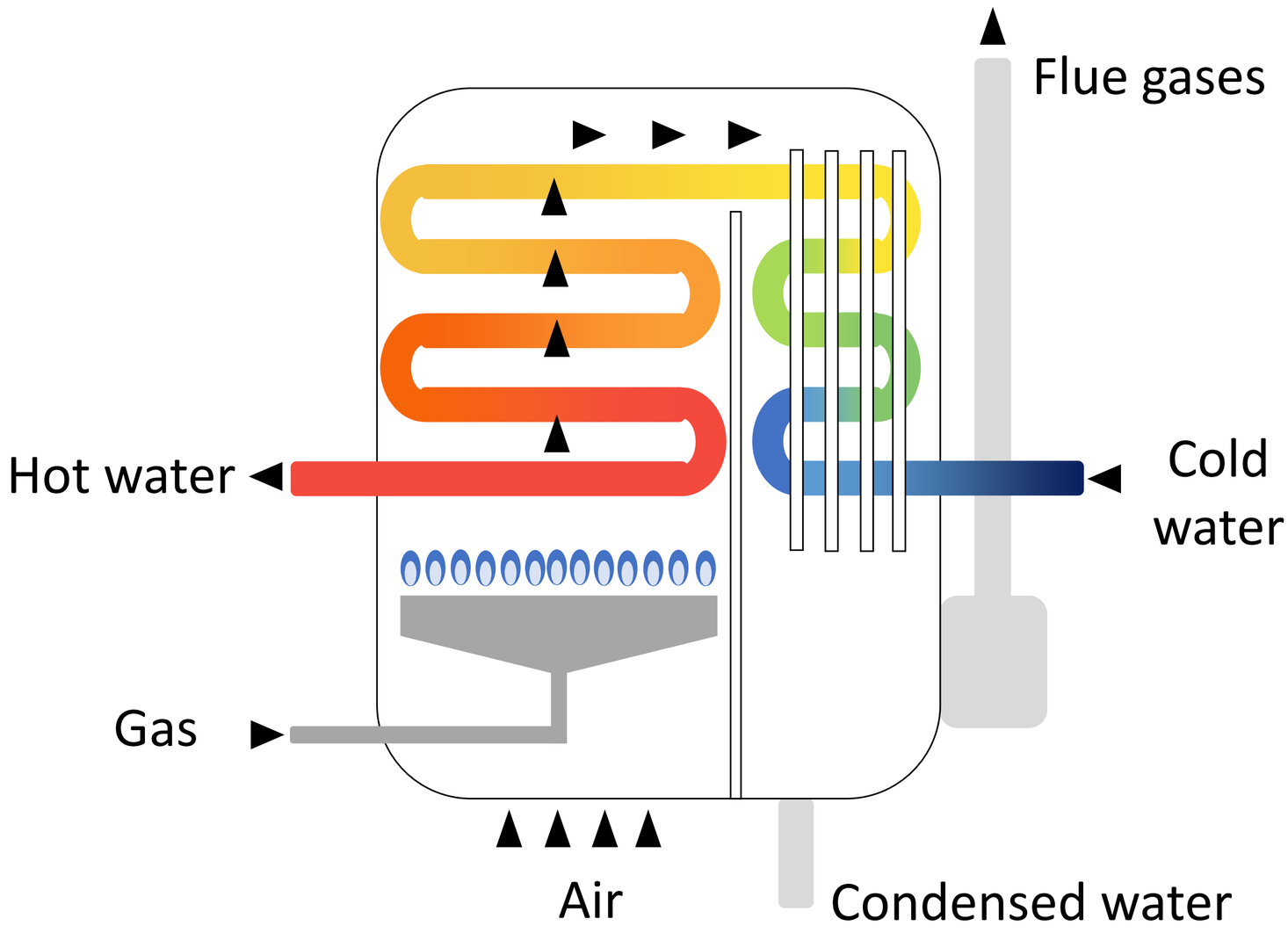
Is the available information enough?

NEPBC

YES

- ✓ Is it possible to use consistently the existing data?
- ✓ If so, is the new model capable to give realistic results?

