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Heat, Air and Moisture (HAM) modeling of historic windows

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Where innovation starts

Content

- Problem statement
  - Energy use
  - Condensation
  - Thermal insulating glazing
  - 2- en 3D-modeling
    - Secondary glazing
    - Vacuum glazing
  - Validating measurements
    - Hot-box measurements
    - In situ measurements
- Conclusions

Energy use improvement?

Photographs: E.J. Nusselder

Energy use improvement?

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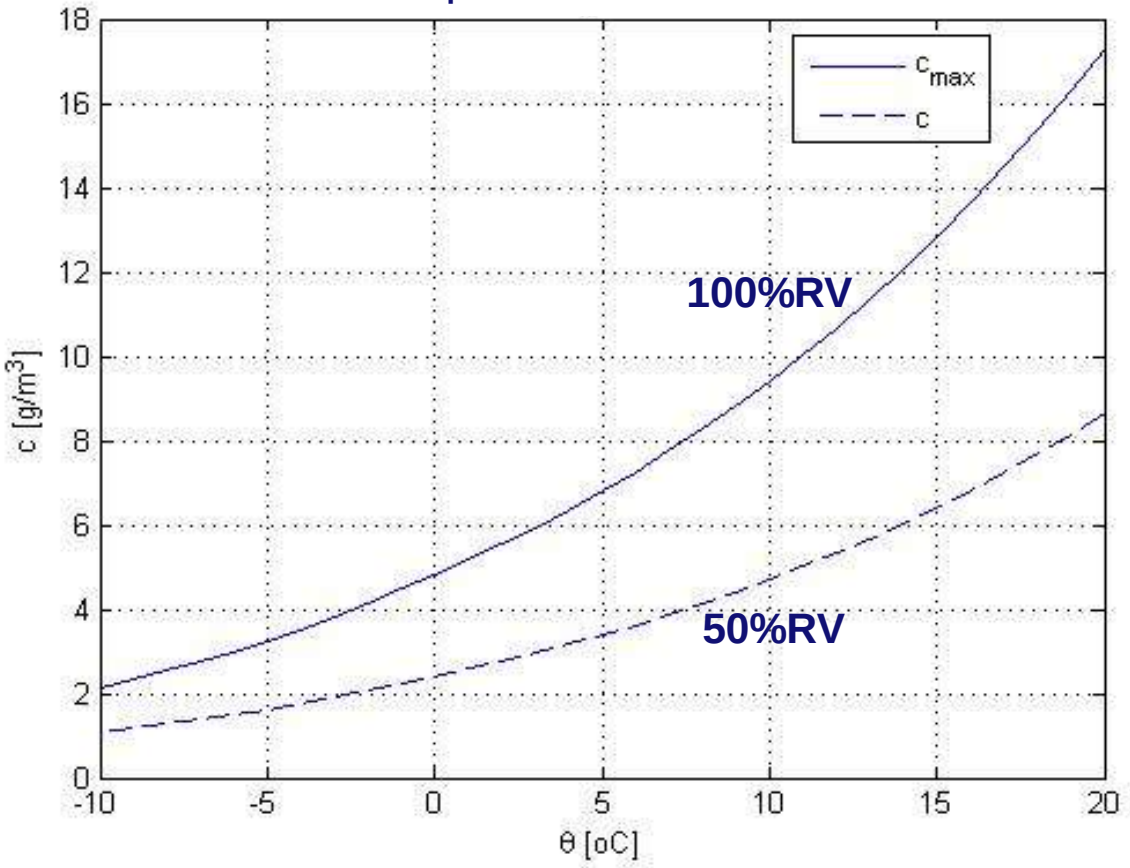
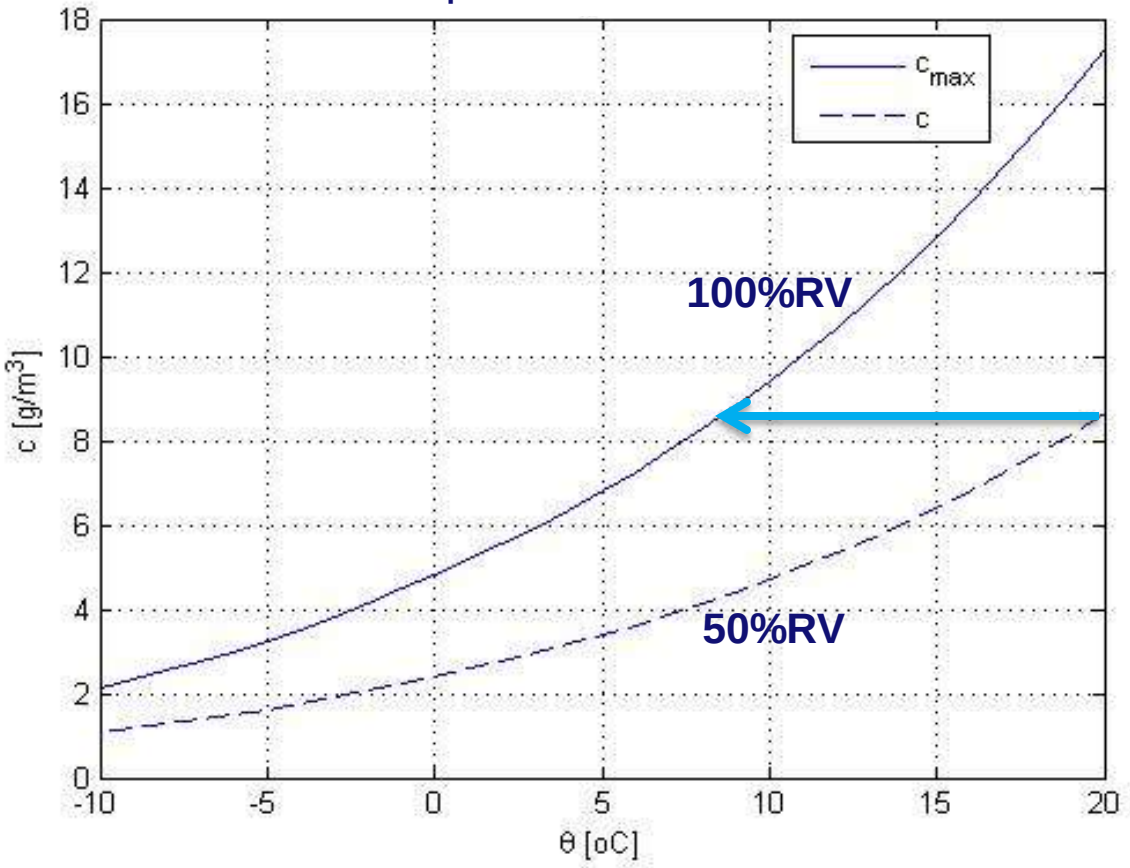
Condensation

