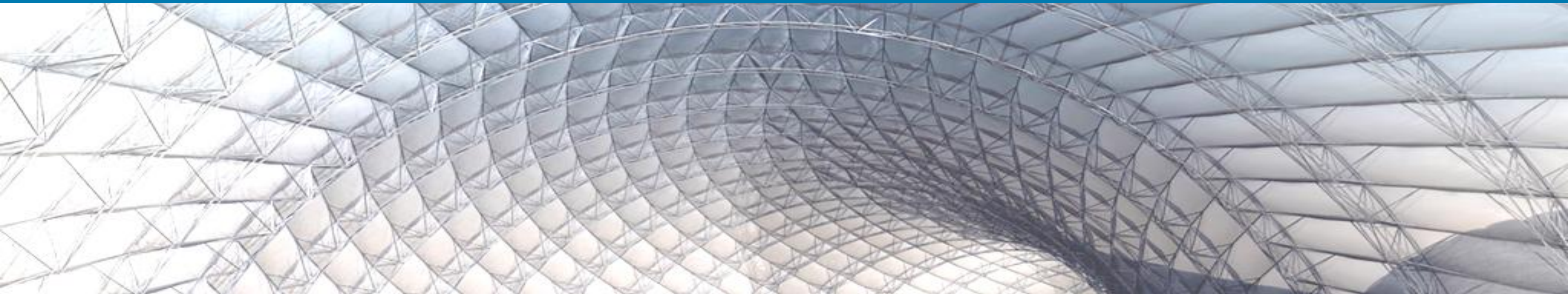
Integrating Active Thermal Mass Strategies in Responsive Buildings

David Warwick - CIBSE Building Simulation Group – 2nd June 2011

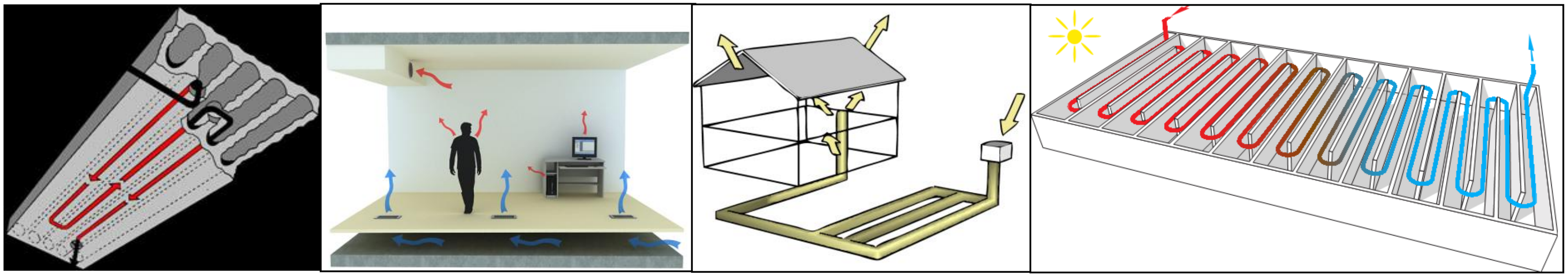
Buro Happold



Contents

Introduction

- Thermal mass reduces the need and dependence on mechanical heating & cooling systems
- Active methods enhance performance by passing air of fluid across or through materials with high thermal mass
- Uncertainty on how to integrate with other environmental systems in buildings
  - Simplified guidelines
  - Confidence in dynamic thermal modelling