Gas-Fired condensing boilers



Gas-Fired condensing boilers

- ✓ Working regimes:
  - ✓ Non-condensing
  - ✓ Condensing

  Inlet water T < 55°C

  η ↗

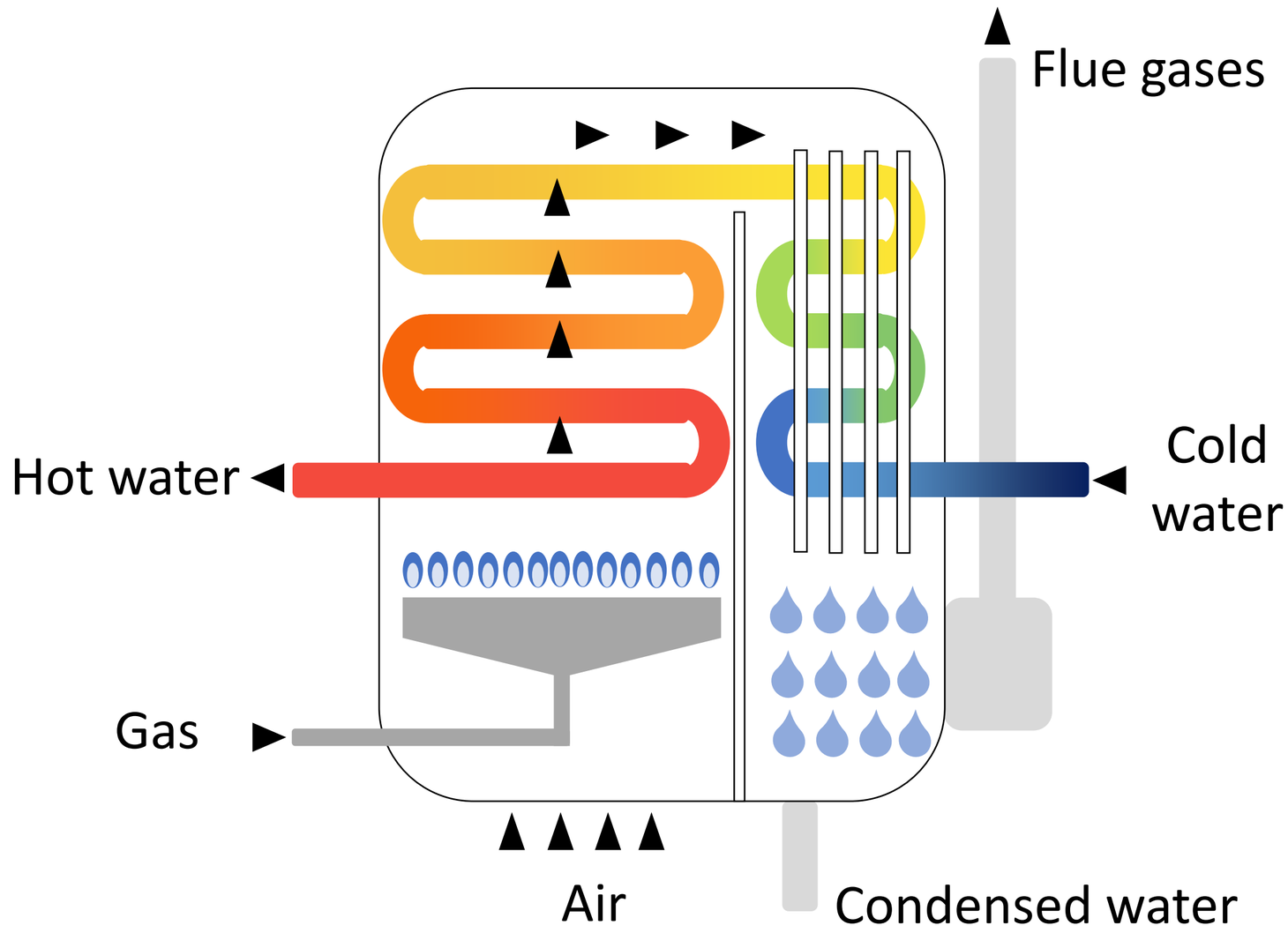
- ✓ **Ecodesign** A, A+
  - ✓ Full & 30% load

    80/60, Q_{water}, efficiency

    50/30, Q_{water}

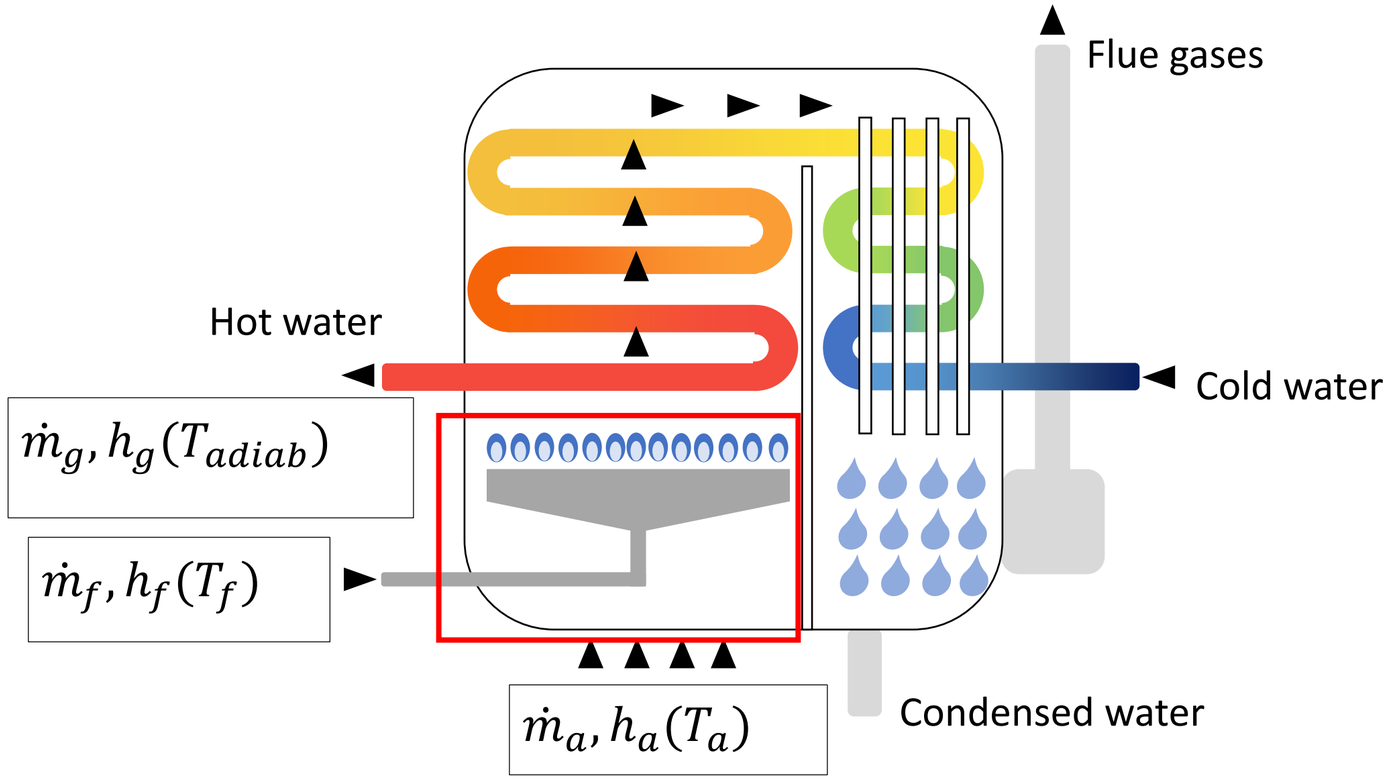
    36/30, Q_{water}, efficiency

- ✓ **Manufactures provide:**
  - ✓ Nominal fuel flow rate
  - ✓ Dry weight
  - ✓ Inner water content