Vapor concentration

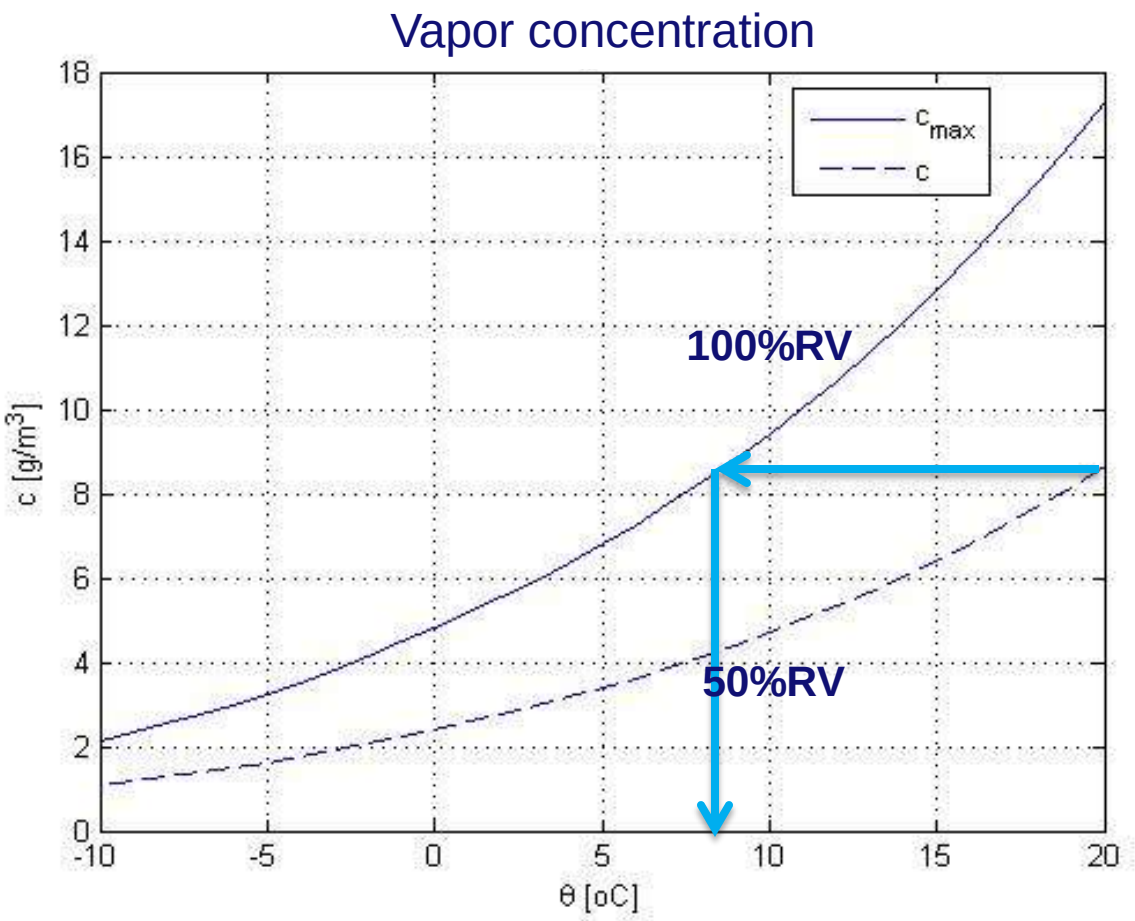


Condensation

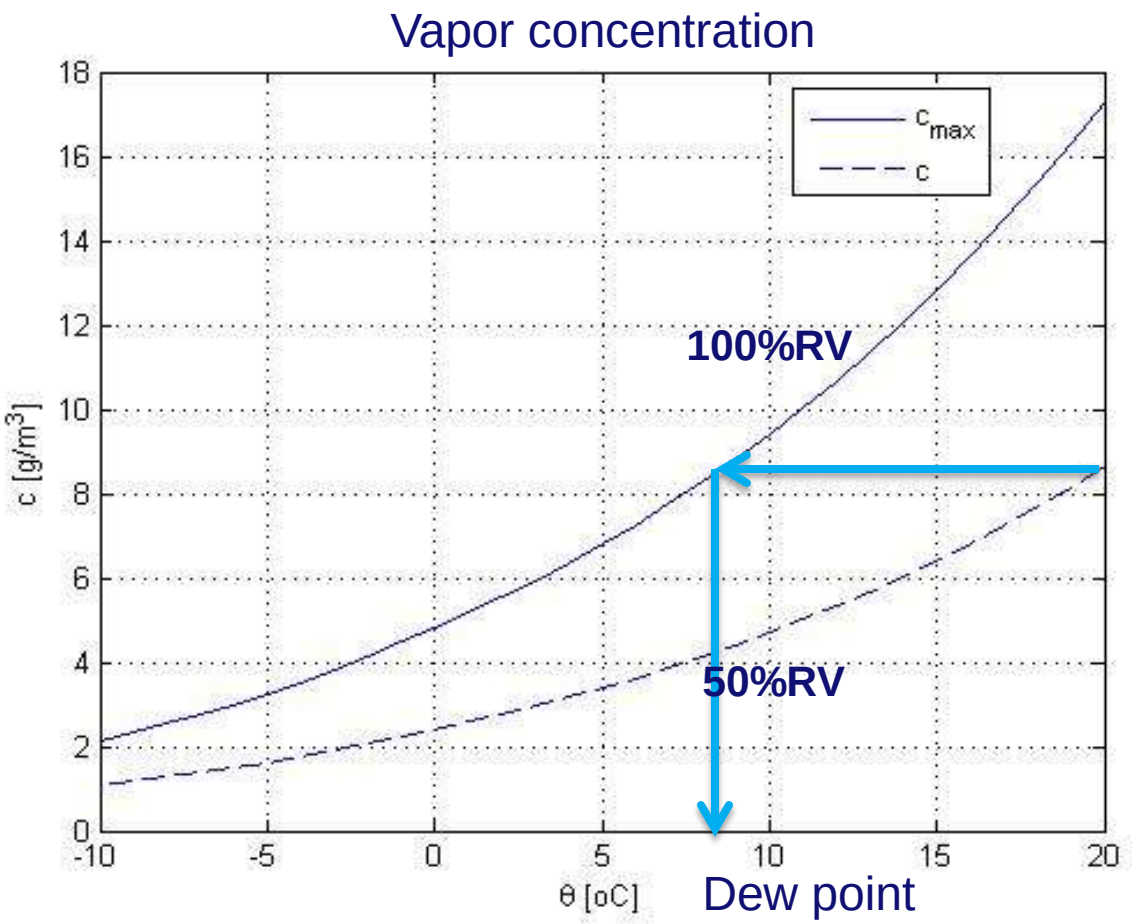
Vapor concentration



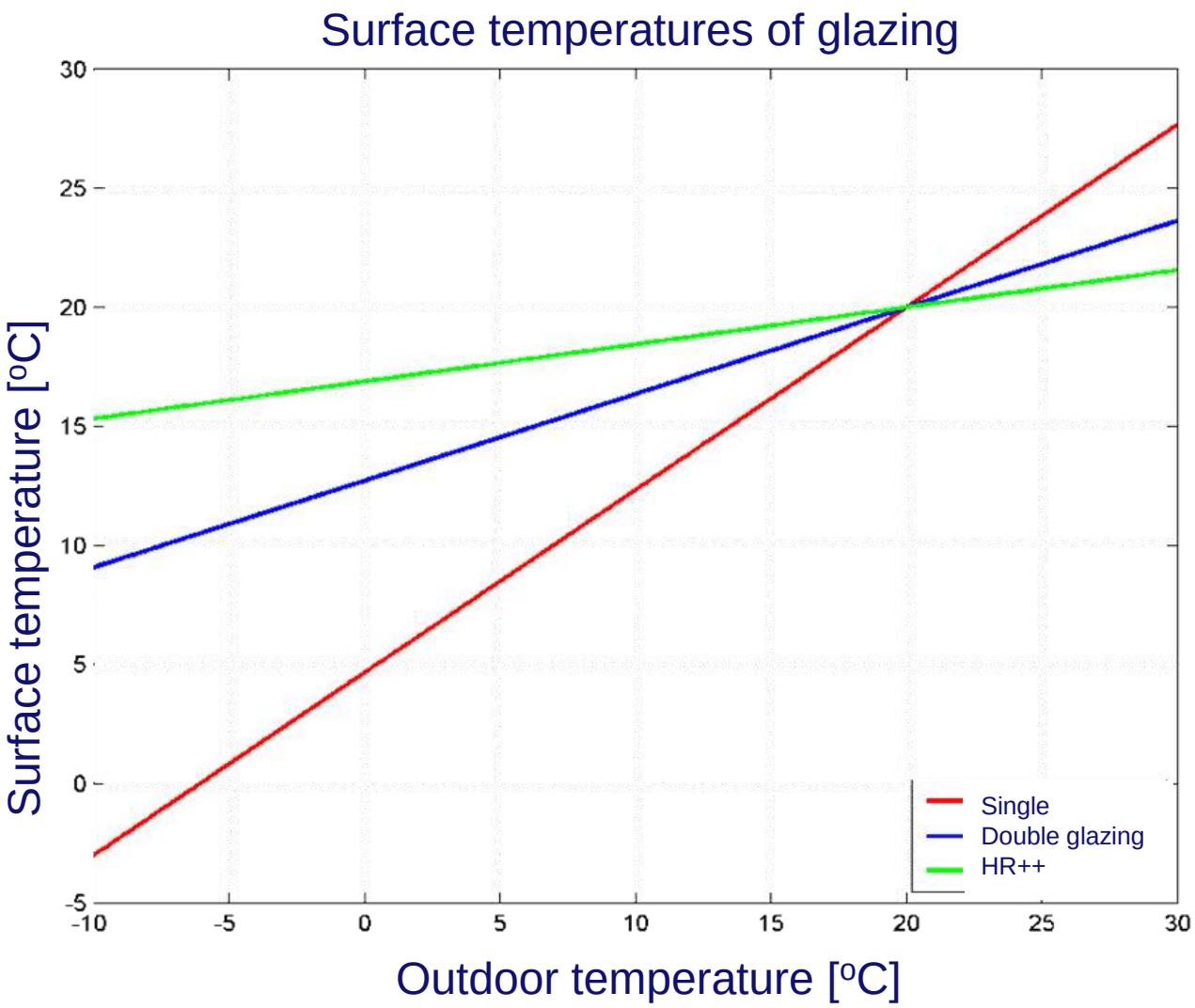
Condensation



Condensation



Condensation on glazing



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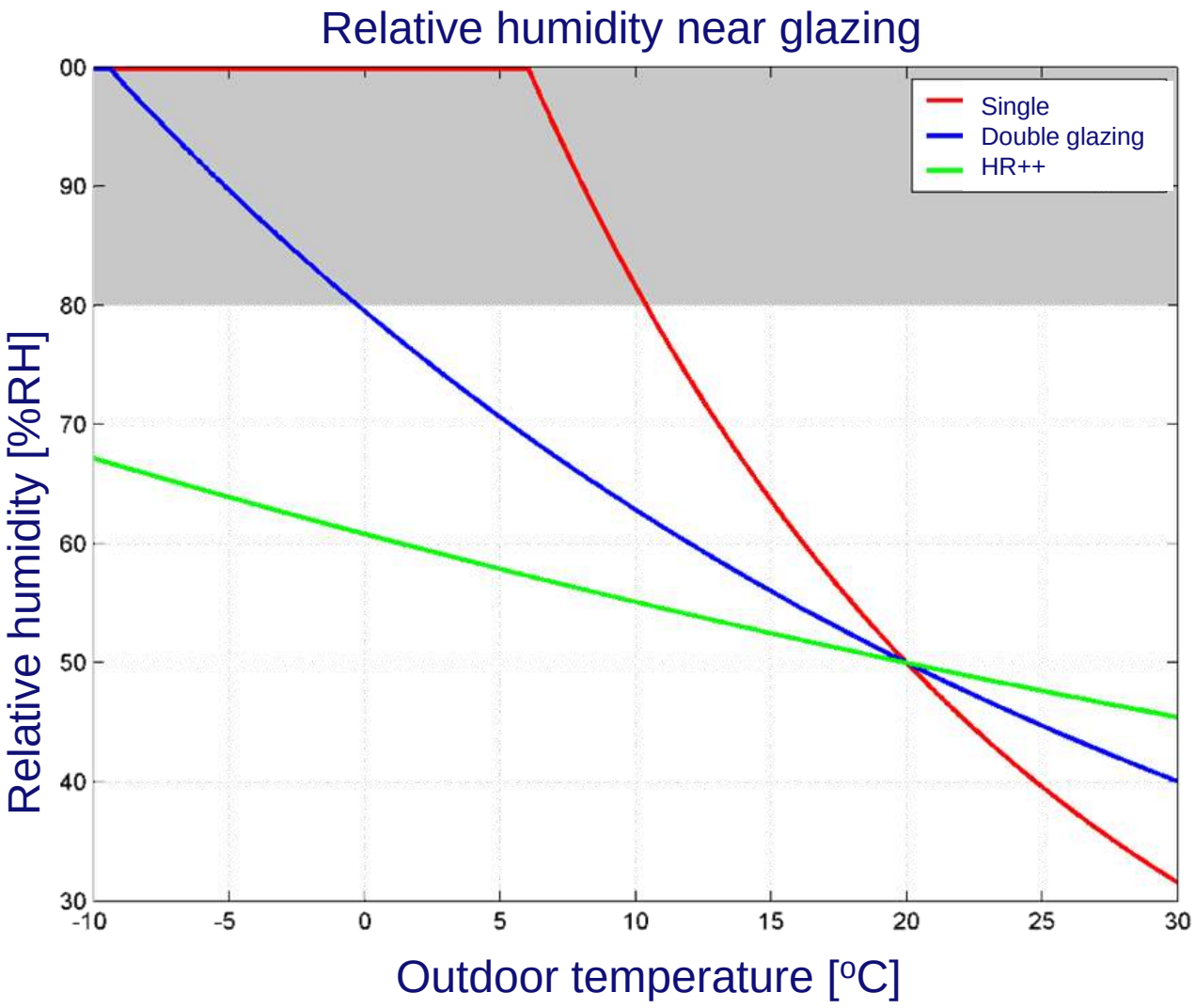

