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Optimising control for environmental quality and energy efficiency

F Wang, Y Zhang, S Ganguly & M Browne*

Royal Academy of Engineering Centre of Excellence in Sustainable Development Building Design

Heriot-Watt University

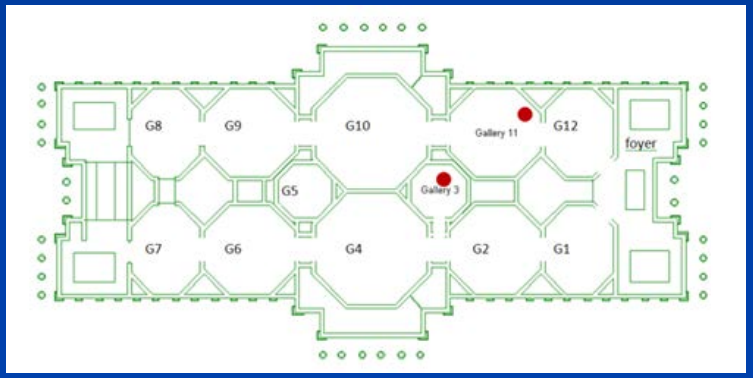
* National Galleries of Scotland

Contents

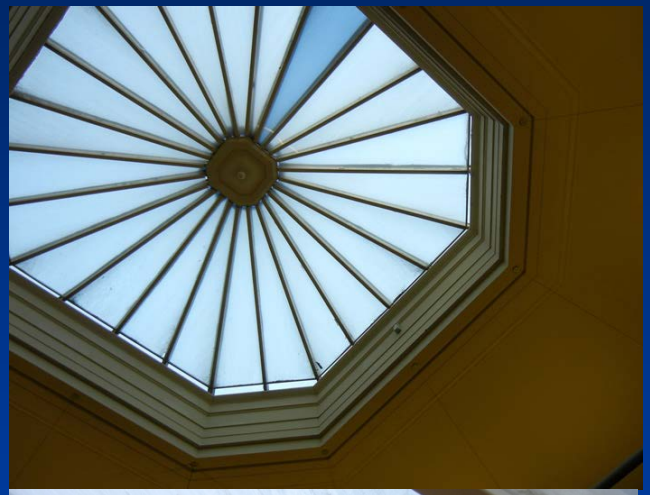
- Background
  - The Building
  - The problems
- The Aim and objectives
- The Methods
  - Assessment criteria
  - Measurement for validation
  - Building the model - specifying & validation
  - Modelling assessment
- The results and dicussion
- Conclusion

The building
Scottish National Gallery

- Constructed and first opened to public in 1859
- Stone-walled with thick exterior walls
- Several galleries distributed at basement, ground and upper level of building
- Houses valuable collections, mostly artwork; hosts world renowned exhibitions, one of the most popular major attractions in the capital.



The problems



- Collections preserved by strictly maintaining indoor conditions as per individual specifications by dedicated AHUs
  - Diurnal fluctuation of room T & RH
  - High energy bills
- Large skylight at roof provides natural lighting to the interiors – single glazed
  - Excessive heat losses and low interior surface temperature
  - High risk of surface condensation
- Recently undergone refurbishment to improve on energy savings

Aim & Objectives

- as a follow-up study to a modelling prediction
- as a parallel study to an assessment on energy/environment quality
- to assess the effects of the skylight refurbishment on the quality of the hygrothermal condition in one of the typical gallery space and energy consumption

Objectives

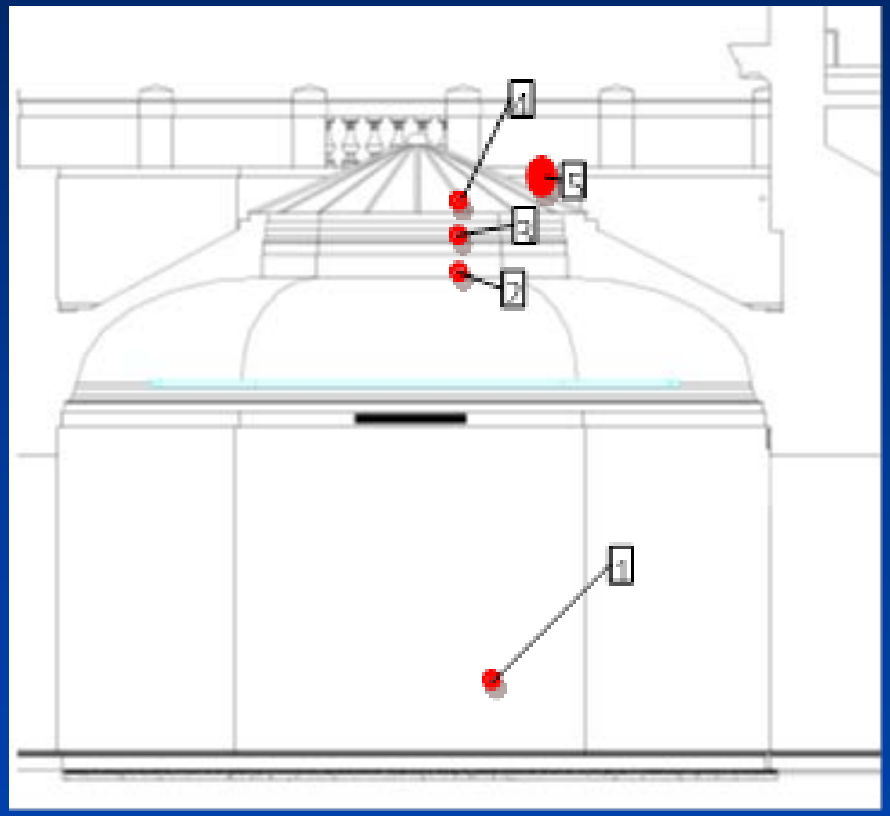
- To develop criteria to assess the skylight refurbishment
- To measure & collect key data before and after the refurbishment for validation of a CFD model for a modelling study
- To design typical cases for validating the model and comparing typical operation conditions before and after the refurbishment
- To develop a CFD model and run simulation for quantitative comparison