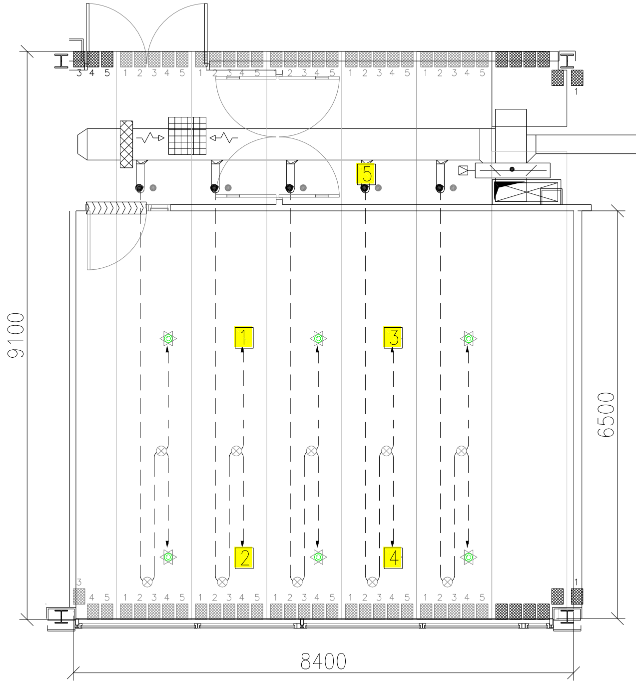


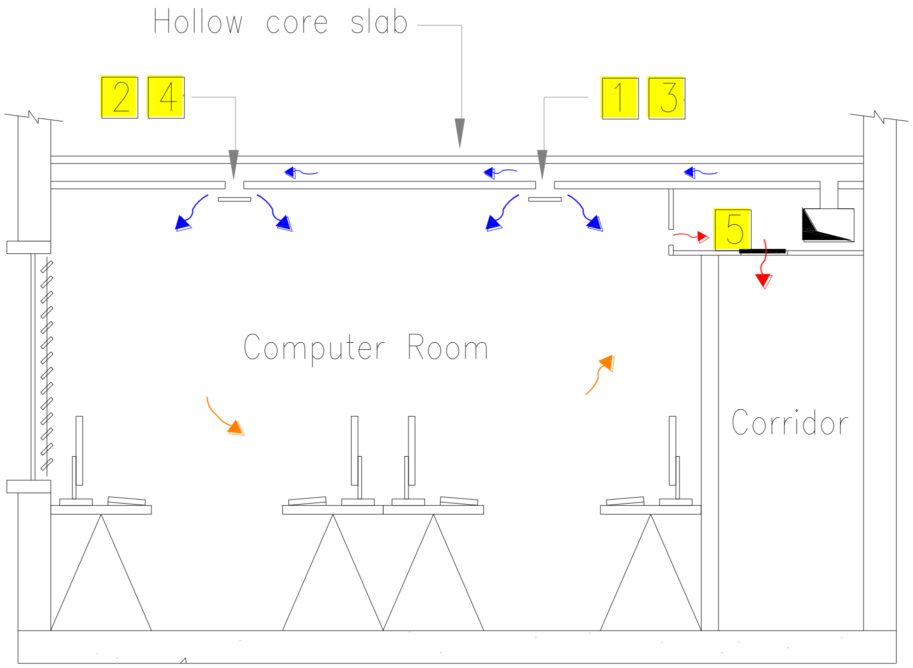
Building Monitoring

Three buildings, incorporating different active thermal mass strategies, were selected for monitoring:

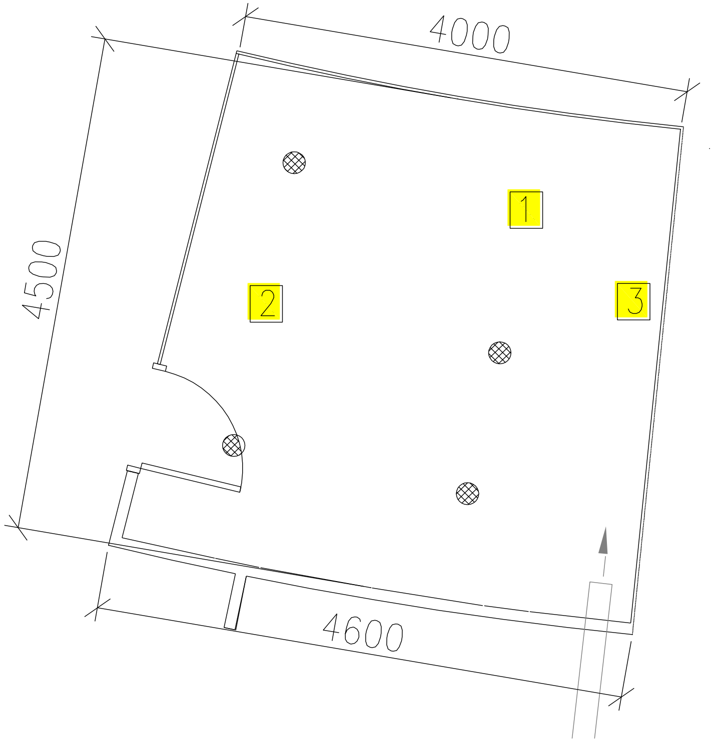
- Building 1: Booth's HQ
  - Floor Void with Mass (FVWM)
- Building 2: Longley Park
  - Hollow Core Slab (HCS)
- Building 3: The Lowry
  - Earth to Air Heat Exchanger (ETAHE)
  - Thermal Labyrinth (TL)

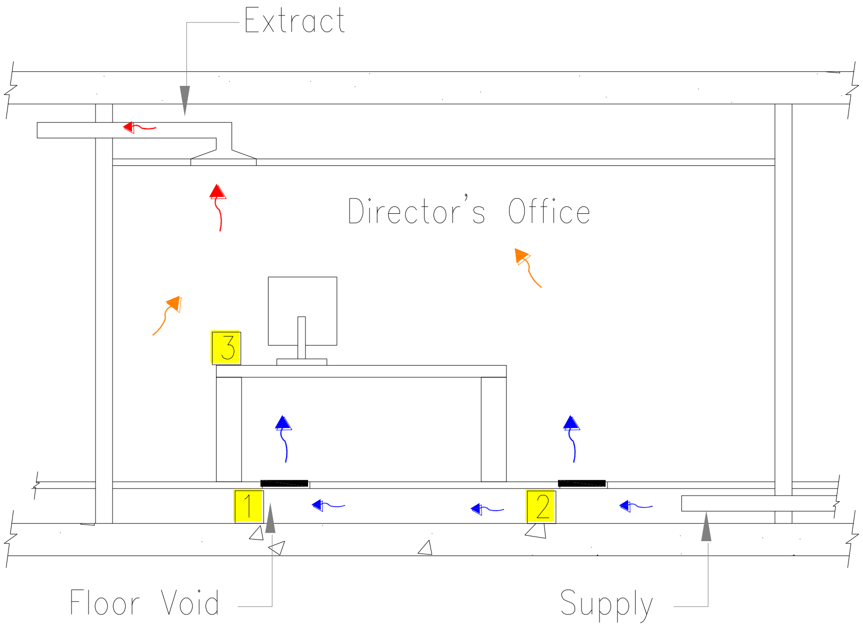
Building Monitoring – Longley Park (Hollow Core Slabs)