Condensation on glazing

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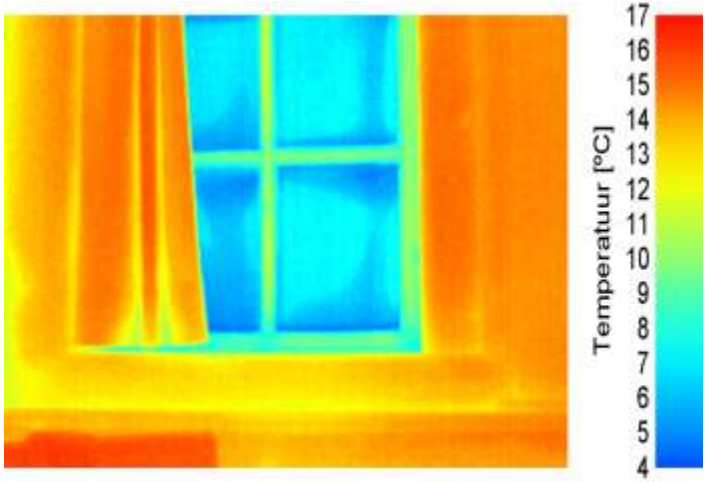
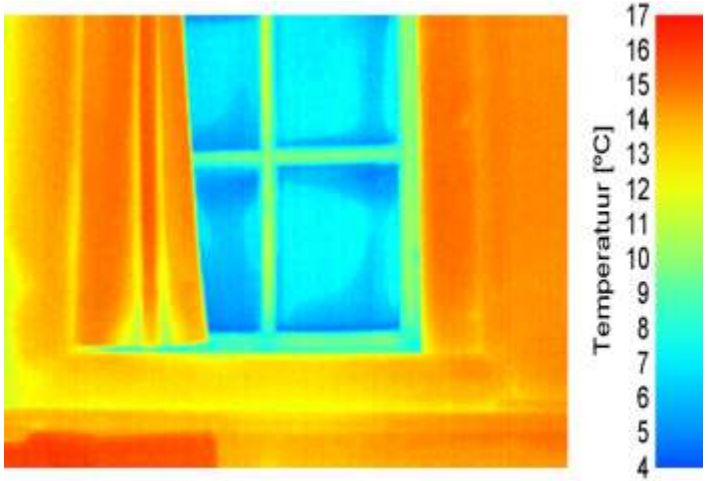
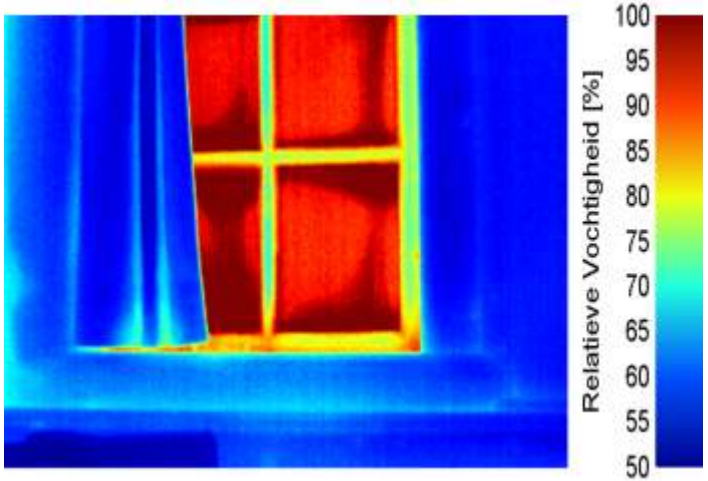


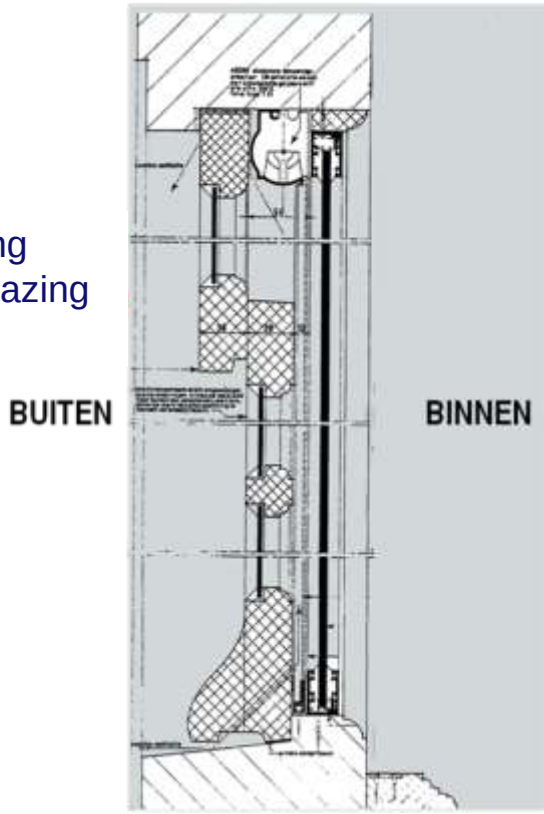
Condensation on glazing





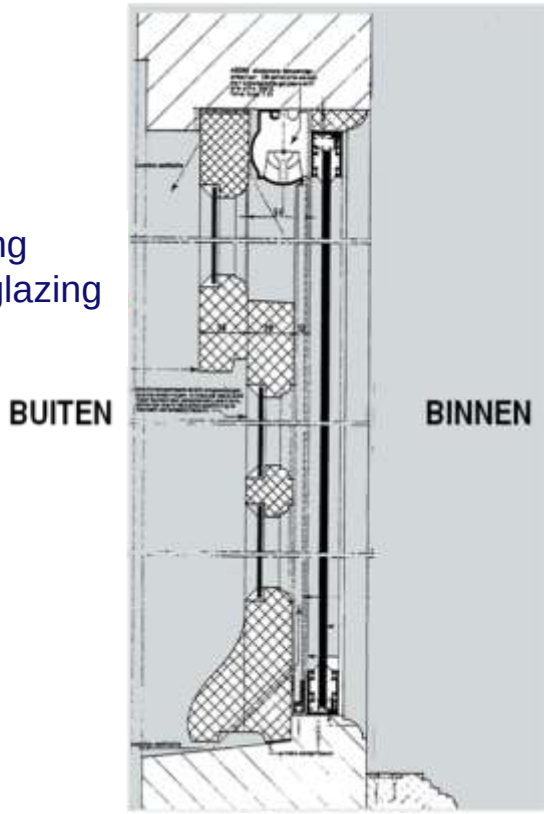
Condensation on glazing

Single glazing
Protective glazing
Screen



Condensation on glazing

Single glazing
Secondary glazing
Screen



2- en 3D-modeling

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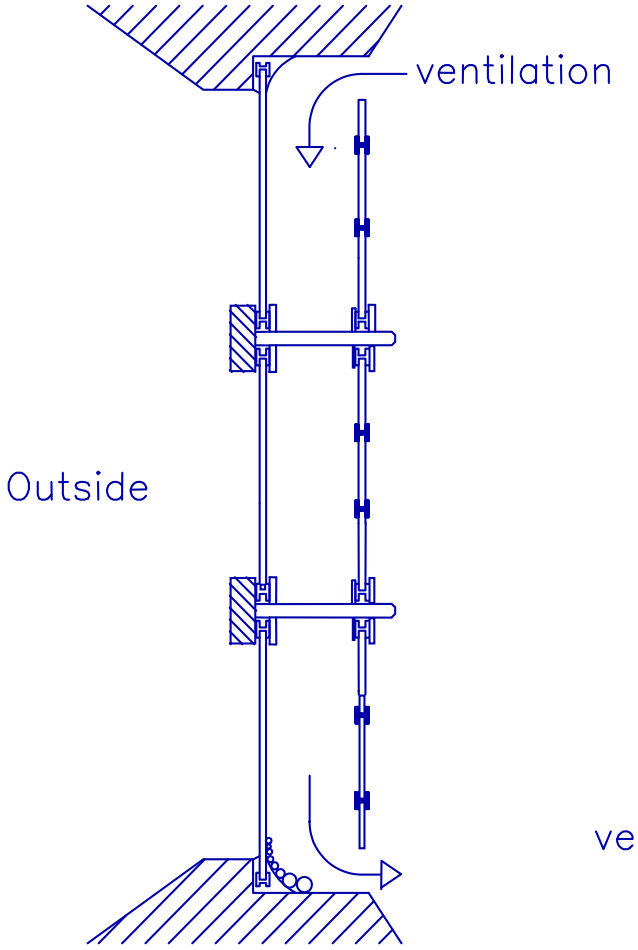
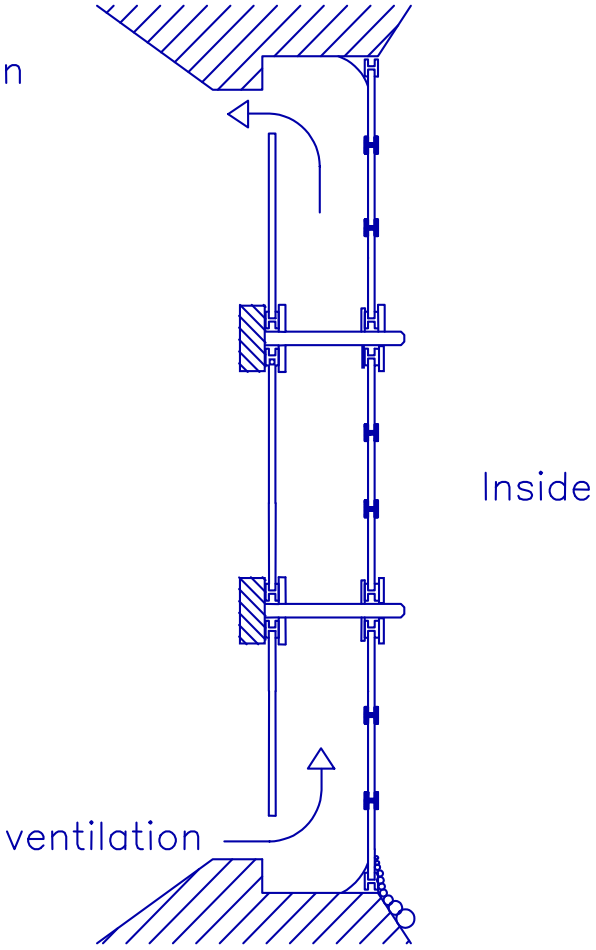
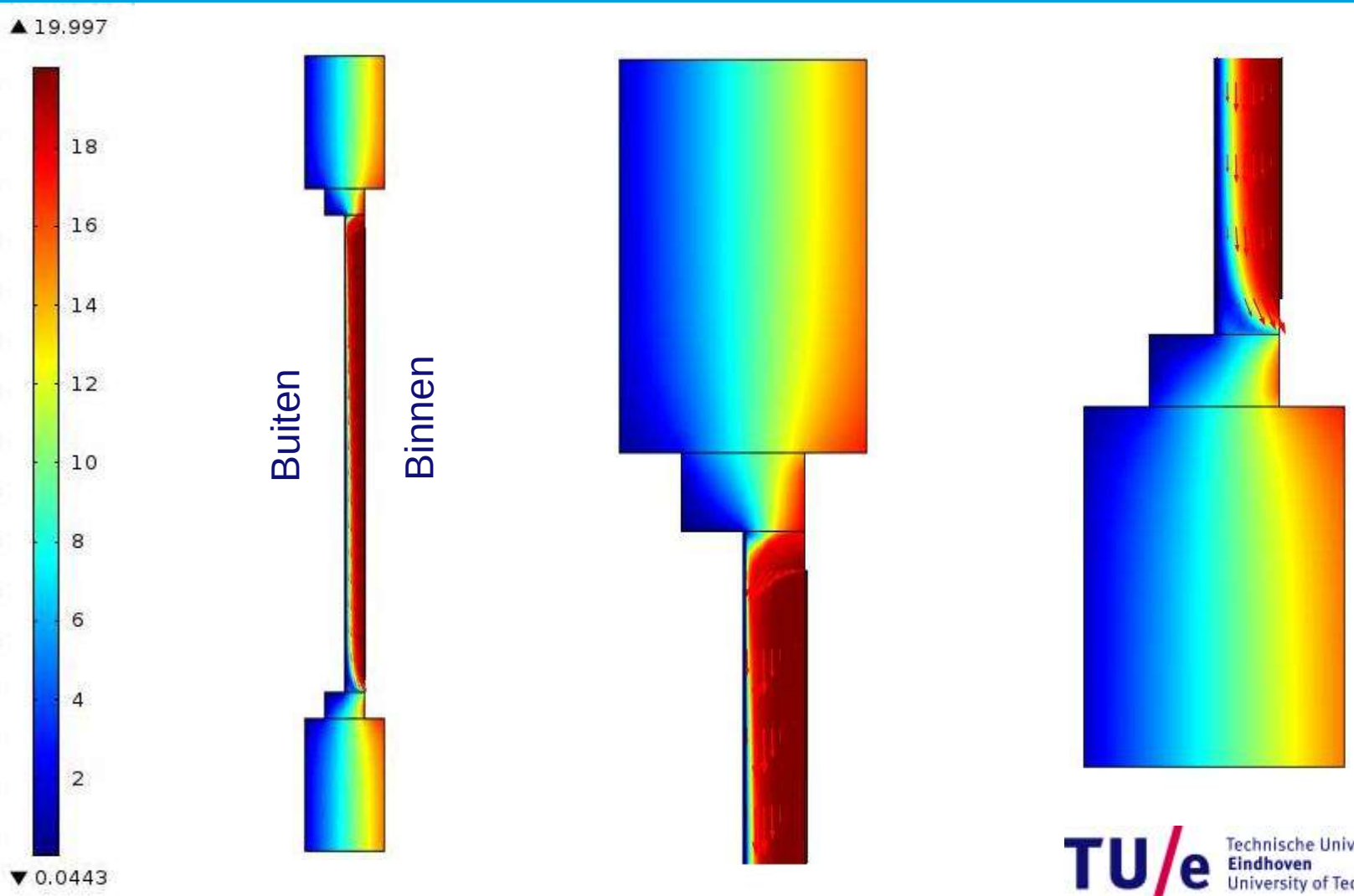