Methods

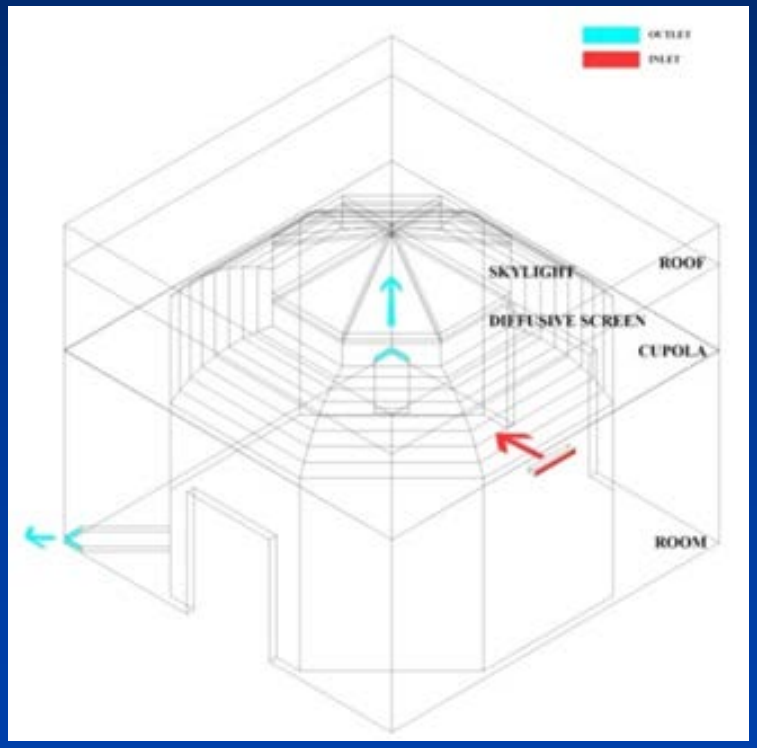
- Assessment criterion
  - Cases: selection of operation conditions
  - Vertical distribution of T & RH
  - Daily swing of T & RH
- CFD model
  - Boundary conditions
  - Validation
- Assessment - comparison

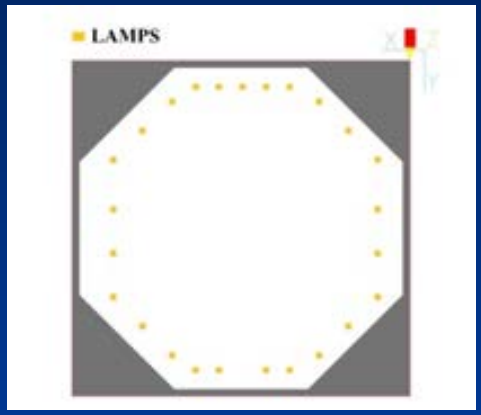
Measurement for validation

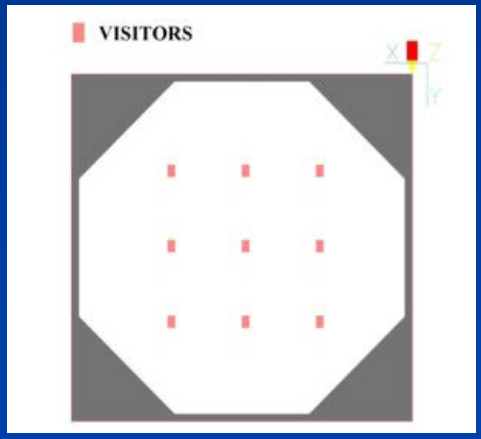
- Seasonal
- 24-hour
- Typical
  - Outdoor – including solar
  - Near glazing
  - Upper cupola
  - Lower cupola
  - Visitor level



The CFD model







Model validation - input

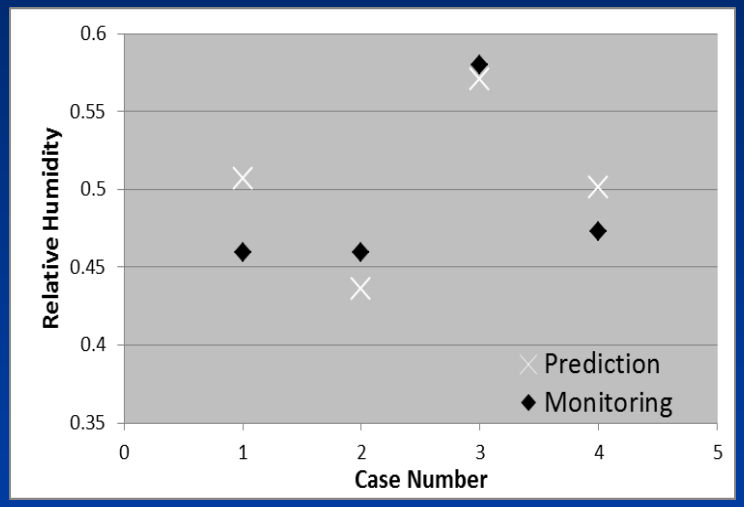
Heat gains (kW) & ventilation		Case 1 01/04/12 07:00	Case 2 01/04/12 16:00	Case 3 01/06/12 16:00	Case 4 13/05/14 16:00
light (W/lamp)	#1	0	23.05	23.05	4.61
Occupants (W/person)	#1	0	75	75	75
Occupants vapor(g/s)	#1	0	0.05	0.08	0.05
Skylight gains (kW)	#2	-2.72	-0.58	0.24	-0.19
Roof gains (kW)	#2	-1.61	-0.34	0.14	-0.28
Infiltration (kW)	#2	-3.11	-1.12	-0.75	-1.00
Solar penetration (kW)	#2	1.21	3.06	4.59	3.33
Outdoor air T (°C)	#4	2.8	15.52	17.74	16.33
Room control T (°C)	#3	21.66	22.29	22.28	22.4
Room control RH (%)	#3	45-60	45-60	58	47
Supply air T (°C)	#4	28.05	20.3	19.6	20.8
Supply air RH (%)	#4	35	41	61	51
Supply flow rate (kg/s)	#4	0.96	1.08	1.97	1.86