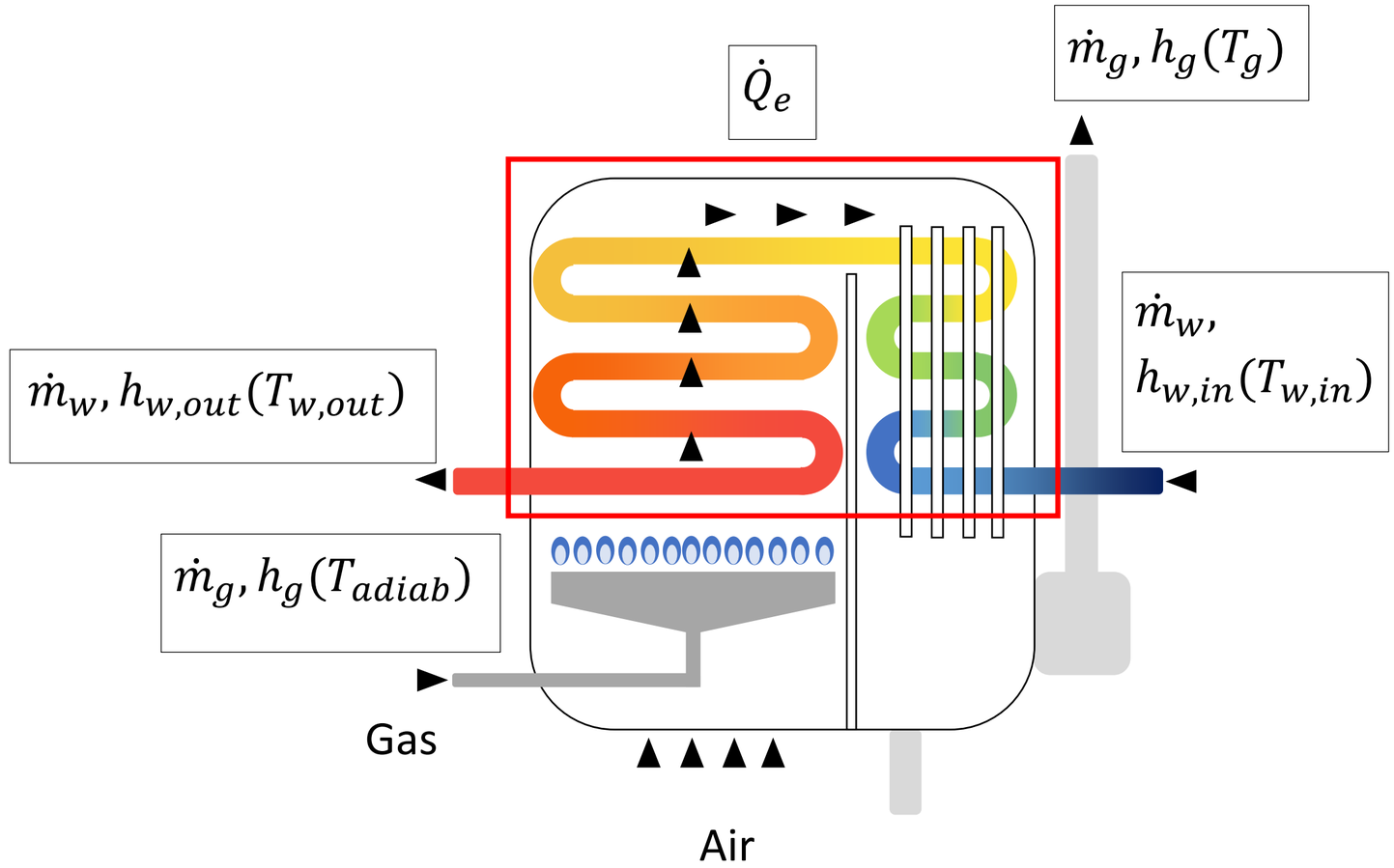
Combustion

- ✓ Input data:
  - h_f Fuel quality, 100%CH_4
  - $\dot{m}_f$ Nominal fuel flow rate,
  - $\dot{m}_a$ Excess amount of air
- ✓ Assumptions:
  - ✓ Complete combustion
  - ✓ Combustion gases are ideal gases
  - ✓ Adiabatic flame temperature
  - ✓ Reference state: 15°C and 101 325 Pa, HHV