Inside ventilation

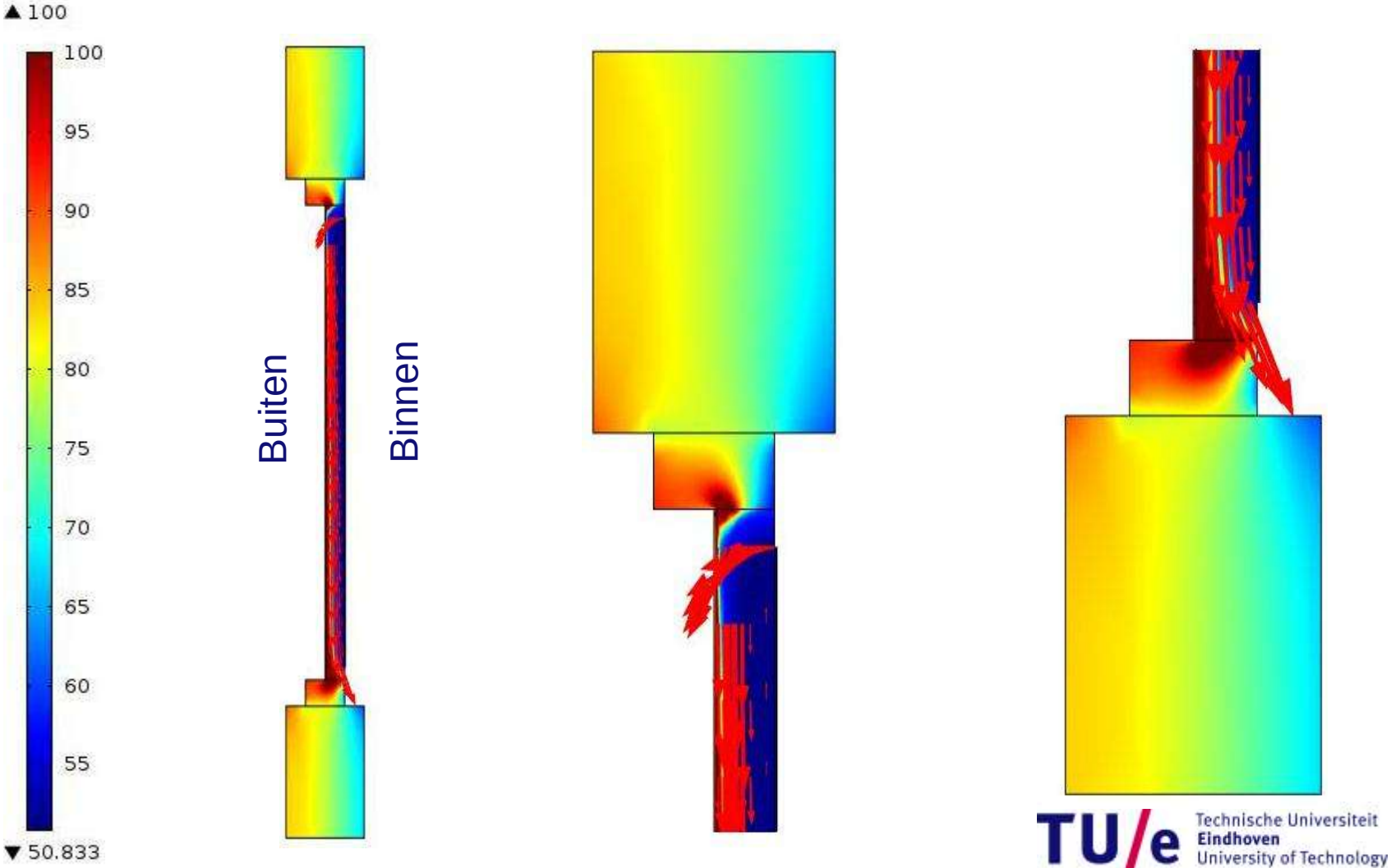


Outside ventilation

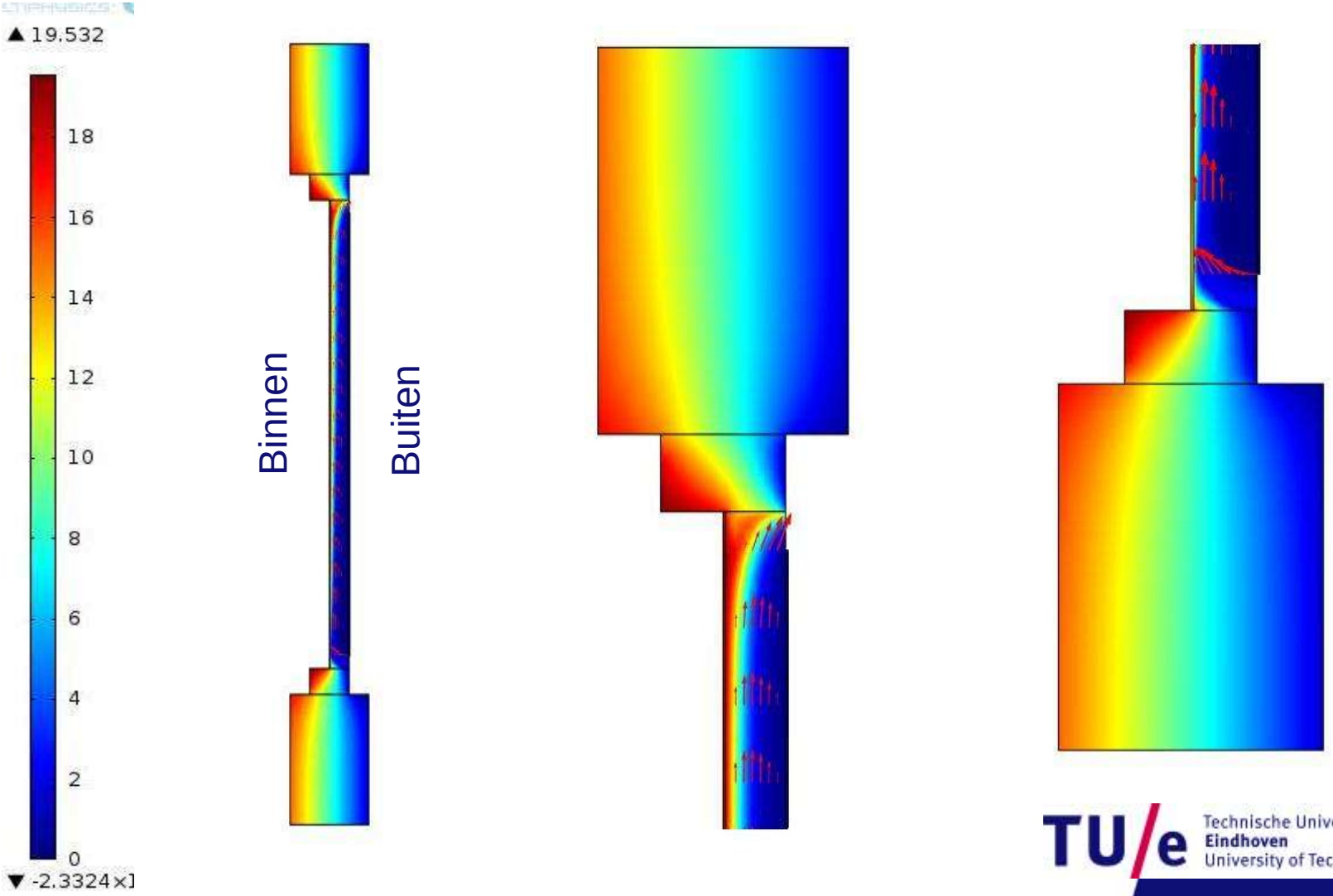
Inside ventilation: Temperatures



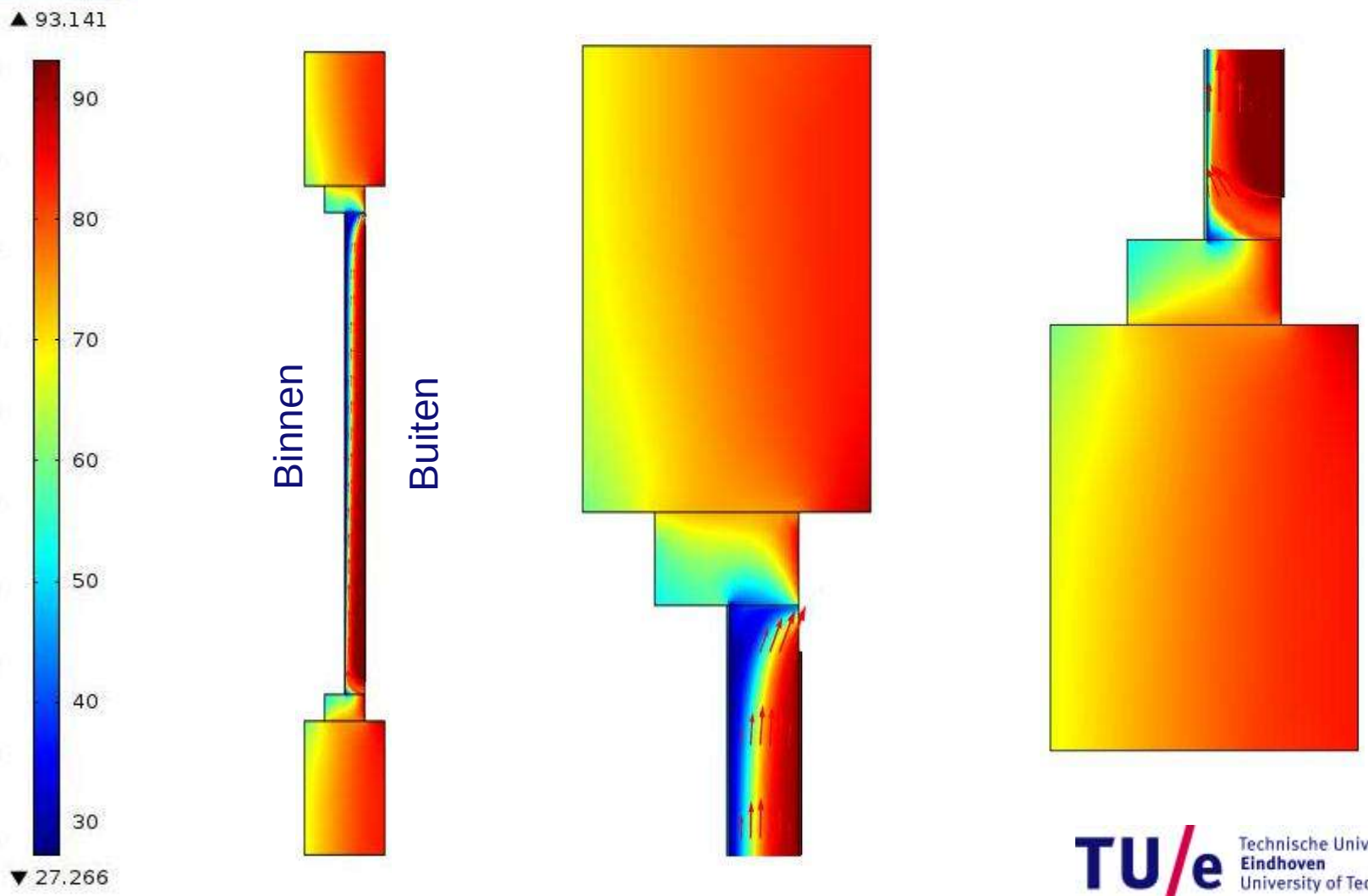
Inside ventilation: Relative humidities



Outside ventilation: Temperatures