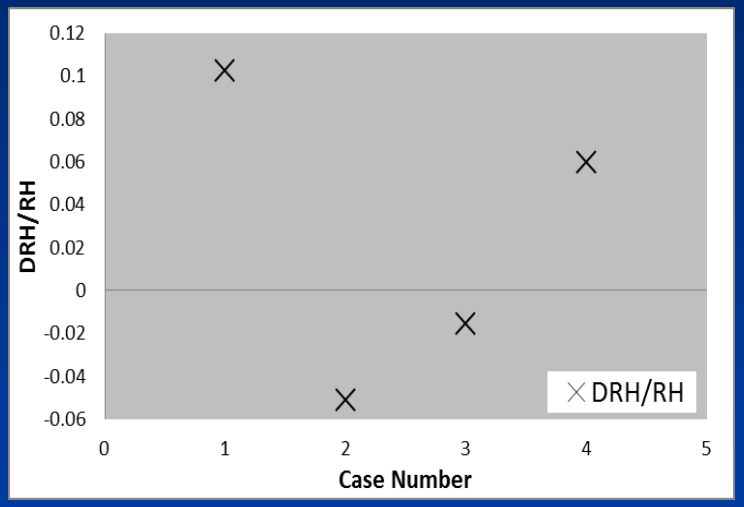
Typical operation conditions

- Combinations of needs for
  - Heating/cooling/humidifying/dehumidifying

	Before refurbishment						After refurbishment					
	winter		mild		summer		winter		mild		summer	
	am	pm	am	pm	am	pm	am	pm	Am	pm	am	pm
scenarios	BWA	BWP	BMA	BMP	BSA	BSP	AWA	AWP	AMA	AMP	ASA	ASP