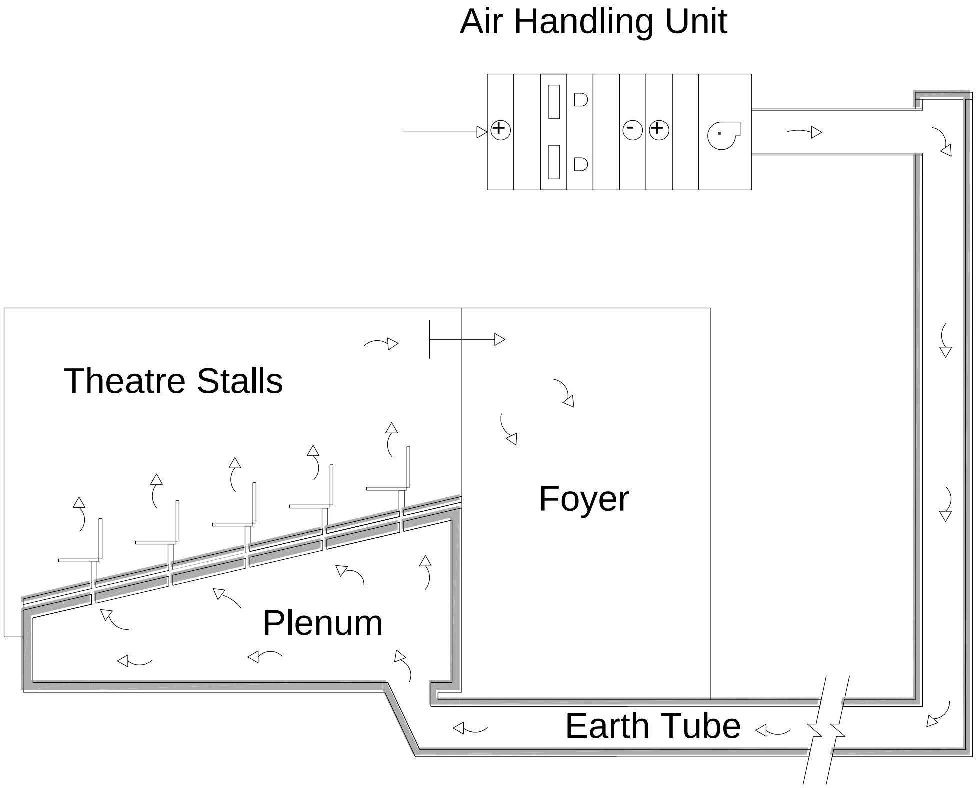


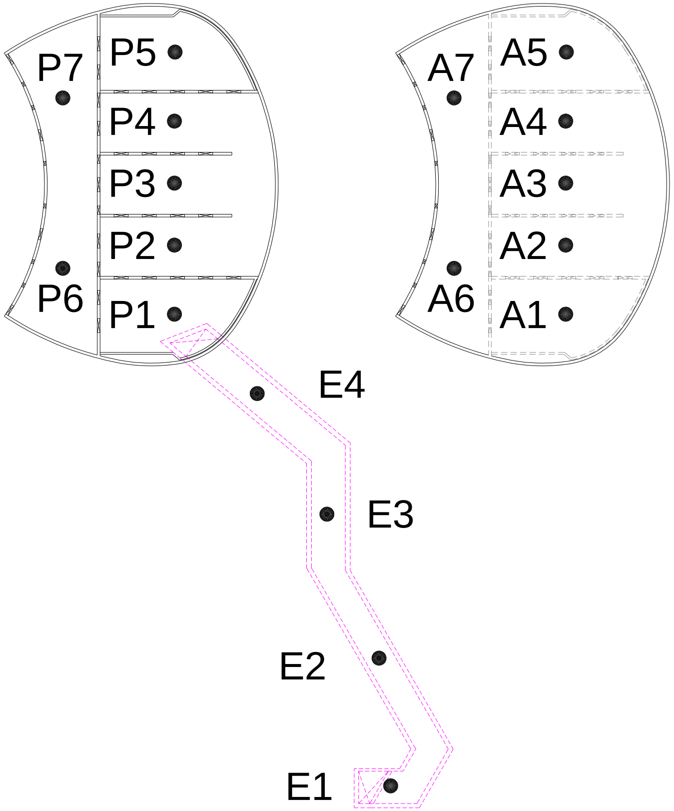
Building Monitoring – Booth's Headquarters (Floor Void with Mass)





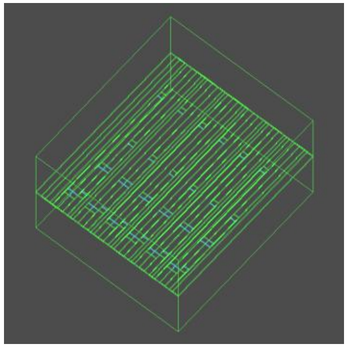
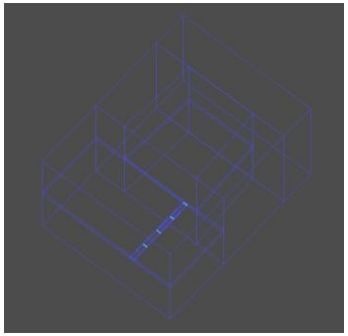
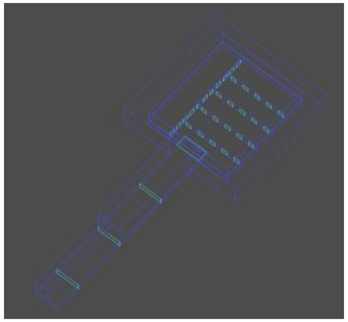
Building Monitoring – The Lowry (ETAHE & Thermal Labyrinth)





Building Simulation

- Models of each building were constructed within IES
- Simplifications for easiness of modelling were made; including changes in physical representation
- Performance of the thermal mass isolated using monitored data as input data into the simulation models
- Heat Transfer Coefficient calculated

Simulation – Heat Transfer Coefficient

- All of the active thermal mass systems described use air as the medium to activate the thermal mass

- To calculate the heat transfer coefficient for turbulent flow in circular and non-circular ducts the following correlation can then be used (CIBSE 2007):

$$h_c = \frac{Nu \cdot k}{d_e}$$

h_c	Heat Transfer Coefficient
Nu	Nusselt Number
k	thermal conductivity ($W.m^{-1}.K^{-1}$)
d_e	effective tube diameter (m)