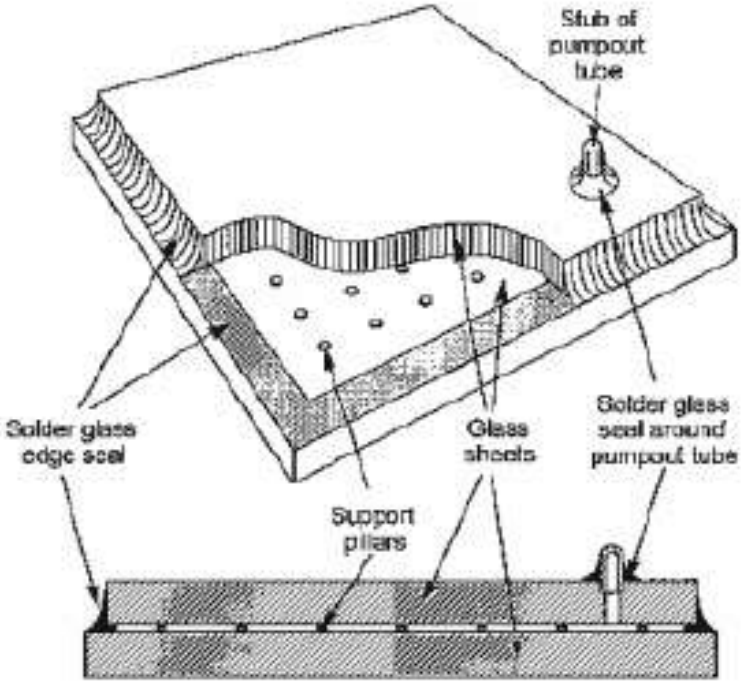


Outside ventilation: Relative humidities



Vacuum glazing

Vacuum glazing modeling



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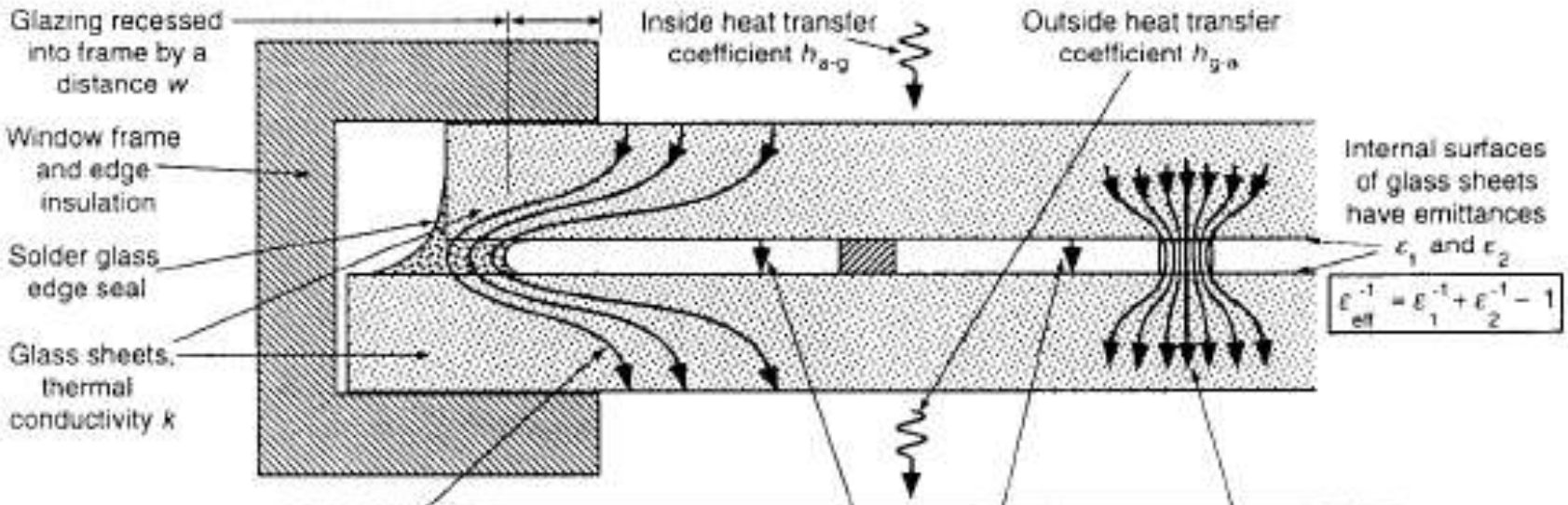
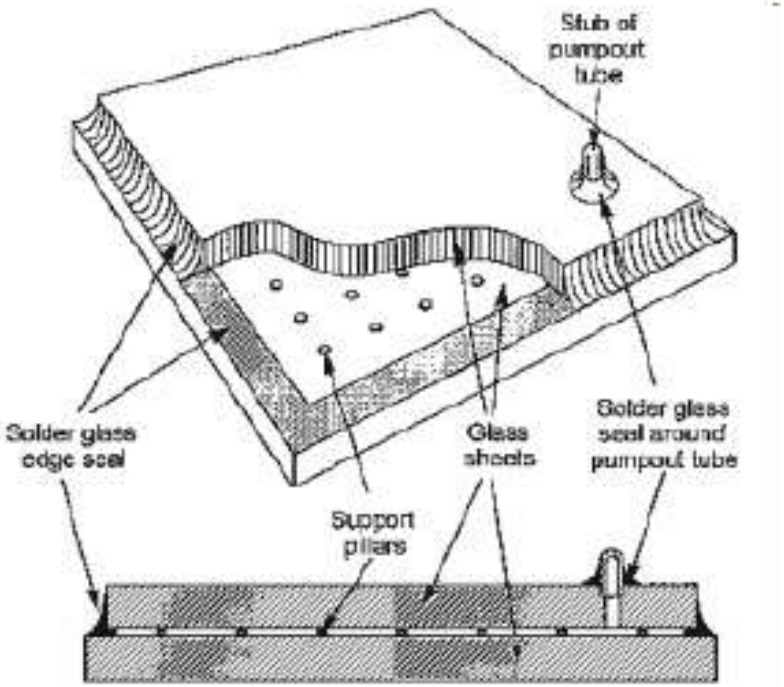
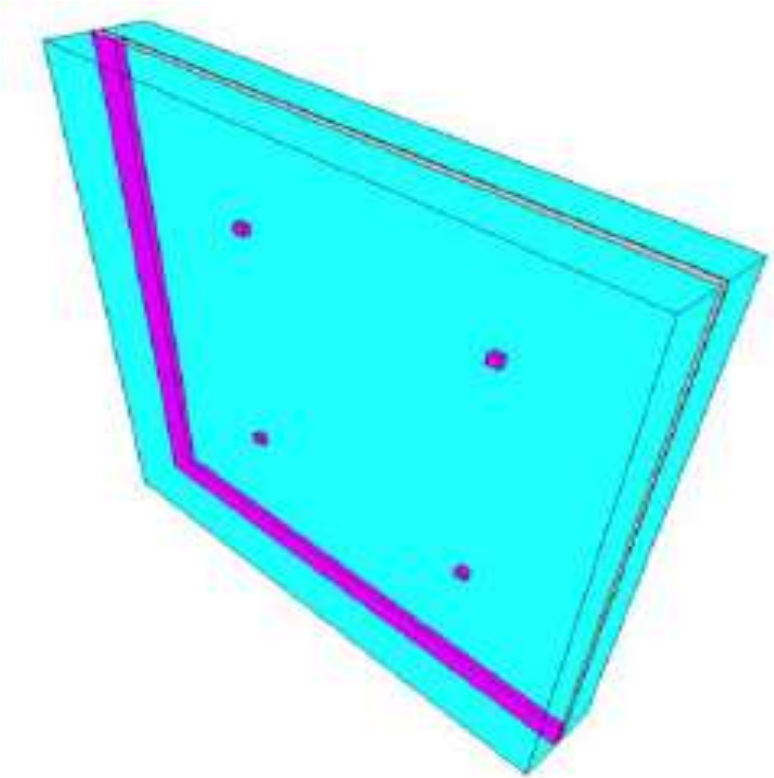