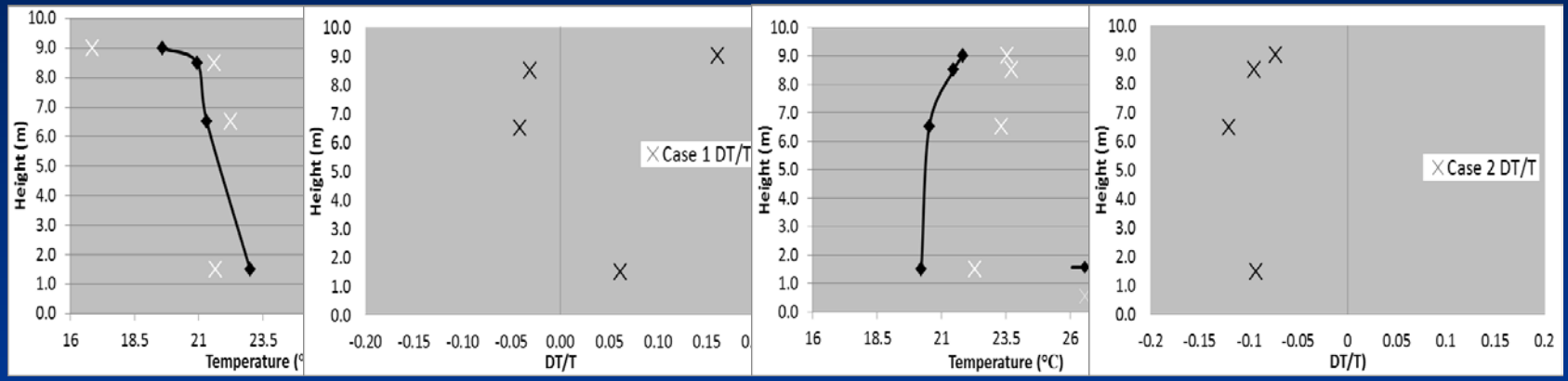
Results 1: validation 4 cases



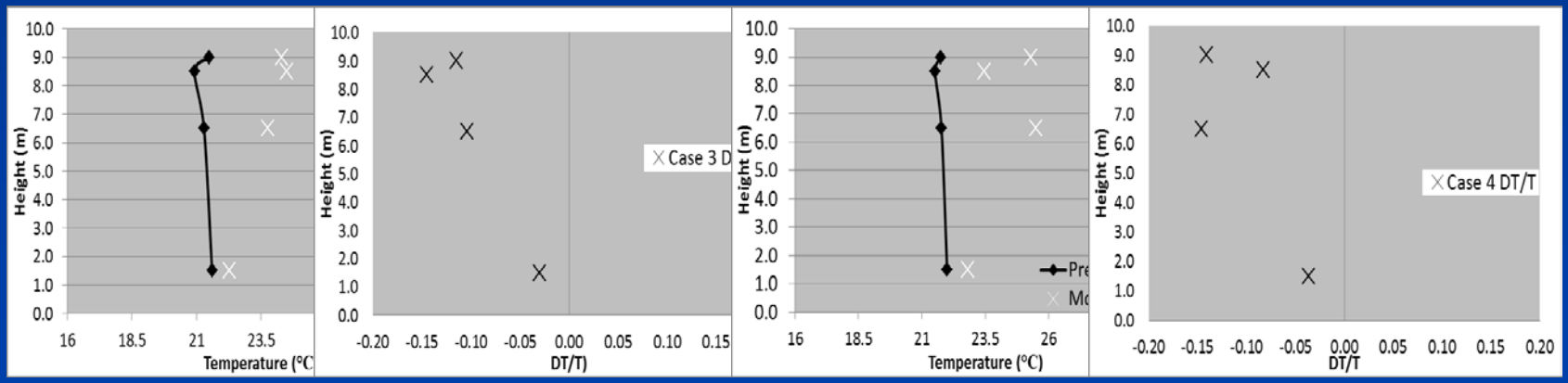


Comparison of RT for all four cases

Results 1: validation 4 cases

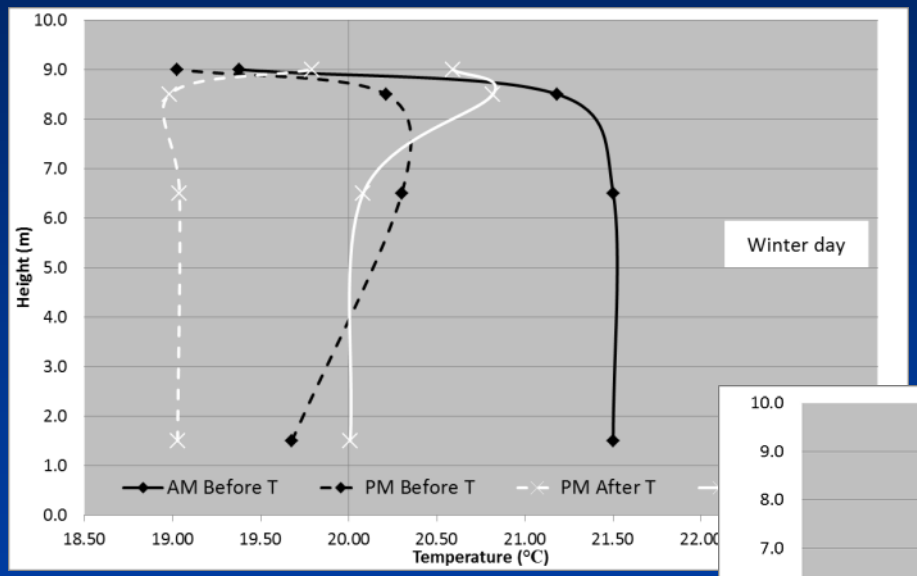


Early morning & later afternoon on the cold day before refurbish.