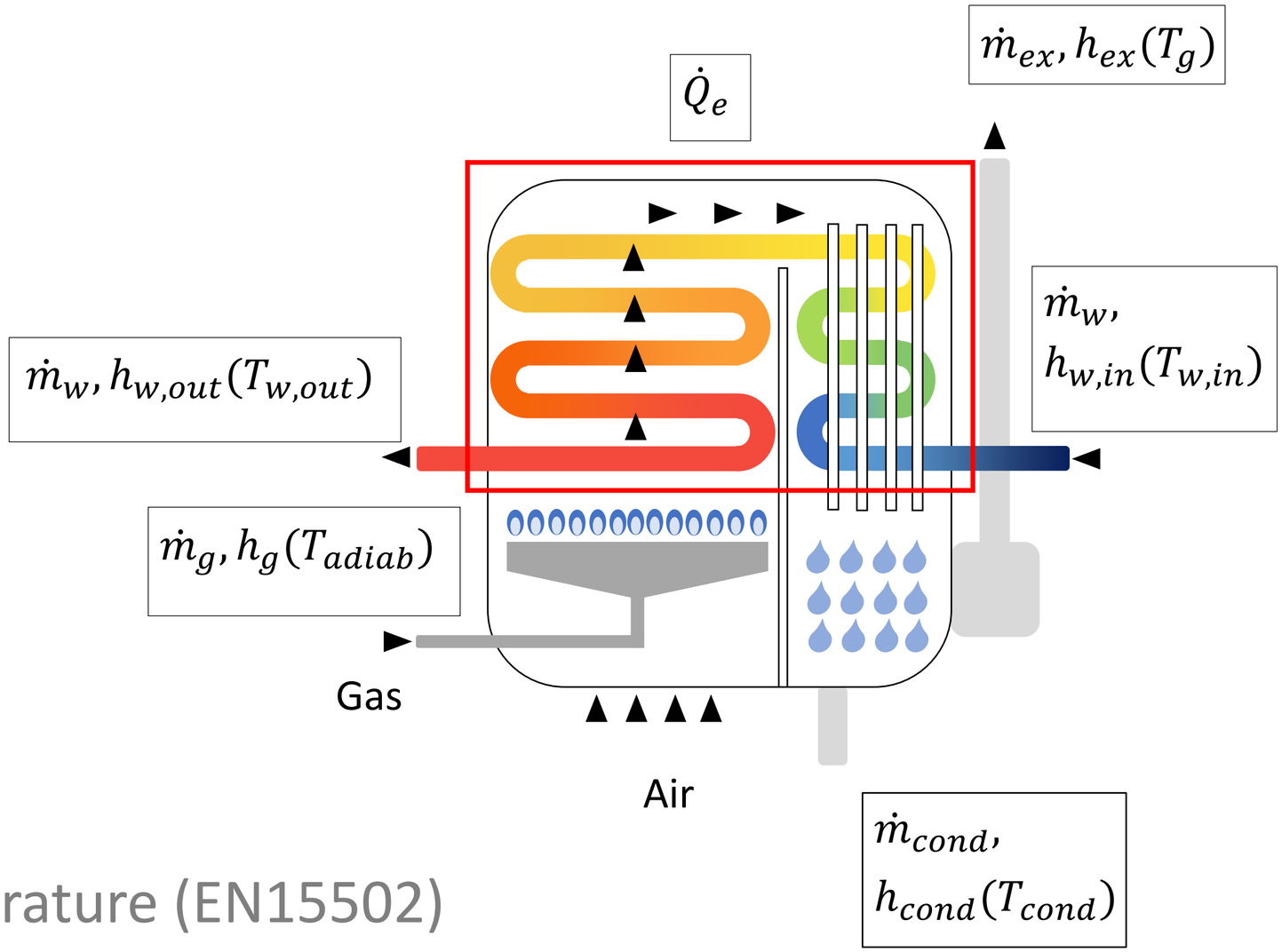
Main heat exchanger

- ✓ Input data:
  - ✓ Design temperature regime $T_{w,out}$/ $T_{w,in}$
  - ✓ Nominal capacity
- ✓ Assumptions:
  - ✓ Envelop losses water to ambient
- ✓ Fitting value:
  - ✓ T_g, exhaust gas temperature (EN15502)



Main heat exchanger

- ✓ Input data:
  - ✓ Design temperature regime
  - ✓ Nominal capacity
- ✓ Assumptions:
  - ✓ Envelop losses water to ambient
- ✓ Fitting value:
  - ✓ T_g, exhaust gas temperature (EN15502)
  - ✓ $\dot{m}_{cond}$, amount of water condensate l/h (EN15502)



Results, Calibration

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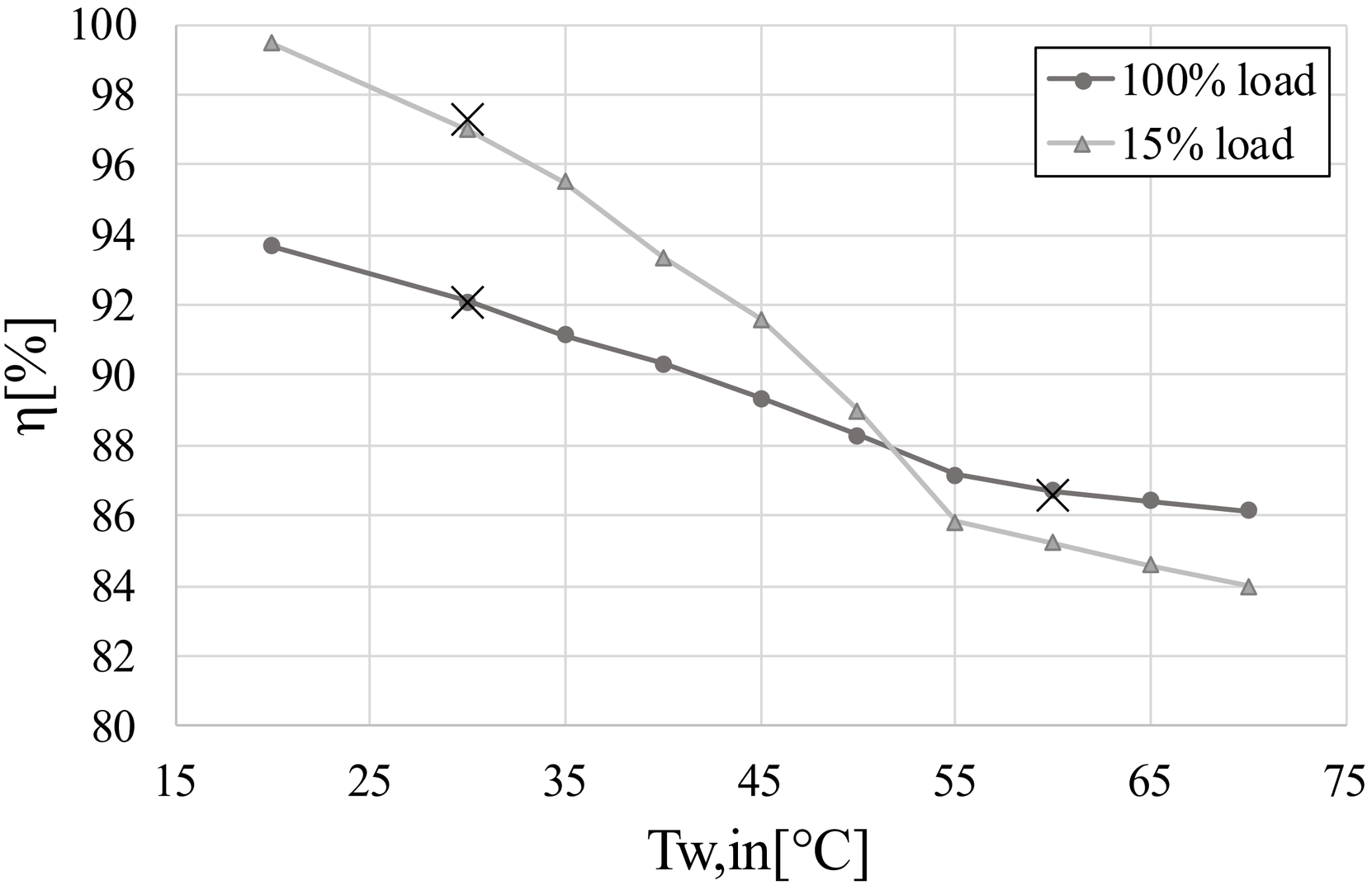
Operational regime	Non-condensing 80/60°C (λ=23.45%)		Condensing 50/30°C (λ=22.49%)	
Data type	Measurements	Simulation	Measurement	Simulation
Rated heat output $\dot{Q}_w$ [kW]	24.0	23.98	26.4	26.43
Nominal mass flow rate of fuel [kg/s]	0.0004986	0.0004986	0.0005163	0.0005163
Heat input, HHV [kW]	27.7	27.7	28.7	28.7
Useful efficiency [%]	86.6	86.6	92.1	92.1
Temperature of the exhaust gases [˚C]	84.5 ≈	84.48	64.0 ≈	64.1
Envelop losses [W]	N/A	211.8	N/A	72.5
Fraction of the envelop losses [%]	N/A	0.76	N/A	0.25
Amount of condensate [l/h]	N/A	N/A	1.75 ≈	1.75
Nominal heat exchanger dew point effectiveness	N/A	N/A	N/A	0.668
UA_{nom} [W/K]	N/A	62.5	N/A	62.3
UA_{env_nom} [W/K]	N/A	3.8	N/A	2.8