Heat flow through edge seal	Heat flow due to residual gas	Heat flow due to radiation	Heat flow through support pillars
Conductance per unit length	Conductance per unit area		
$[(kth_{a\text{-}g})^{-1/2} + (2w/kt) + (kth_{g\text{-}a})^{-1/2}]^{-1}$	0	$4\varepsilon_{eff}\sigma T^3$	$2ka/\lambda^2$
Total air-to-air conductance of a vacuum glazing of dimensions $c \times d$			
$[2(c+d)/cd] \times [(kth_{a\text{-}g})^{-1/2} + (2w/kt) + (kth_{g\text{-}a})^{-1/2}]^{-1} + [h_{a\text{-}g}^{-1} + \{(4\varepsilon_{eff}\sigma T^3) + (2ka/\lambda^2)\}^{-1} + h_{g\text{-}a}^{-1}]^{-1}$			

Vacuum glazing modeling





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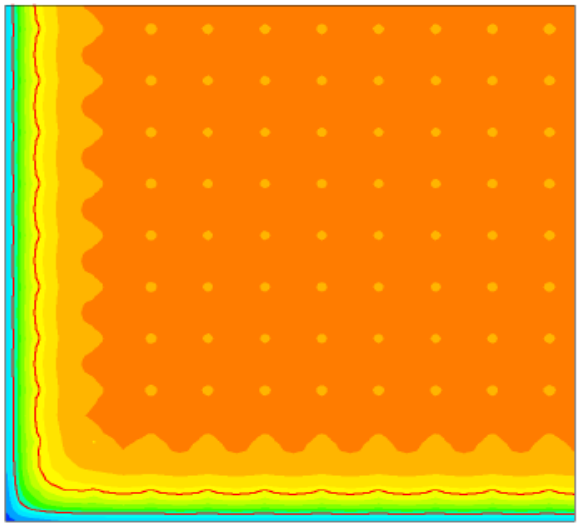

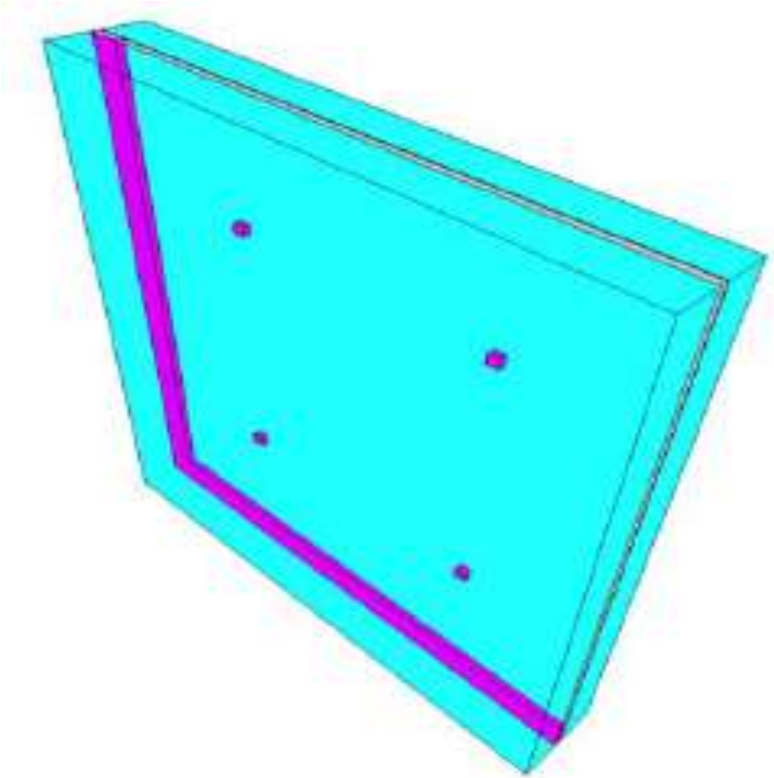

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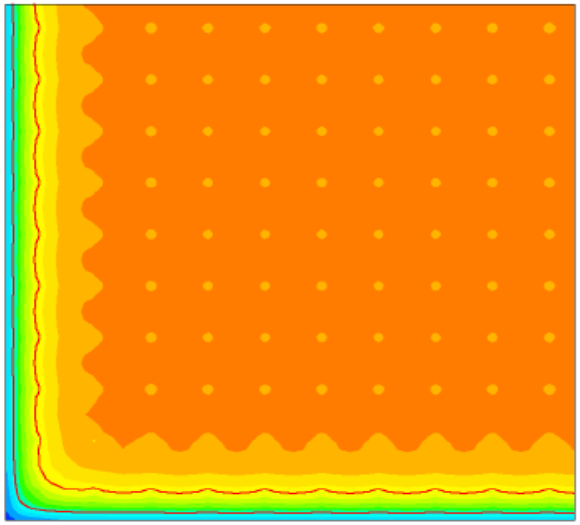
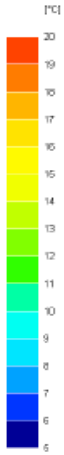
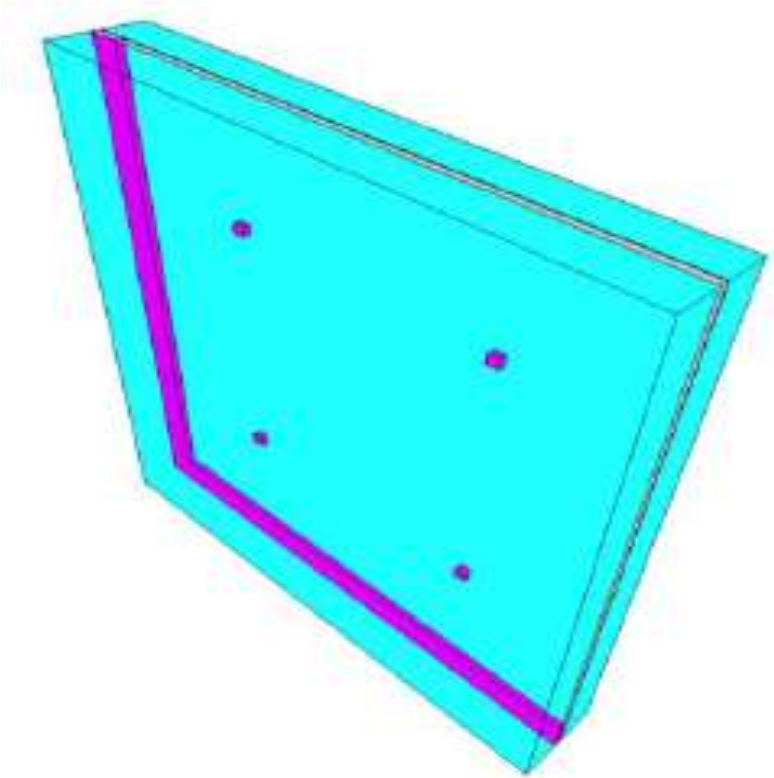
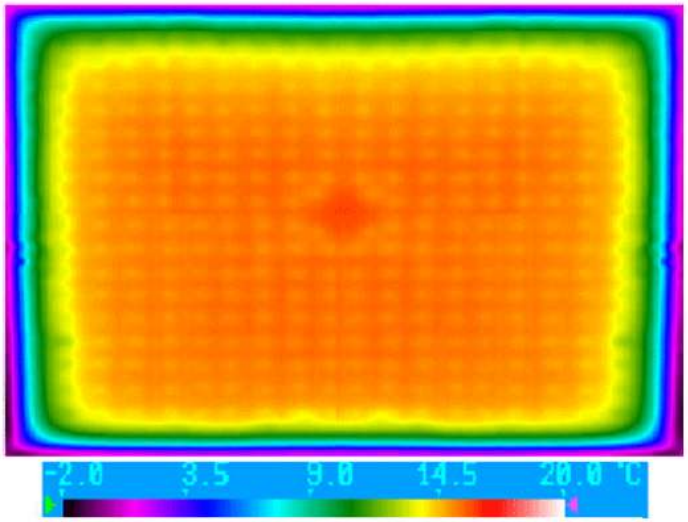
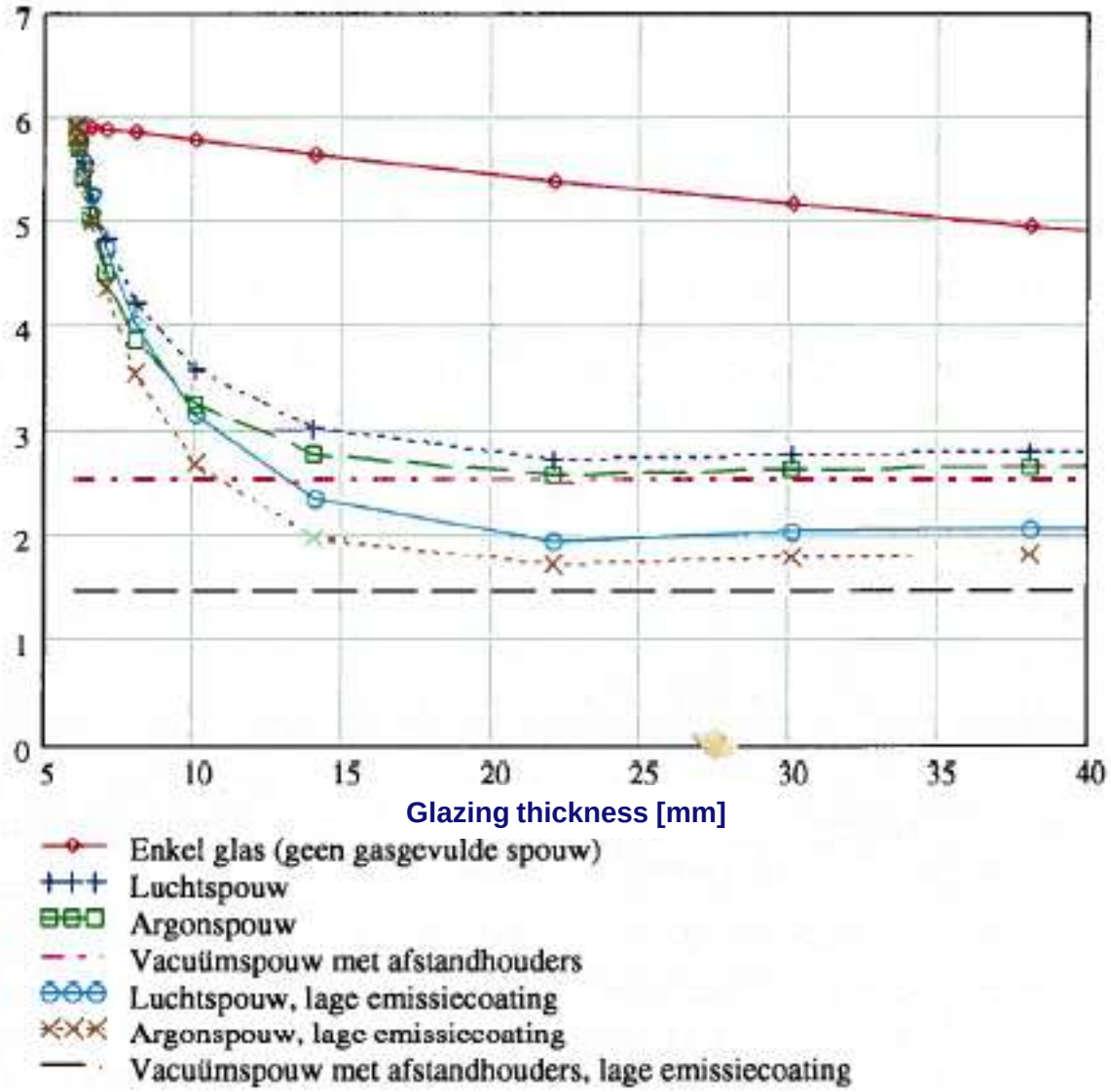