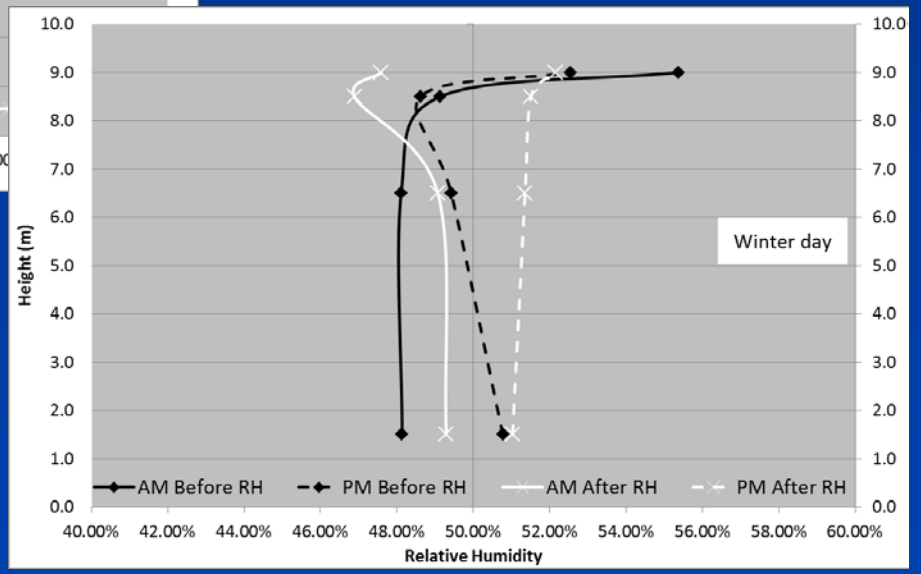


Later afternoon on the warm day before & after refurbish

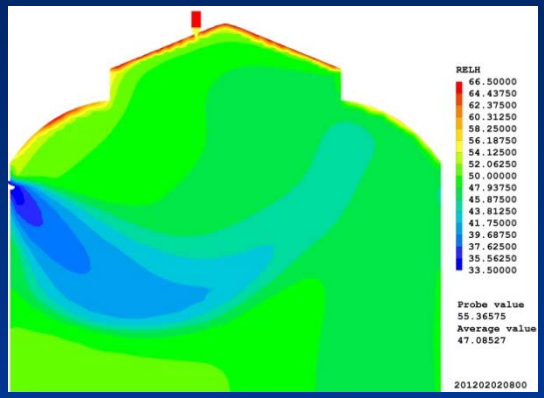
Results 2 – assessment



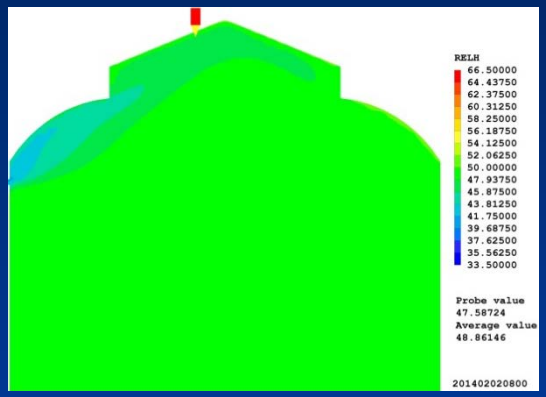
- A winter day



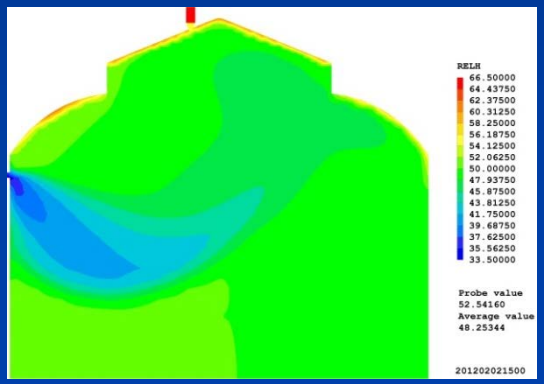
A winter day