- Flow in tubes is considered to be turbulent when the Reynolds Number (Re) > 3000 (CIBSE 2007)
- When the flow isn't turbulent the CIBSE variable heat transfer coefficients (CIBSE, 2007) can be used

Simulation - Heat Transfer Coefficient

- However, as Barnard (1994) discussed this relationship is based on the surface roughness of the air path being smooth.
- The Reynolds-Colburn analogy (Holman, 1990) relates heat transfer and fluid friction and leads to an expression in terms of the Stanton Number (St):

$$St.\cdot \mathrm{Pr}^{2/3} = f/2$$

where

$$St = \frac{h_c}{\rho \cdot u \cdot c_p}$$

therefore

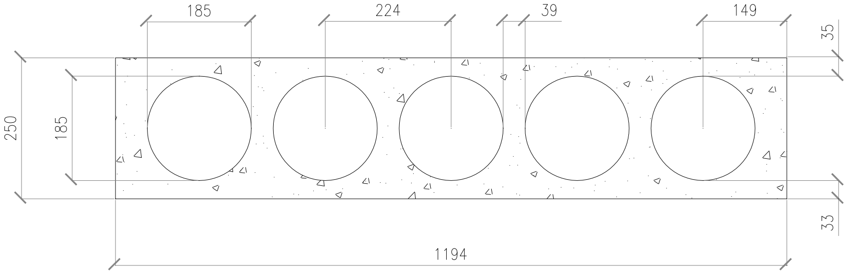
$$h_c = \frac{p \cdot u \cdot c_p \cdot f}{2\,\mathrm{Pr}^{2/3}}$$

– h_c	Heat Transfer Coefficient
– p	air density ($kg.m^{-3}$)
– u	air velocity ($m.s^{-1}$)
– cp	specific heat capacity ($J.kg^{-1}.K^{-1}$)
– f	friction coefficient
– Pr	Prandtl Number

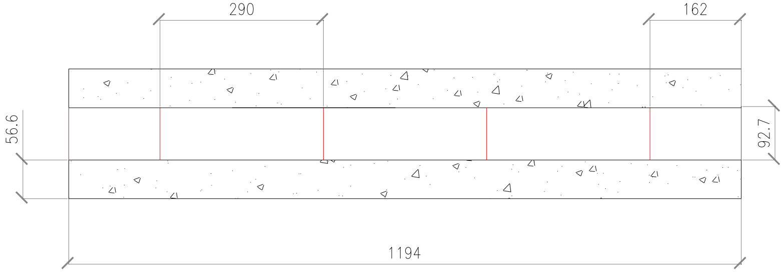
Simulation – Hollow Core Slab

- The slab cores have been simplified as two parallel plates with air passing between then, one in contact with the room above and one in contact with the room below
- The internal surface area of the concrete in the cores remains the same
- The volume of concrete remains the same
- The cross sectional area remains the same
- Heat Transfer Coefficient calculated

- Input data:
  - Air Temperature entering the slab
  - Room temperatures above and below
  - Fan running times



cross section of actual hollow core slab



cross section of simplified slab modelled

Simulation – Floor Void with Mass

- The floor void was added into the model with the same geometry as the actual building
- 200mm Floor Void with suspended floor above and concrete slab below
- Due to the low air flow rate into the floor void the turbulence in the floor void is low, therefore the CIBSE variable heat transfer coefficients (CIBSE, 2007) have been used for the surfaces in the floor void

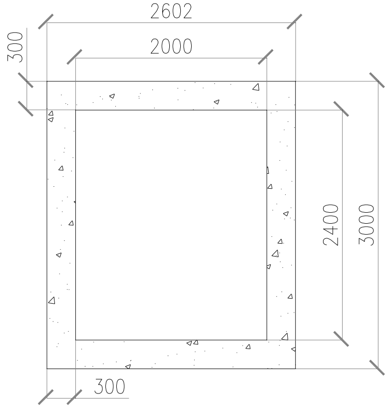
- Input data:
  - Ambient Air Temperature
  - Room temperatures above and below
  - Fan running times

Simulation - ETAHE

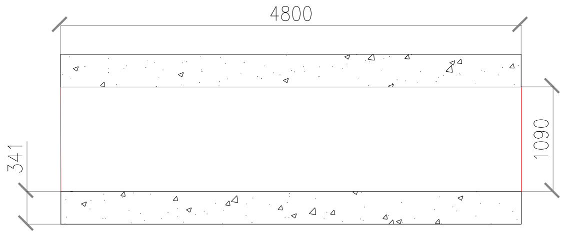
- The ETAHE has been simplified as two parallel plates with air passing between then, one in contact with the ambient air temperature/room above and one in contact with the undisturbed ground temperature
- Carslaw & Jaeger (1959) equation used to calculate undisturbed ground temperature

$$T(z,t) = T_m - A_s \exp\left[-z(\pi/365\alpha)^{1/2}\right]\cos\left\{2\pi/365\left[t - t_0 - z/2(365/\pi\alpha)^{1/2}\right]\right\}$$

- This depth of soil has also been included within the model
- Again the internal surface area of the concrete, the volume of concrete and the cross sectional area remain the same
- Heat Transfer Coefficient Calculated using
- Input Data:
  - Air Temperature entering ETAHE
  - Ambient Air Temperature
  - Temperature in Foyer
  - Undisturbed Ground Temperature