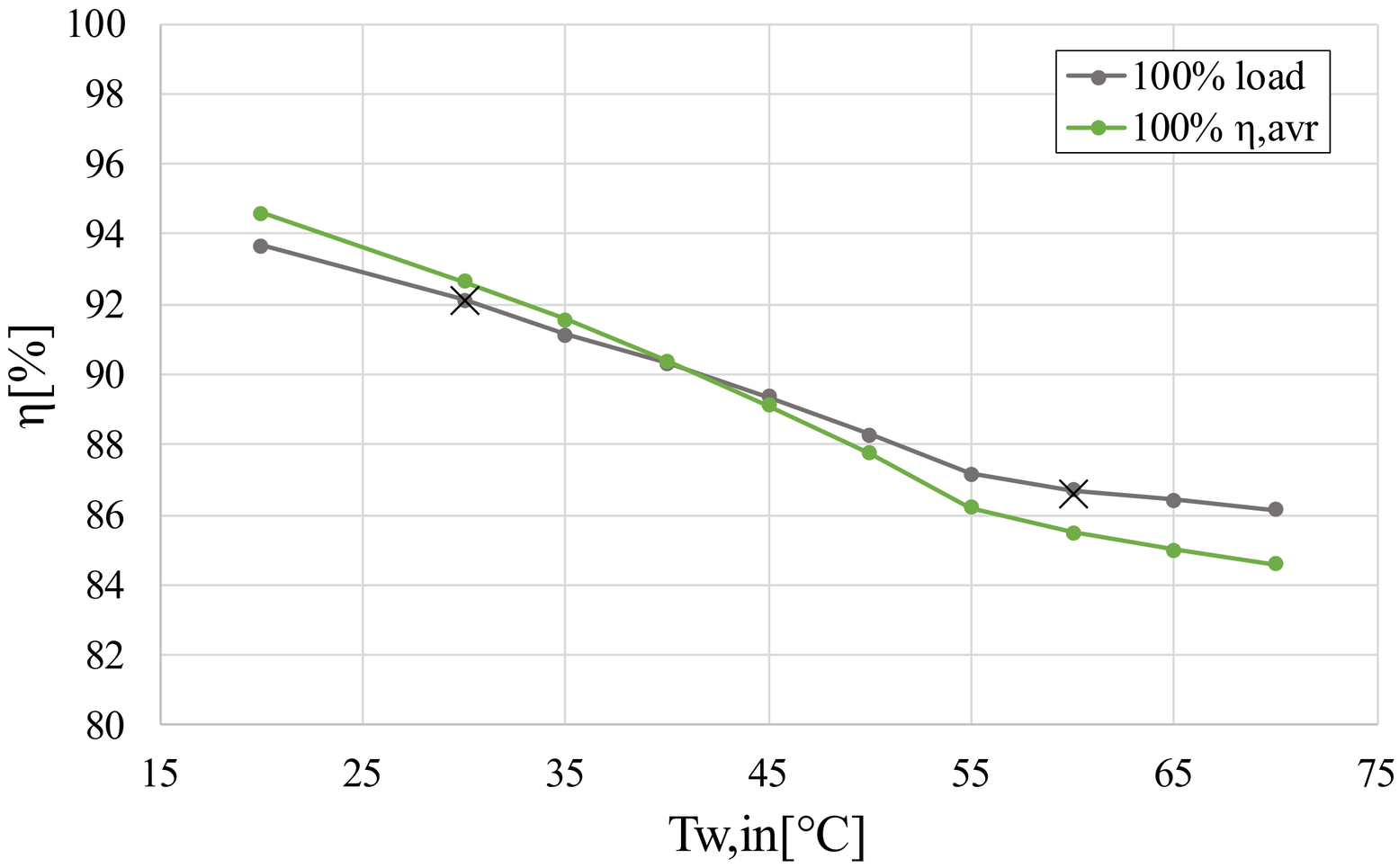
Steady-state comparison

- ✓ Data Gas.be
  - ✓ 100% load
  - ✓ 15% load
- ✓ Realistic results
- ✓ Expected trend



What if average values are used?