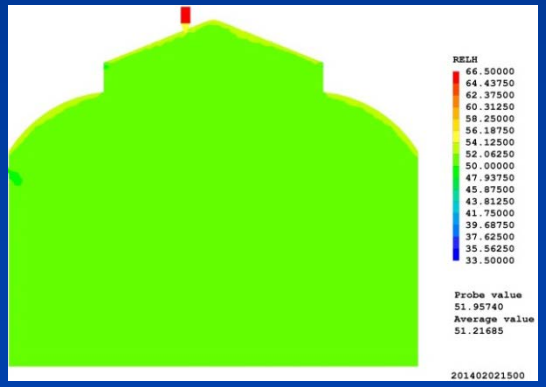
Early morning / before



Early morning / after

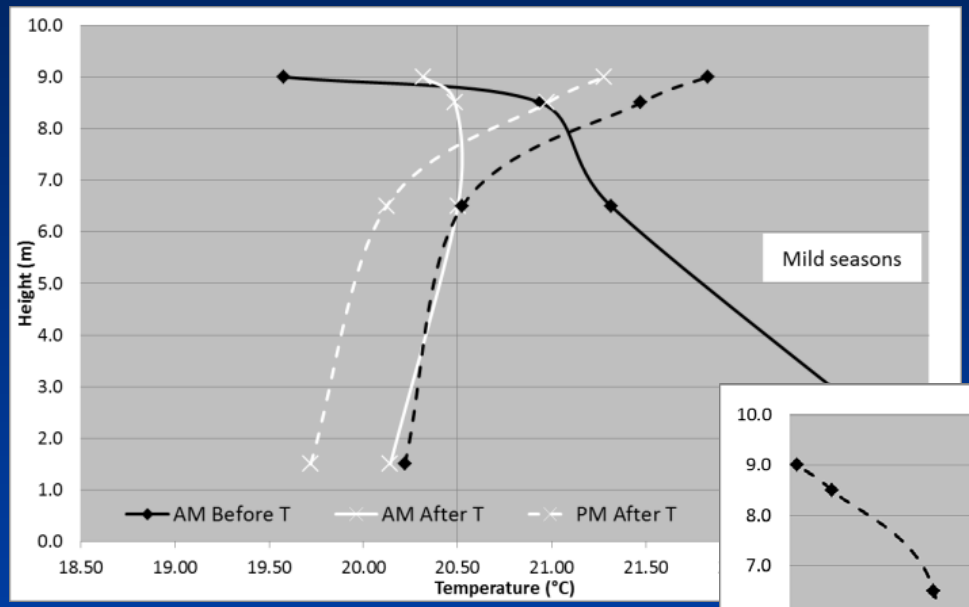


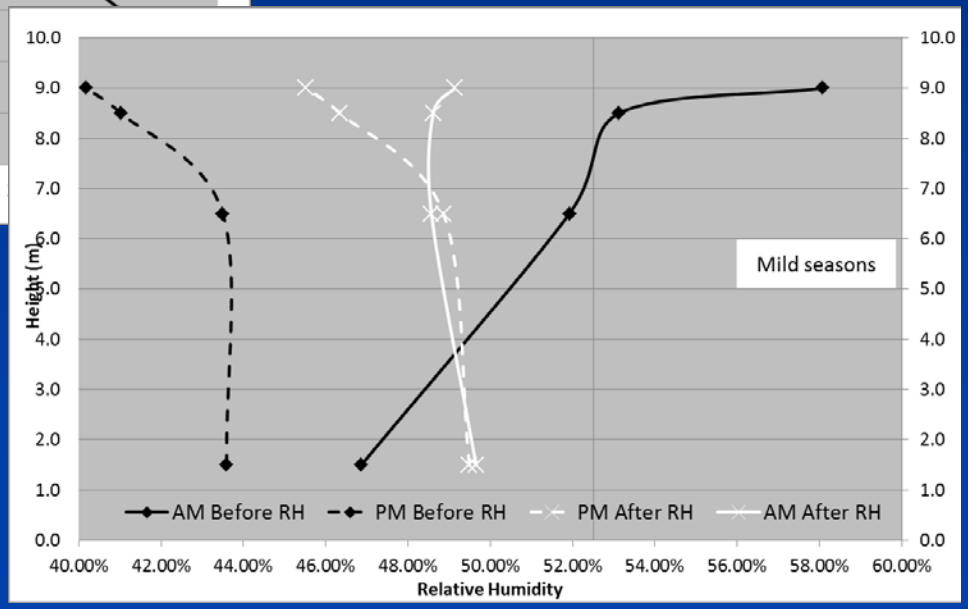
Afternoon / Before



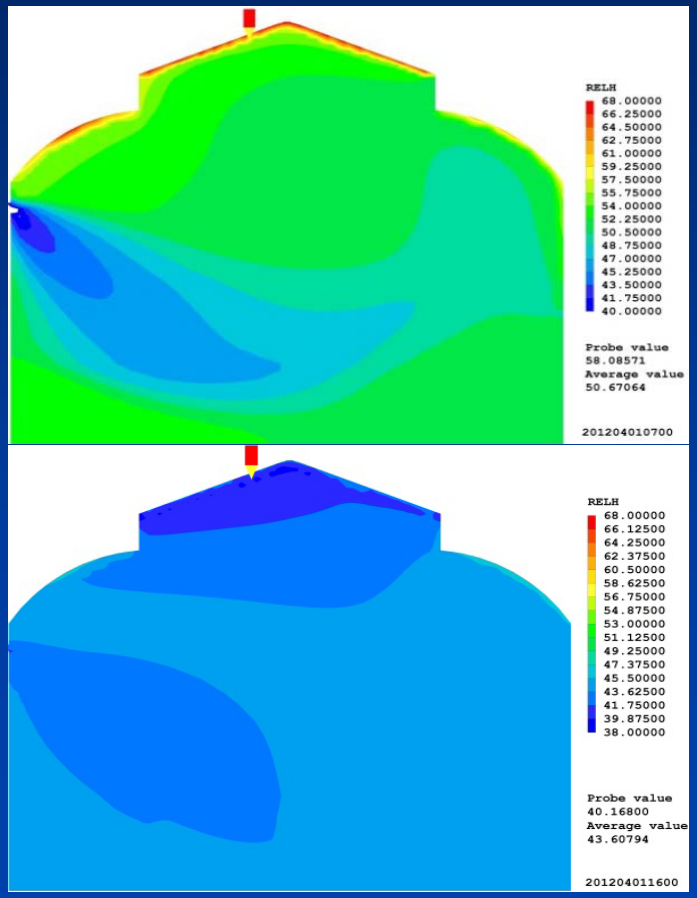
Afternoon / After

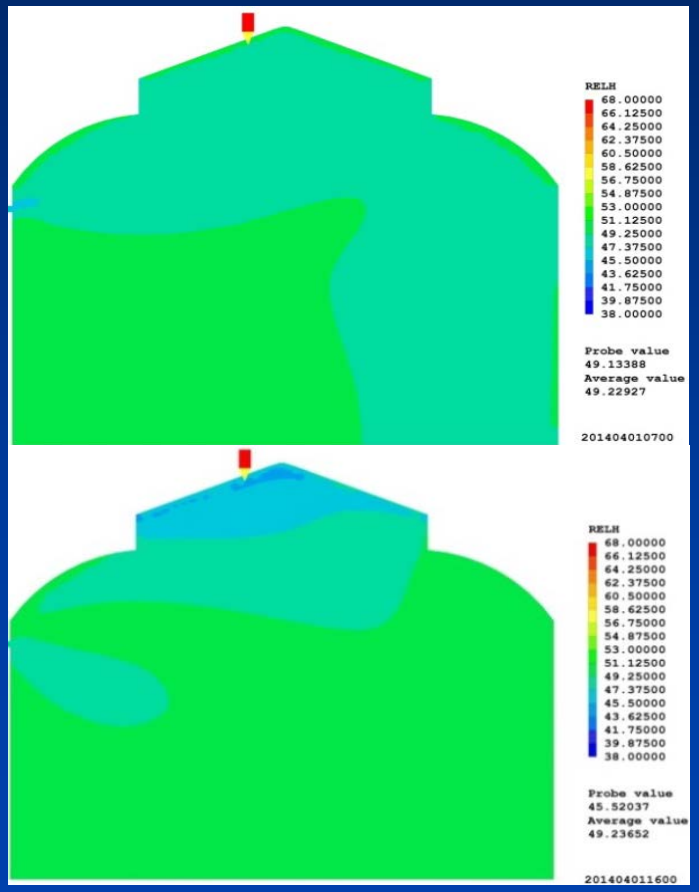