cross section of actual ETAHE



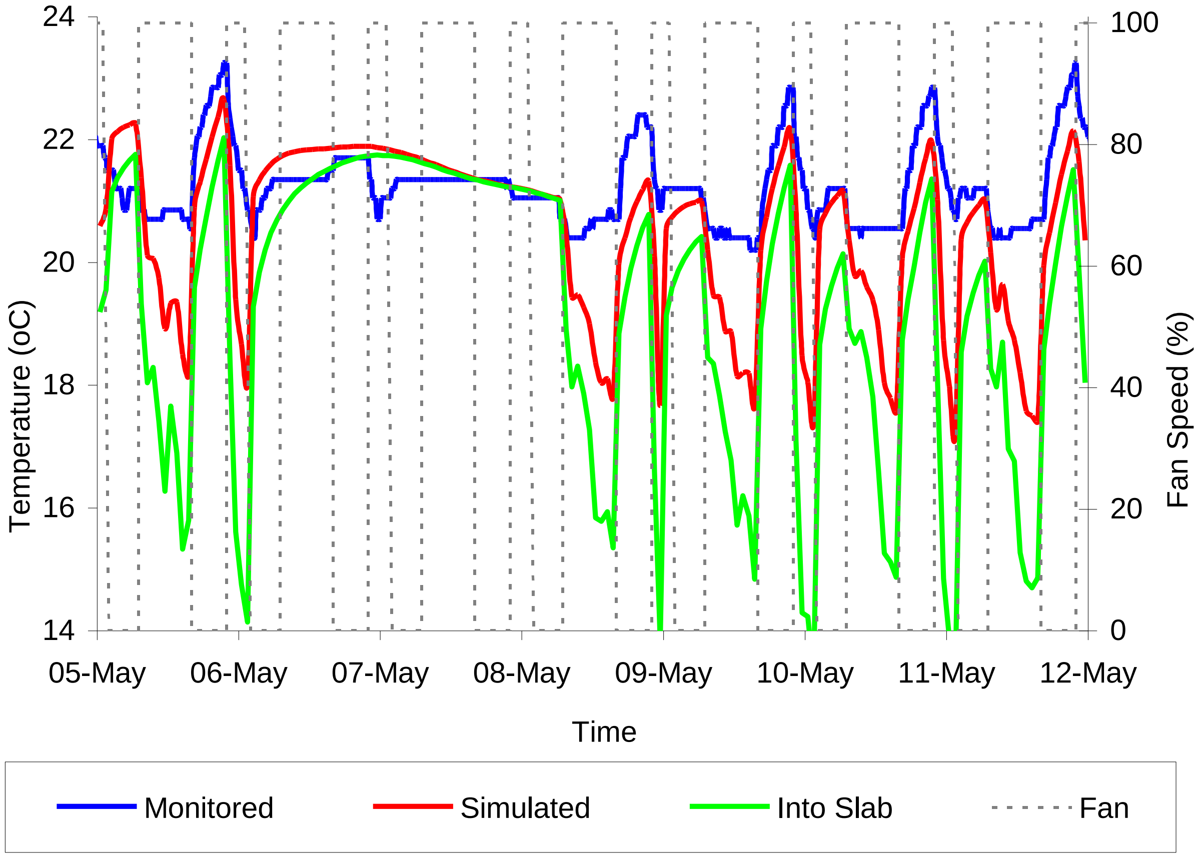
cross section of simplified ETAHE modelled

Simulation – Thermal Labyrinth

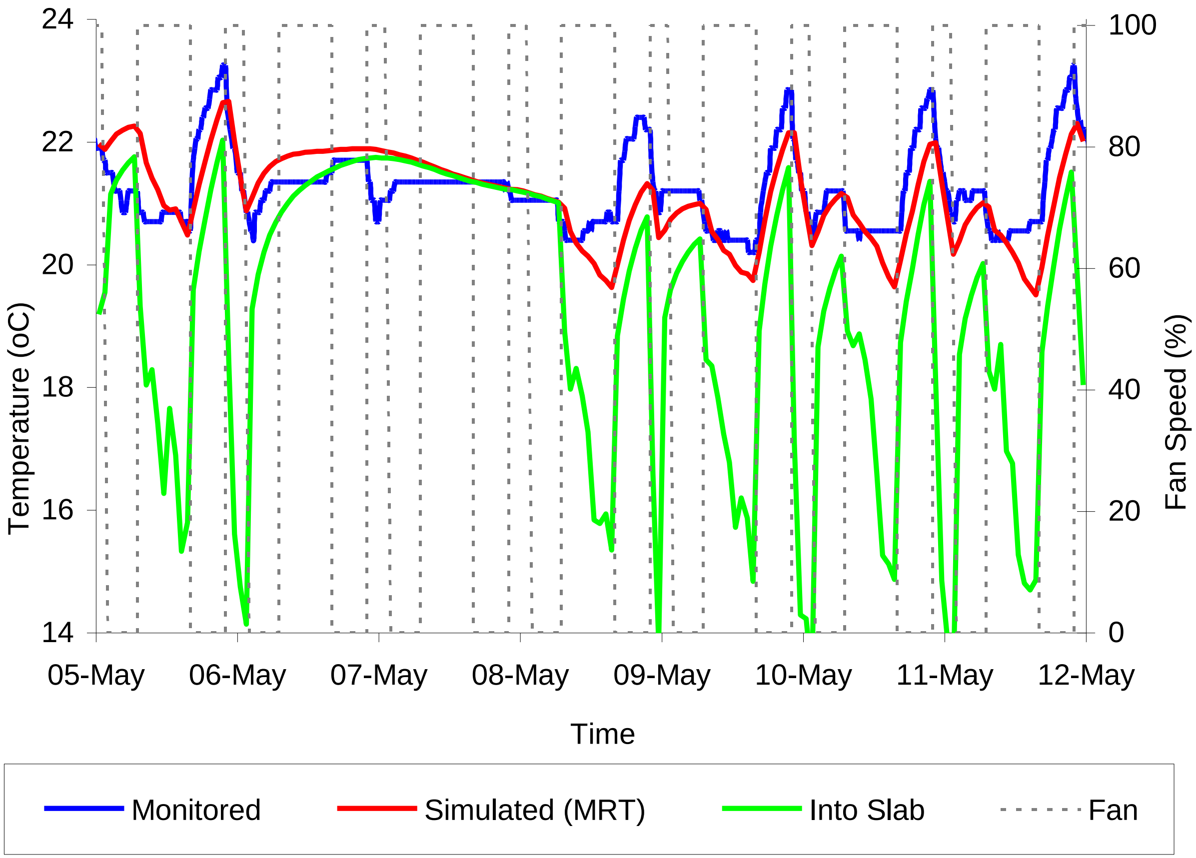
- The theatre plenum has a floor area of 291.3m^2 and an internal volume of 410.154m^3
- The geometry of the plenum is complex as it is formed beneath the raked theatre stalls
- To represent the amount of mass that the plenum has, in the model a rectangular room (16m wide x 18m long x 1.425m high) with the same surface area and air volume has been constructed
- The internal sleeper walls have also been included within the model