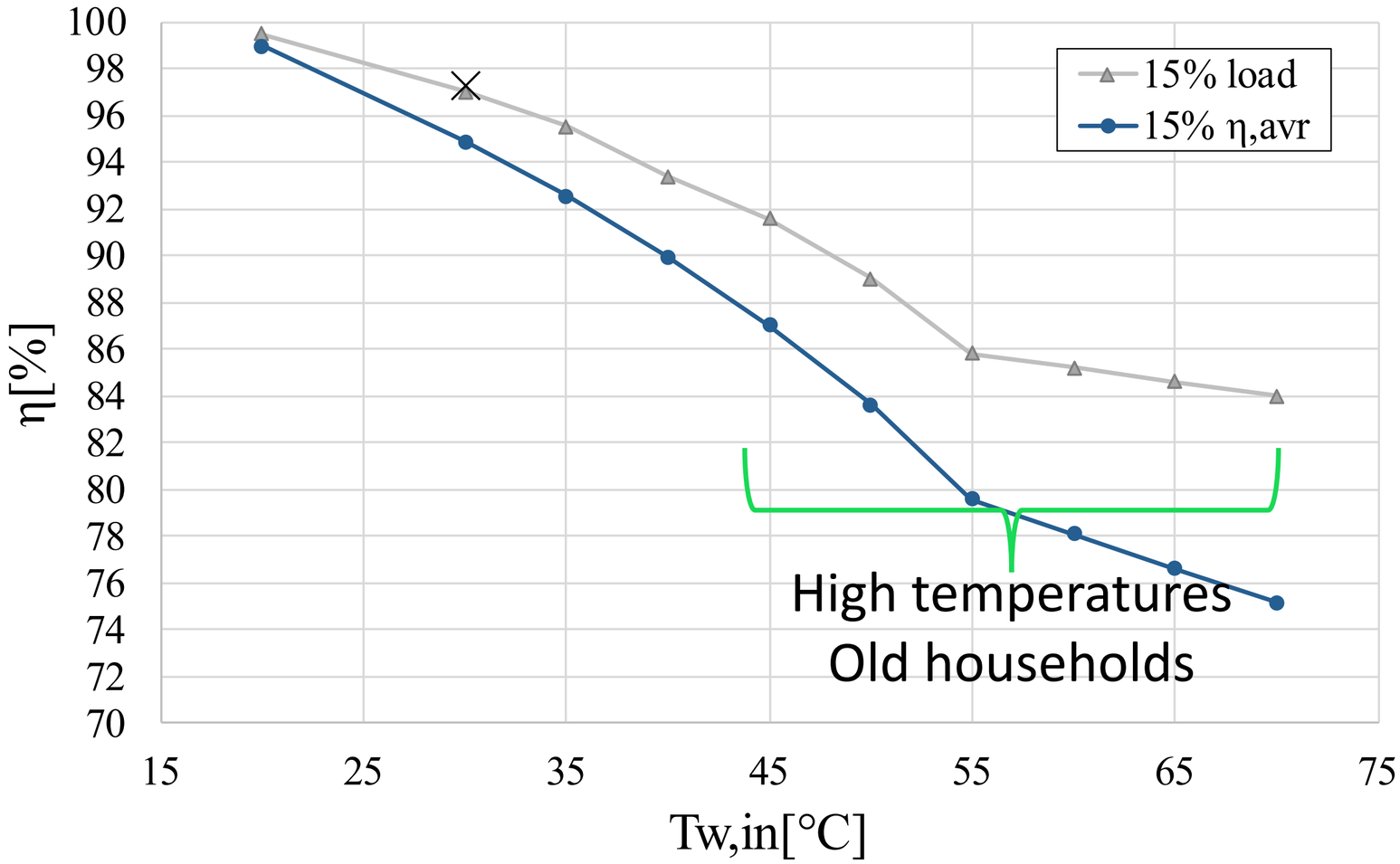
- ✓ 80/60
  - ✓ $T_{g,av} = 77.5\,℃$
- ✓ 50/30
  - ✓ $T_{g,av} = 57.8\,℃$
  - ✓ $\dot{m}_{cond,av} = 2.16\,\frac{\mathrm{kg}}{\mathrm{h}}$
- ✓ 36/30
  - ✓ $T_{g,av} = 33.7\,℃$
  - ✓ $\dot{m}_{cond,av} = 0.557\,\frac{\mathrm{kg}}{\mathrm{h}}$



- ✓ Irregularities in envelop losses
  - ✓ Higher envelop loses in the case of condensing regime

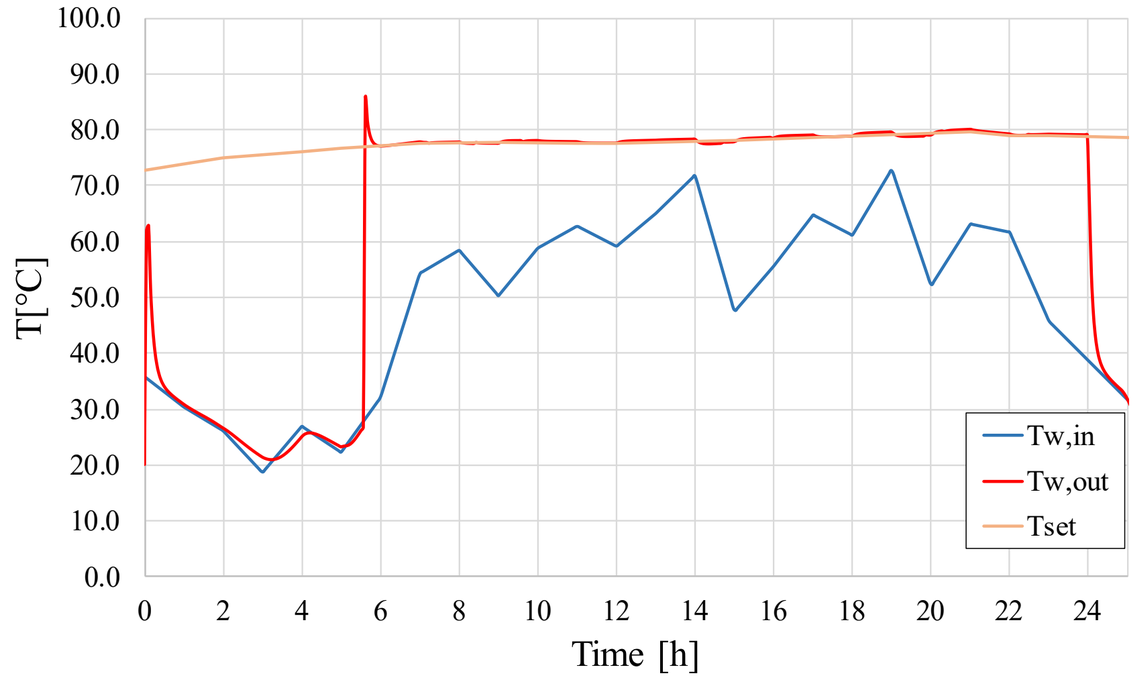
What if average values are used?