Vacuum glazing modeling



Single

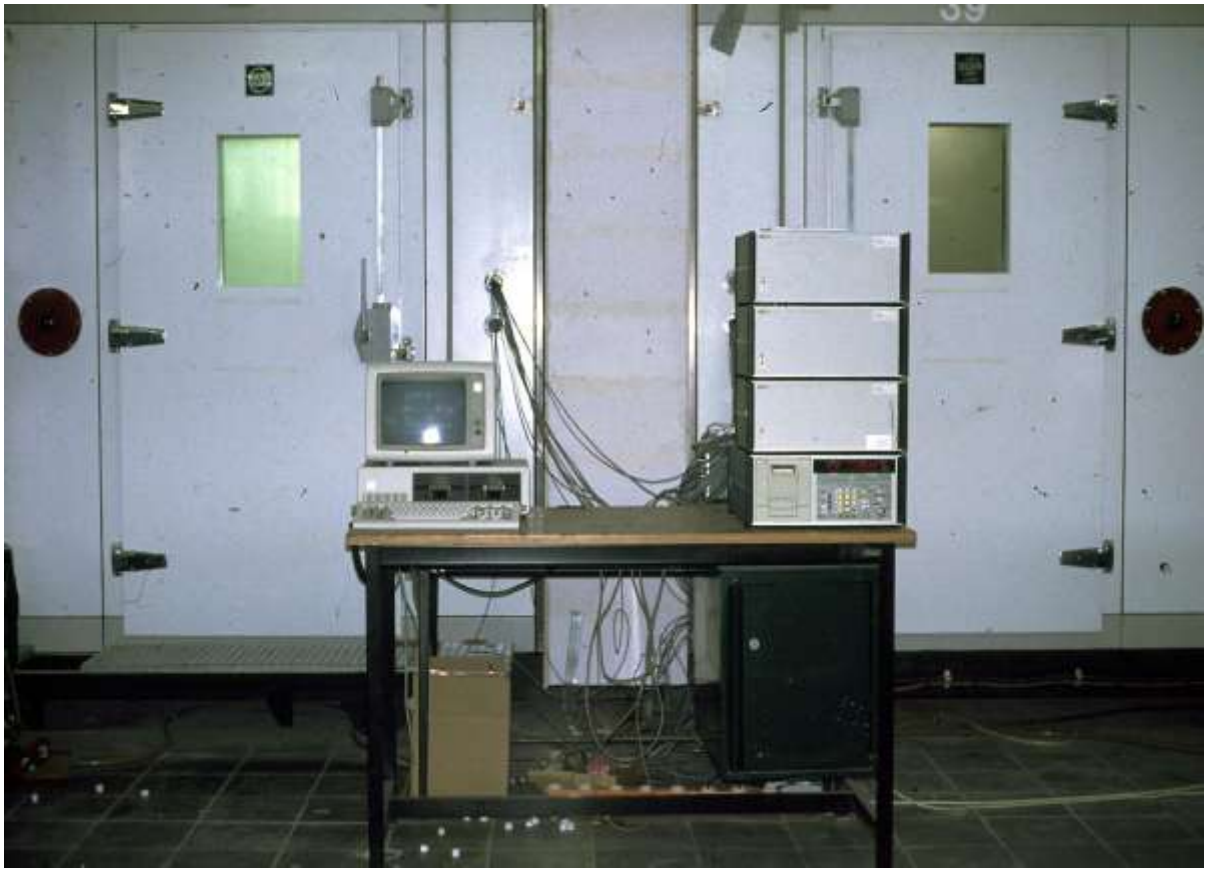
Double

HR^{++}

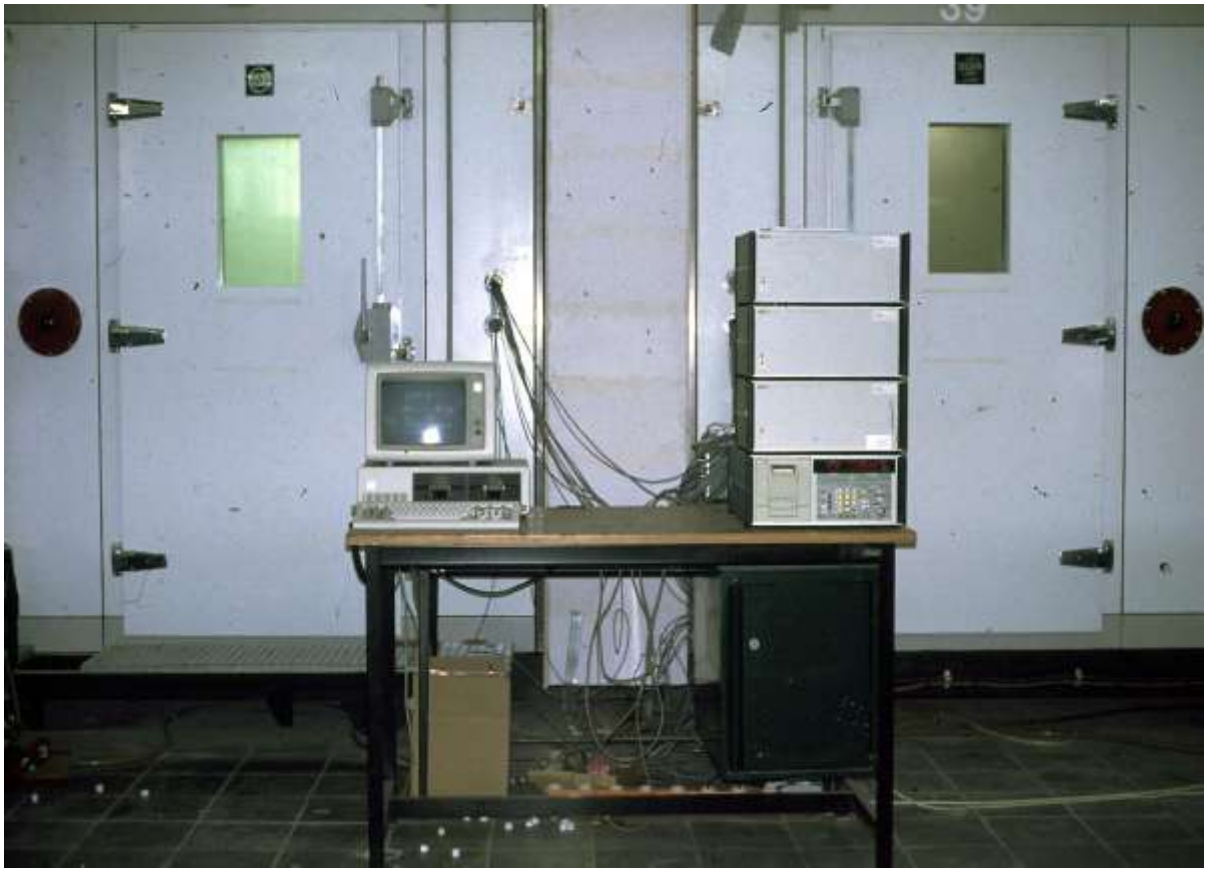
Vacuum

Measurements

Hot-box measurements TU/e



Hot-box measurements TU/e



Hot-box measurements GCU(Glasgow Caledonian University)