- Input Data:
  - Air Temperature in Foyer
  - Undisturbed Ground Temperature
  - Air Temperature in the air space above plenum

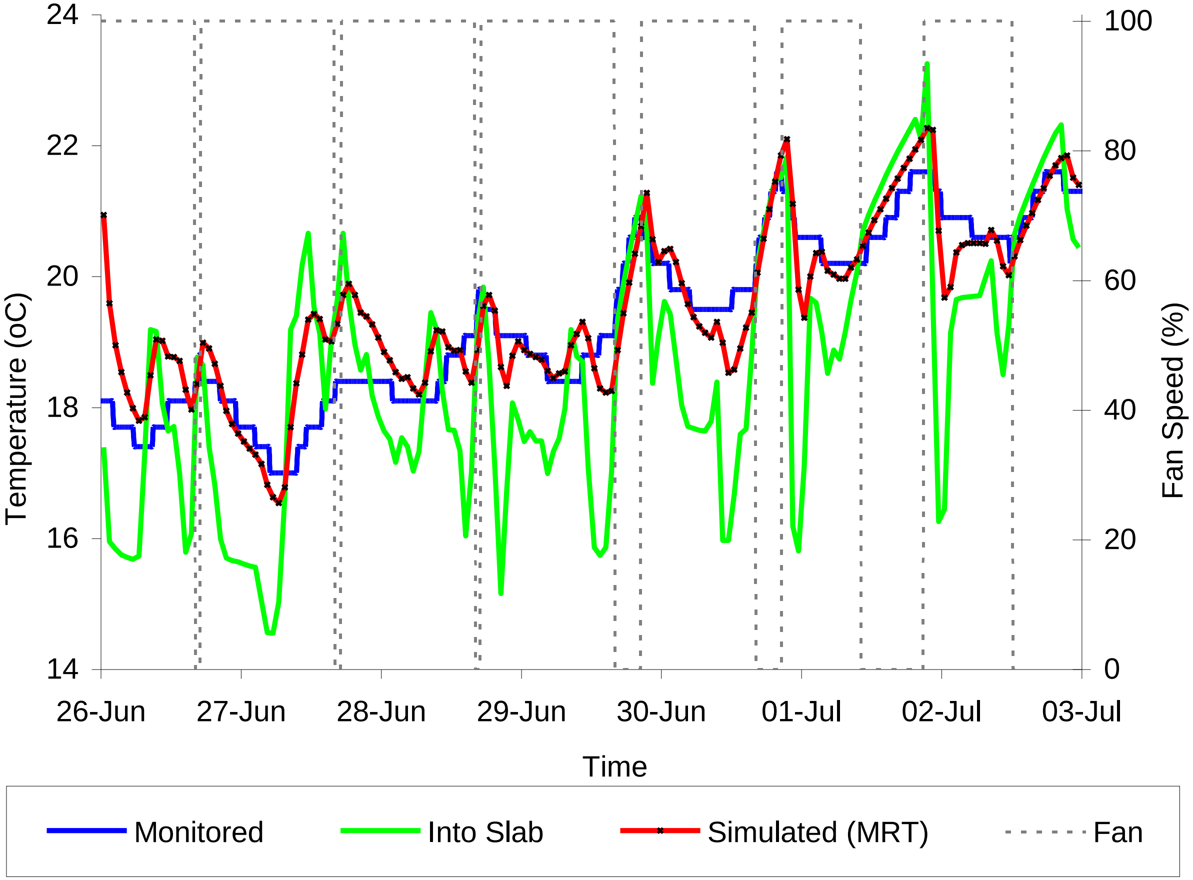
Comparison of Monitored & Simulated Data – Longley Park (Mid Season)