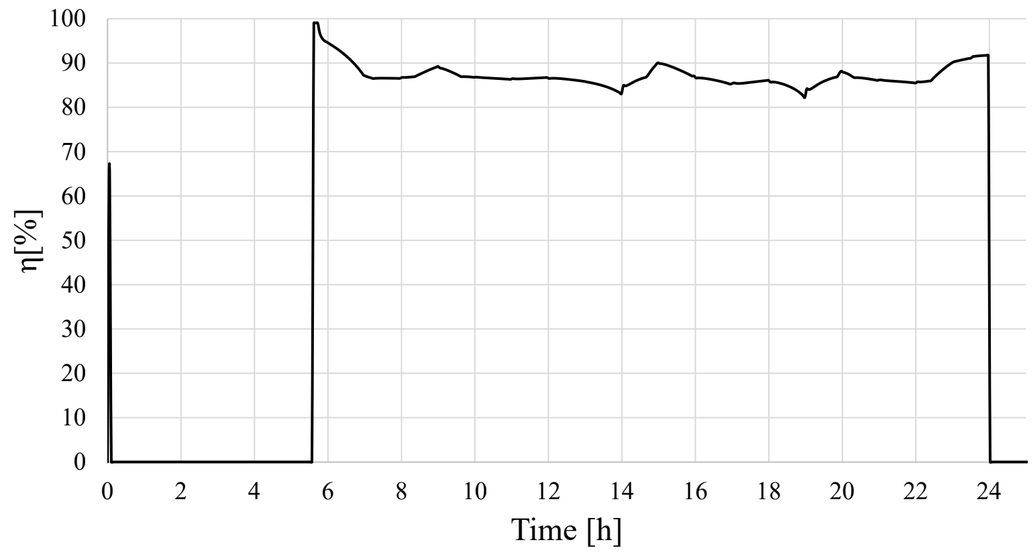
- ✓ 80/60
  - ✓ $T_g = 77.5\,℃$
- ✓ 50/30
  - ✓ $T_g = 57.8\,℃$
  - ✓ $\dot{m}_{cond} = 2.16\,\frac{\mathrm{kg}}{\mathrm{h}}$
- ✓ 36/30
  - ✓ $T_g = 33.7\,℃$
  - ✓ $\dot{m}_{cond} = 0.557\,\frac{\mathrm{kg}}{\mathrm{h}}$

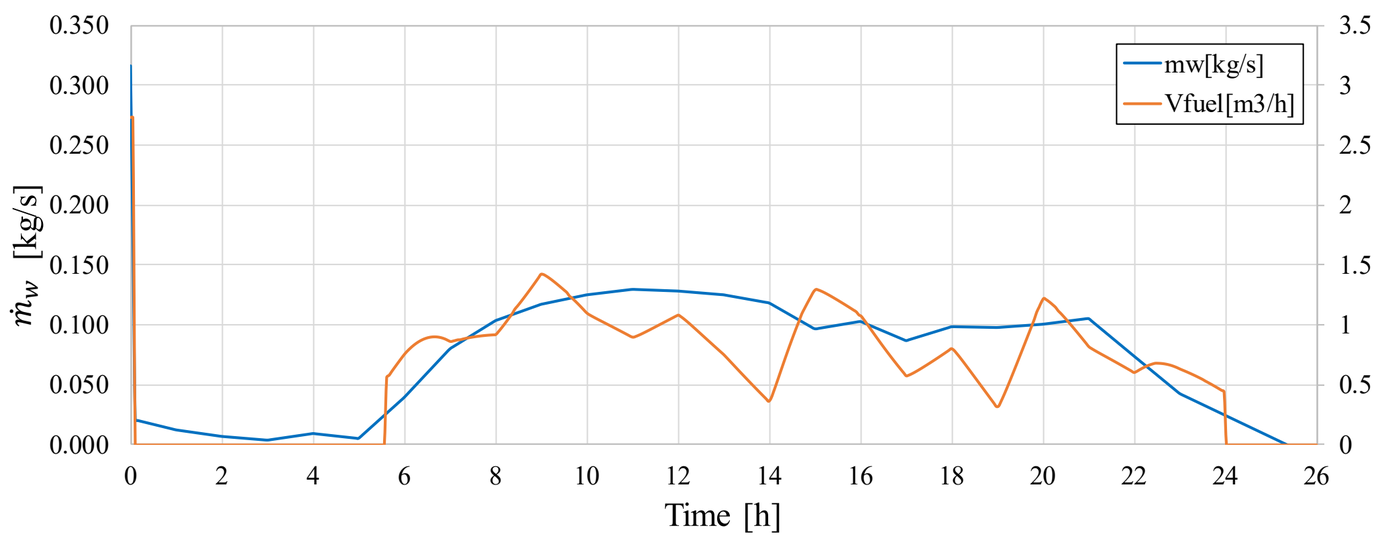


Dynamics

- ✓ Dynamic inputs
  - ✓ Dry weight
  - ✓ Inner water content
- ✓ Lacking data:
  - ✓ Controlling principles
  - ✓ Heat recovery ⇨ Measurements