Mild seasons



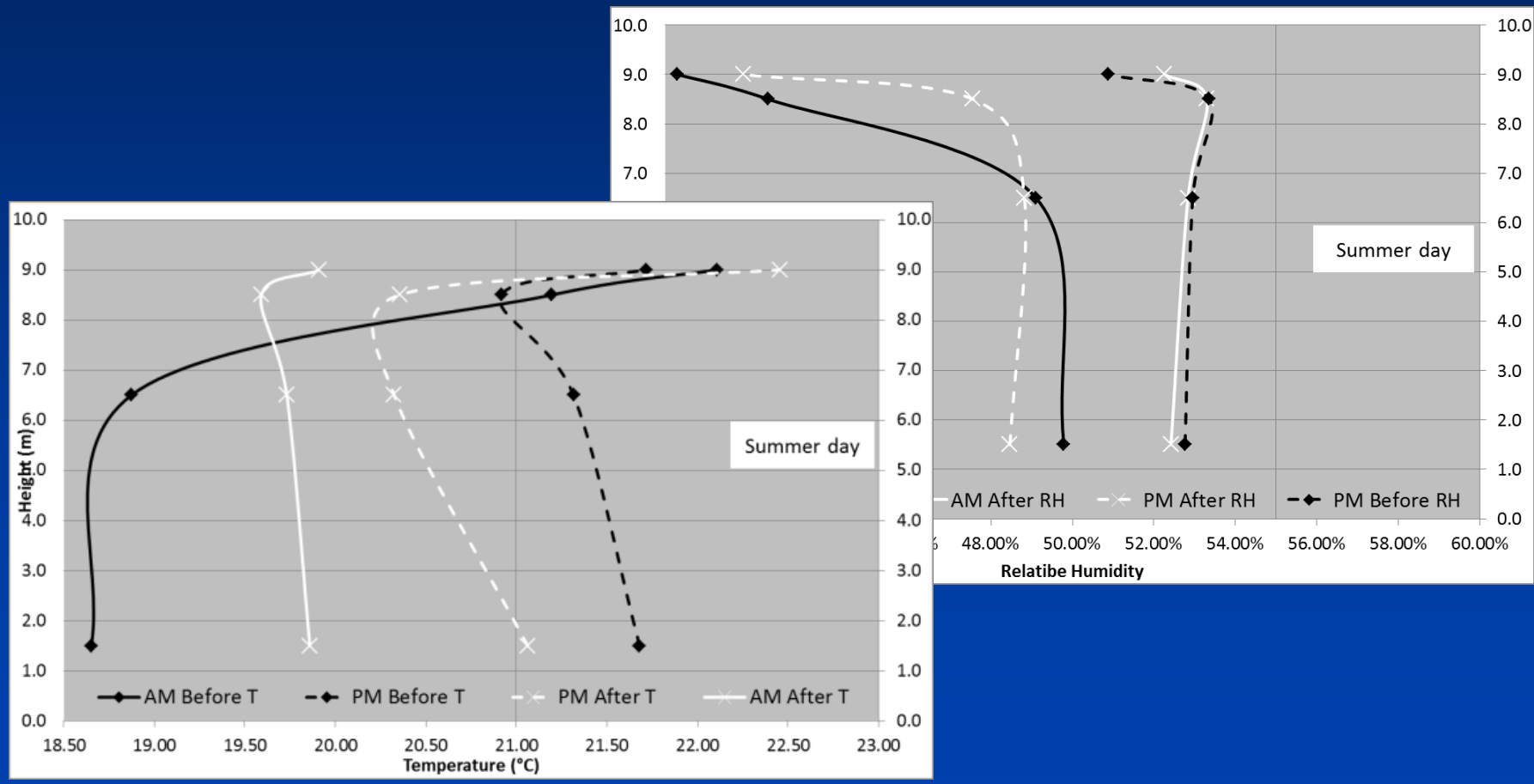


Mild seasons

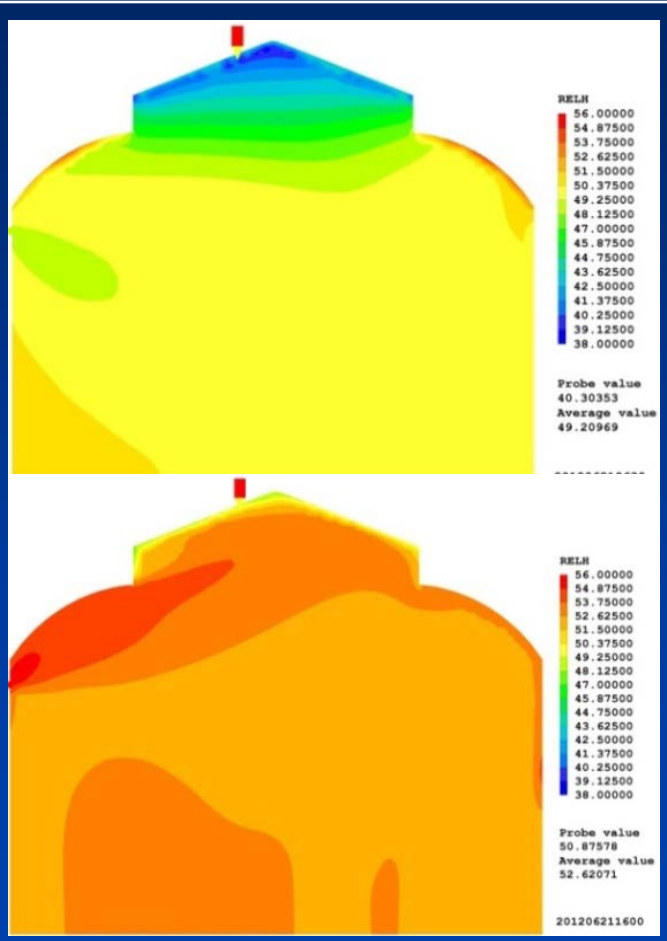




A Summer day


Summer day
AM After RH
PM After RH
PM Before RH
Relatibe Humidity
Summer day
AM Before T
PM Before T
PM After T
AM After T
Height (m)
Temperature (°C)