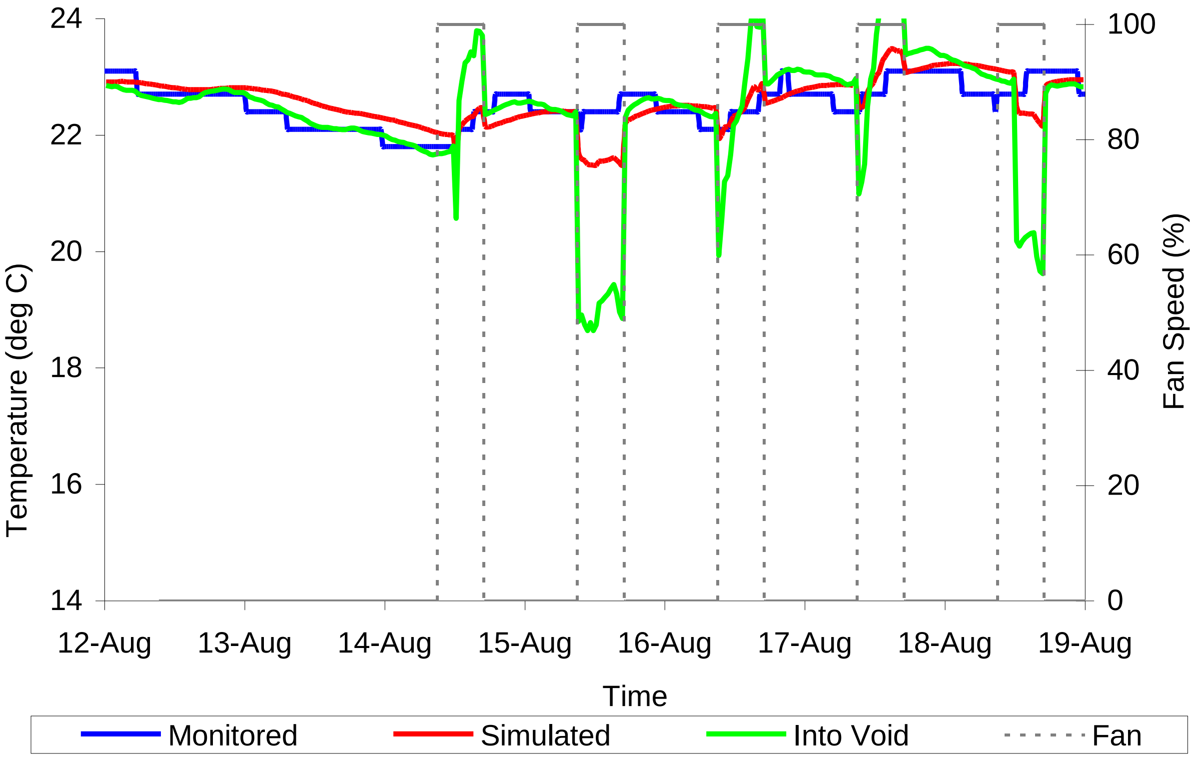
Comparison of Monitored & Simulated Data – Longley Park (Mid Season)



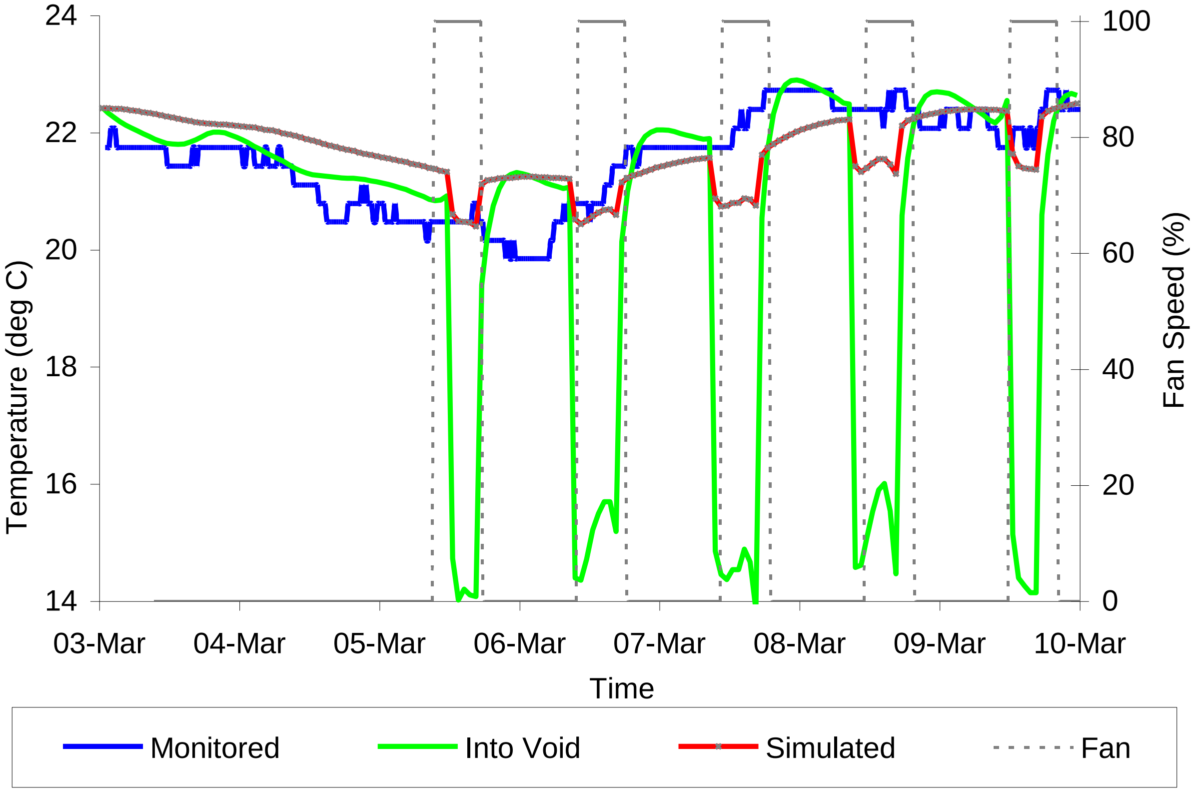
Comparison of Monitored & Simulated Data – Longley Park (Summer)