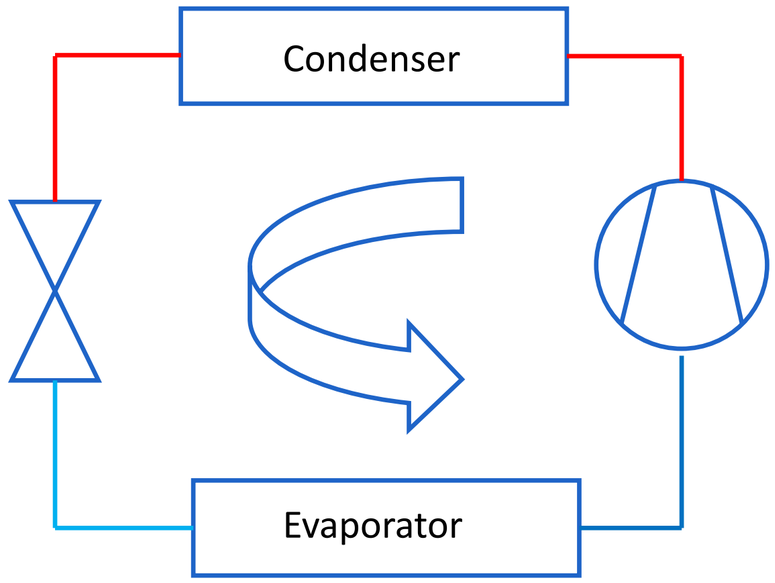




Dynamics

New technologies, Heat pumps and fuel cells

- ✓ Heat pumps
  - ✓ Full load, steady state data
  - ✓ Data less complete
- ✓ Manufacturers do have extended data
- ✓ Control principles unknown
- ✓ Complex solutions



- ✓ Fuel cells
- ✓ Lack of standards for evaluating the performance
  - ✓ PEM, H2
  - ✓ SOFC, CH4

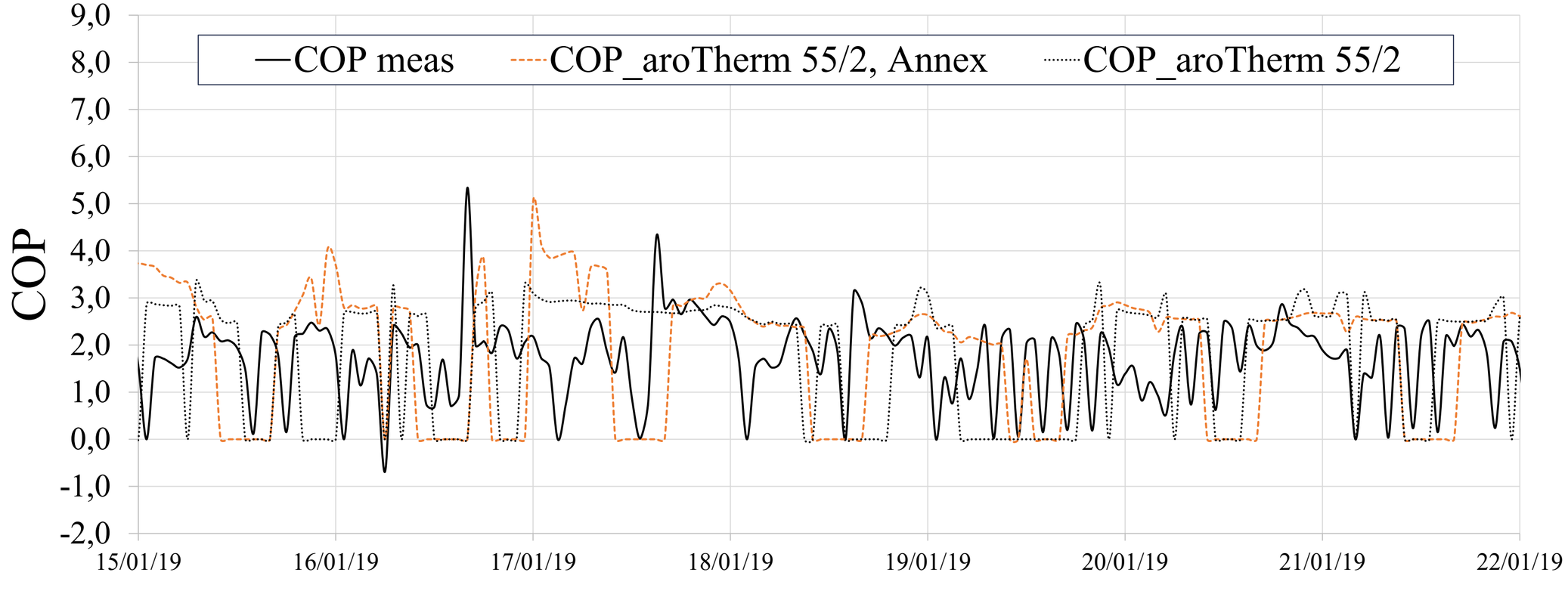
Experimental evaluations ⇨ Control!

Heat pumps, Case study

NEPBC

- ✓ Annex 71
  - ✓ Well insulated house
  - ✓ Air to water HP
  - ✓ UFH and DHW
- ✓ Performance based model
  - ✓ Official data
  - ✓ Vaillant data (internal correspondence)

Data type	Measured	Simulation, official	Simulation, Vaillant
COP average	1.70	2.18	1.99
COP absolute average	1.96	3.17	2.79



Conclusion

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Van slimme verwarming tot je voordeur automatisch vergrendelen: dit betaal je voor smart home-snufjes

MULTIMEDIA In tegenstelling tot wat veel mensen denken, kost het echt geen duizenden euro's om je woning tot een 'smart home' om te toveren. De kostprijs hangt immers af van hoe ver jij wil gaan in alles automatiseren. Onze techredacteur bekeek de mogelijkheden en de prijskaartjes van de meest gekozen slimme upgrades.

vrt NWS

BEKIJK - Gloednieuwe woonwijk in Gent toont energielandschap van de toekomst

Conclusion

- ✓ With proper physical models, the existing data are sufficient
- ✓ Including of physical systems helps in reducing the performance gap as the real behaviour is not lumped
- ✓ Every unit needs a calibration procedure data sheets ⟺ model

Calibration procedure

- ✓ Use existing data, do not overcomplicate the existing procedures
- ✓ The real performance is impossible to completely capture
- ✓ Extra communication, data is available (+cloud data)
- ✓ For the complete results
  - ✓ Running simulations of different data sheets of units would be necessary while also comparing these results to the ones of EPB (future research?)
- ✓ Final conclusions in the PhD book, end of Spring 2022

Elsevier

- ✓ Journal article:
  “Modelling of a gas-fired heating boiler unit for residential buildings use based on public data”

- ✓ Description of the applied modelling method
- ✓ Use of the input data
- ✓ Discussion over the calibration and verification of the model
- ✓ Further results, load profiles

Thank you for your attention!

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SCAN ME!

free till 19/11