A Summer day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53.75000
52.62500
51.50000
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48.12500
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43.62500
42.50000
41.37500
40.25000
39.12500
38.00000
Probe value
40.30353
Average value
49.20969
RELH
56.00000
54.87500
53.75000
52.62500
51.50000
50.37500
49.25000
48.12500
47.00000
45.87500
44.75000
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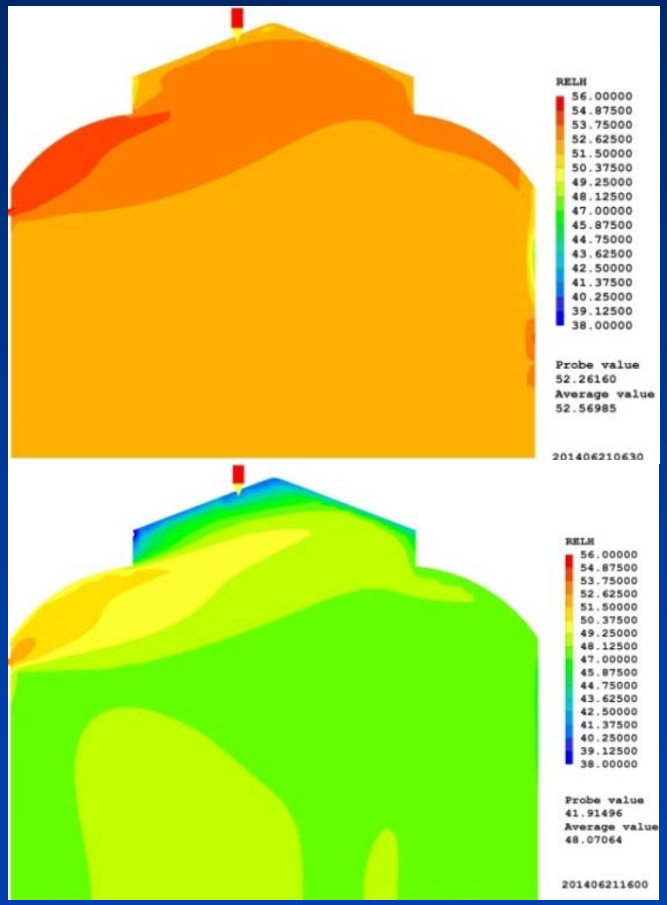
RELH
56.00000
54.87500
53.75000
52.62500
51.50000
50.37500
49.25000
48.12500
47.00000
45.87500
44.75000
43.62500
42.50000
41.37500
40.25000
39.12500
38.00000
Probe value
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Average value
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RELH
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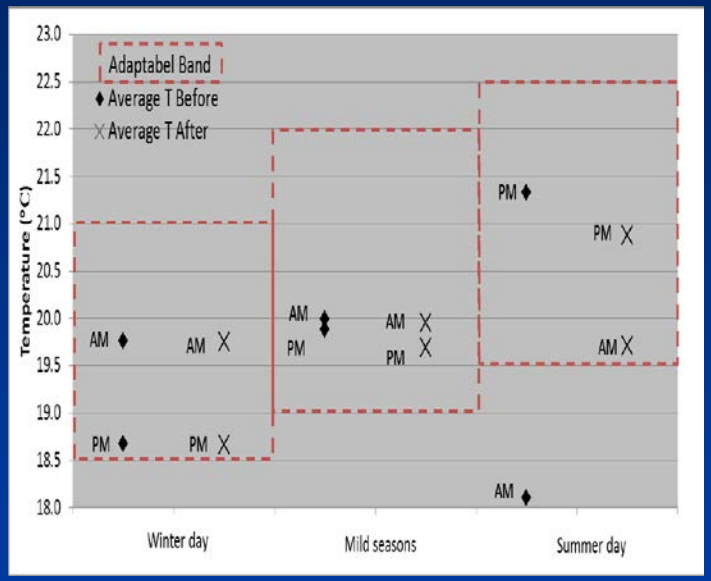
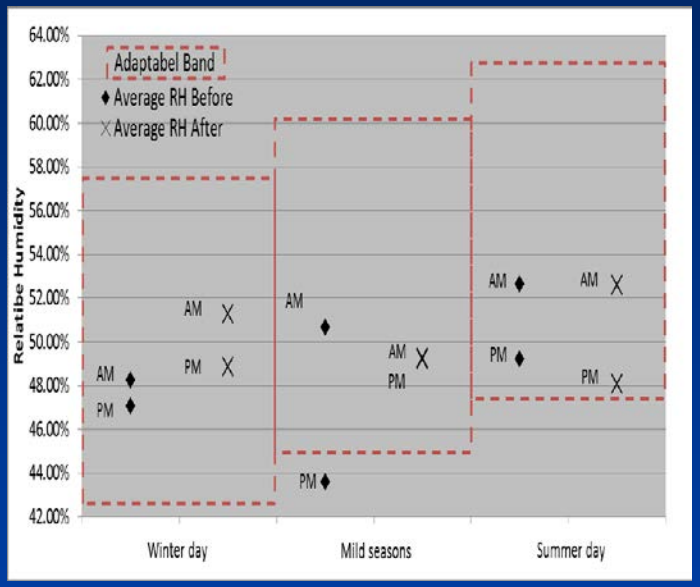
Environmental control



- *The temperature in morning and afternoon*



The relative humidity in morning & Afternoon

Conclusions

- The CFD model was robust and model results were reliable, the predictions of the 12 scenarios were also validate.
- The indoor environment was improved, as T & RH
  - daily fluctuation smaller
  - vertical spatial gradient smaller
- The low part of space, 5m above the floor, had been rather even all the time. Before the refurbishment, the evenness was not good in the mornings of mild seasons.
- Before refurbishment:
  - often extra humidification was needed as RH went out the control zone and,
  - extra heating was required when the temperature was too low.
- Further studies:
  - Energy saving calculation , adjusted with outdoor conditions
  - Effects of hygroscopic materials on energy consumption and environmental quality
  - Optimised control – use the thermal mass and moisture buffering capacity of the building fabric and interior deco materials.