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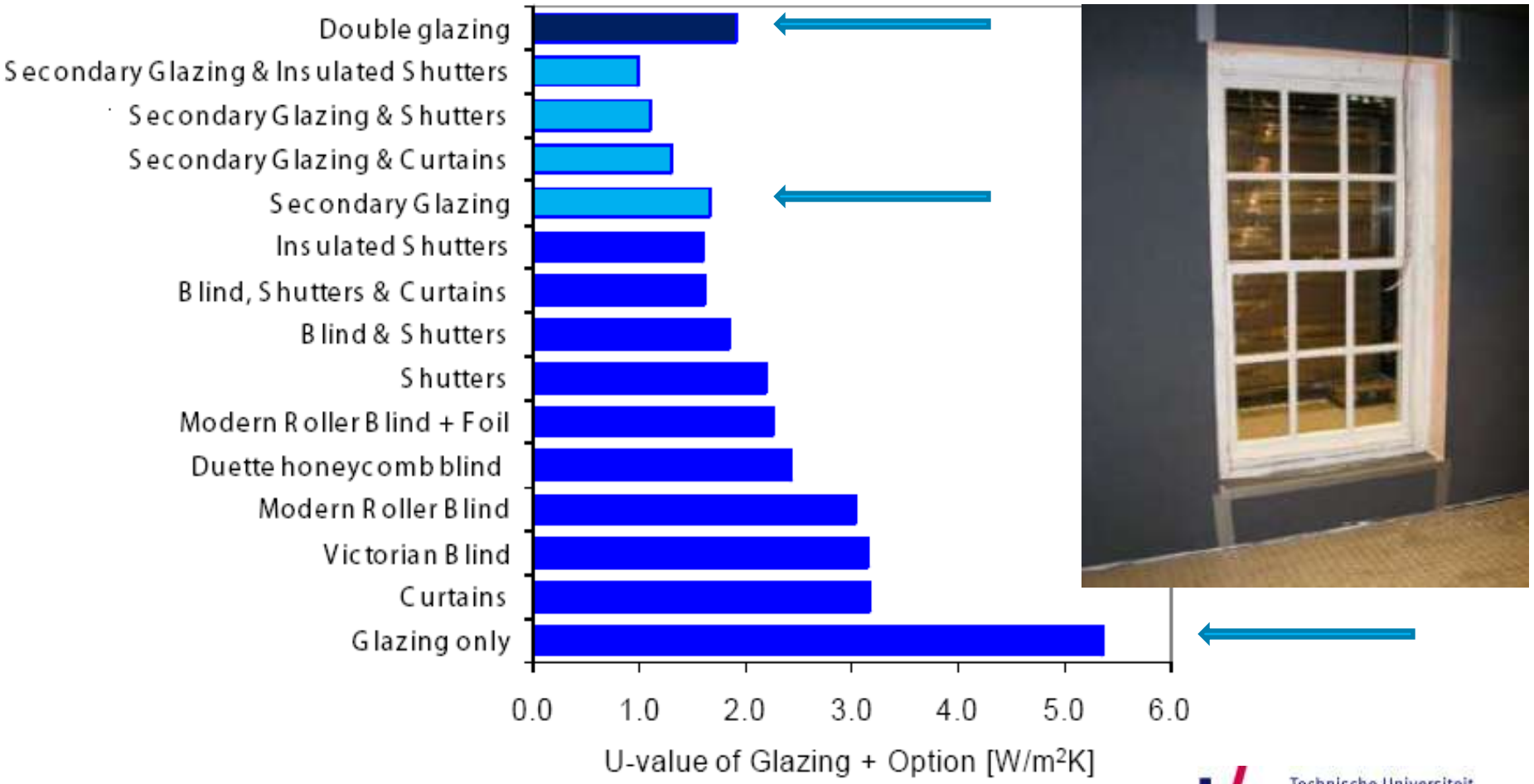
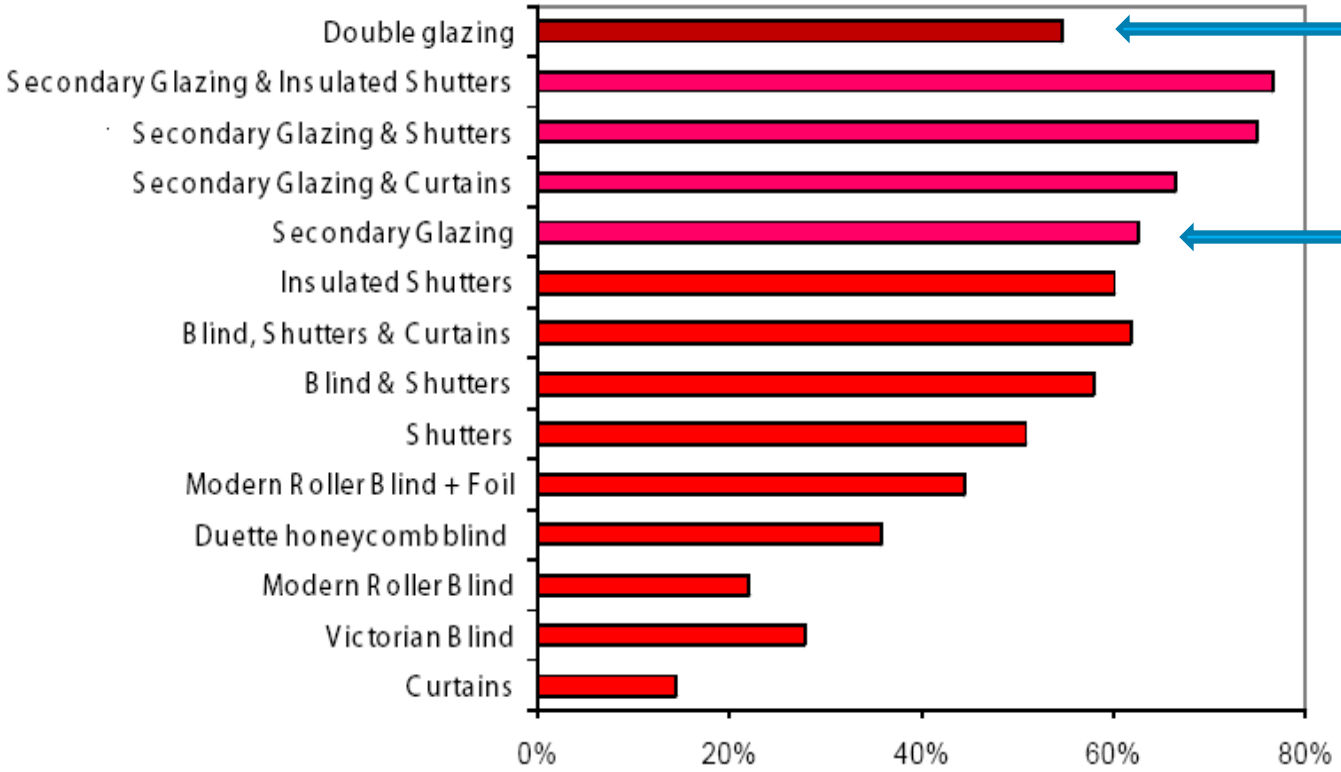


Hot-box measurements GCU



In situ measurements

In situ measurements GCU

In situ measurements GCU

Slimlite® beglazing

In situ measurements GCU

Address	System / manufacturer	Glazing configuration - inner pane / cavity / outer pane (mm)	Inner pane glazing type	Gap fill	Comments	Manufacturer's Centre of Pane U-value - upper limit [W/m^{2}K]
1/1 Archibald Place	Sashworks	4-8-4	Low-E	argon	New sashes	1.8
1/2 Archibald Place	Histoglass	3-4-4	Low-E	krypton		1.9
1/3 Archibald Place	Histoglass	3-4-4	Low-E	krypton	Crown-effect outer pane	1.9
1/4 Archibald Place	Pilkington energiKare Legacy	4-0.2-3	Low-E	vacuum		1.3
1/5 Archibald Place	Slimlite	3-3-3	Low-E	air		2.6
1/6 Archibald Place	Slimlite	3-3-3	Low-E	xenon & krypton	Crown-effect outer pane	2.1
1/7 Archibald Place	Slenderglaze	4-3.9-4	Low-E	xenon & krypton		2.1
1/8 Archibald Place	Slimlite	3-3-3	Low-E	xenon & krypton		2.1
37 Lauriston Place	Supalite	4-4.8-3	Low-E	argon	New sashes	2.5
5 Charlotte Square	Slimlite	3-3-3	Low-E	xenon & krypton	New sashes	2.1

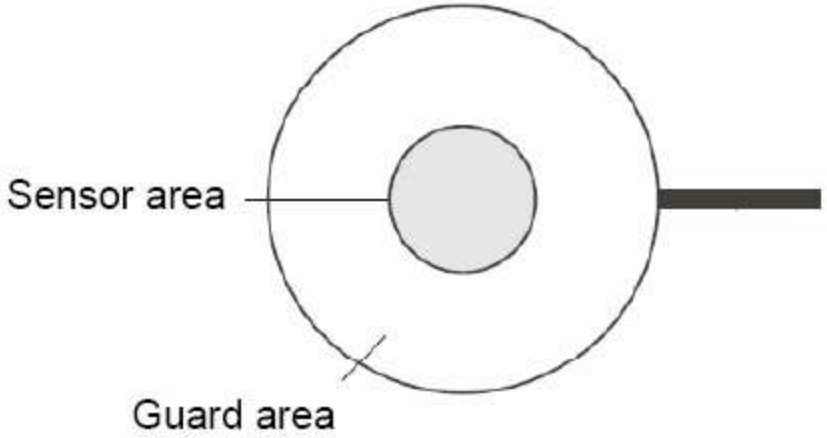
6,2 mm

9,0 mm

In situ measurements GCU

Glazing Type	Location	Test start	Test end	U-values, W/m2K	Uncertainty
Sashworks (new sashes, argon fill)	1/1 Archibald Place	22/02/2010	08/03/2010	2.0	7%
Histoglass (D11, krypton fill)	1/2 Archibald Place	08/03/2010	22/03/2010	2.7	5%
Histoglass (D10, krypton fill, hand drawn outer)	1/3 Archibald Place	08/03/2010	22/03/2010	2.3	5%
Pilkington energiKare Legacy (vacuum)	1/4 Archibald Place	08/03/2010	22/03/2010	1.0	11%
Slimlite (air fill)	1/5 Archibald Place	05/02/2010	22/02/2010	2.8	5%
Slimlite (xenon & kryton fill, Crown-effect outer)	1/6 Archibald Place	22/02/2010	08/03/2010	2.3	5%
Slenderglaze (xenon & krypton fill)	1/7 Archibald Place	22/02/2010	08/03/2010	1.7	6%
Slimlite (xenon & krypton fill)	1/8 Archibald Place	05/02/2010	22/02/2010	2.3	7%
Supalite (argon fill, new sashes)	37 Lauriston Place	08/03/2010	22/03/2010	2.8	14%
Slimlite (xenon & krypton, new sashes)	5 Charlotte Sq.	22/12/2009	13/01/2010	2.0	7%

Measurement errors heat flux devices



$$U = \frac{1}{\left(\frac{T_{si} - T_{se}}{Q}\right) + 0.17 - 6.25 \times 10^{-3}} \; W/m^2K$$

Conclusions

- Windows in historic buildings and monuments are critical regarding energy losses and condensation
- They might be improved by secondary and vacuum glazing
- To estimate thermal behavior, its complexity asks for 2- and 3-D modeling
- Calculations should be validated
- Generally the best measurement results in laboratory
- In situ, large measurements errors might occur