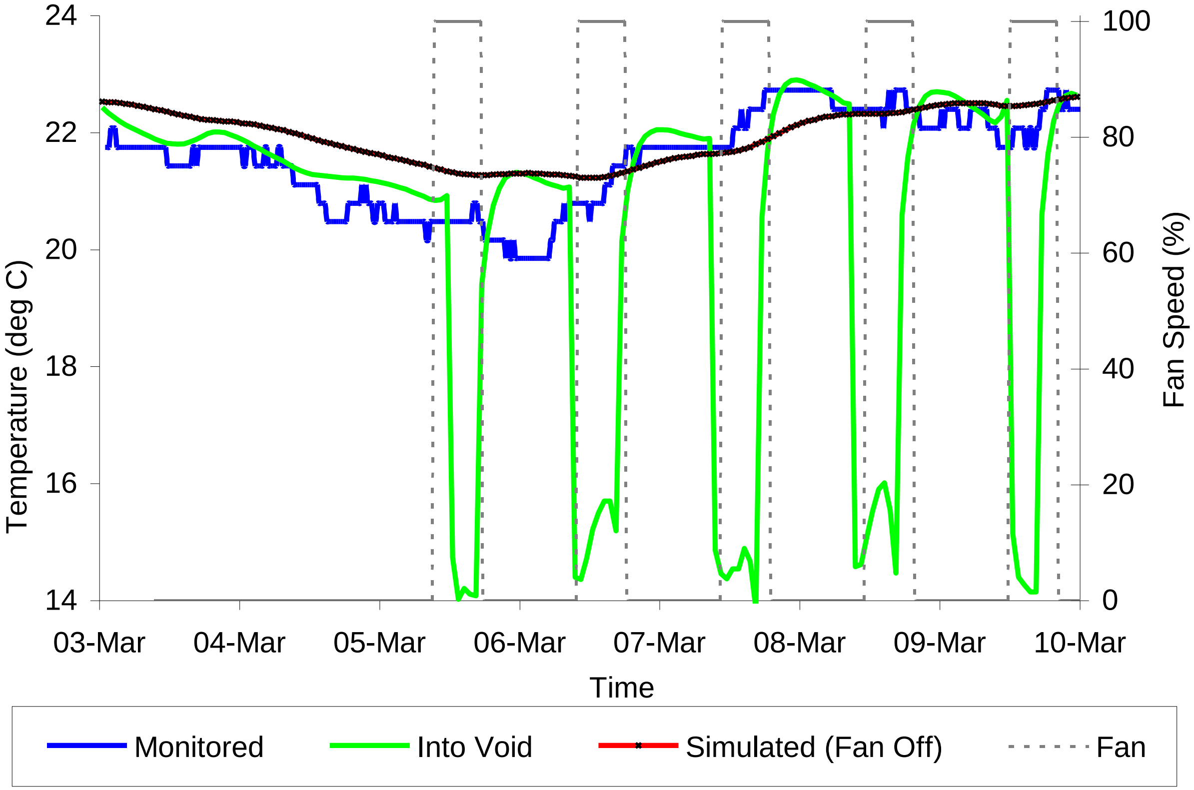
Comparison of Monitored & Simulated Data – Booth's Headquarters (Summer)



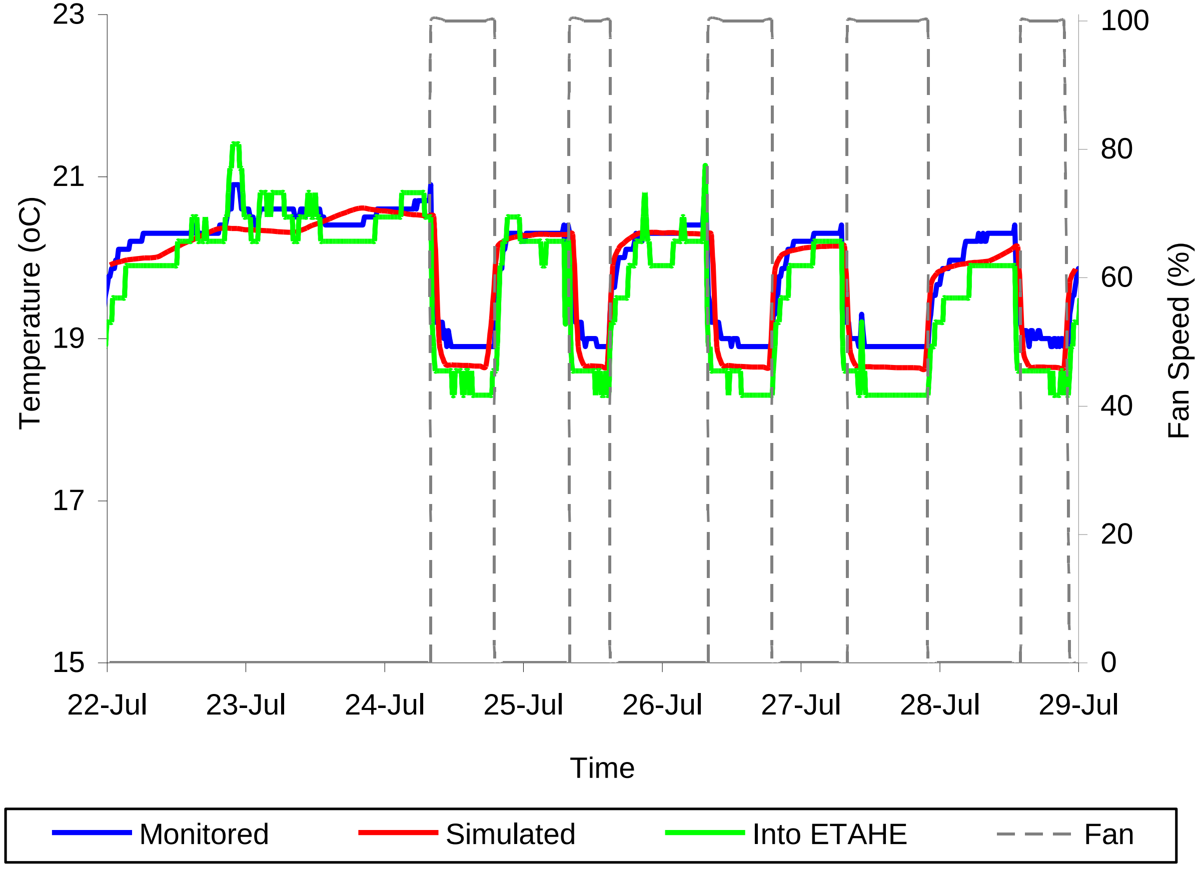
Comparison of Monitored & Simulated Data – Booth’s Headquarters (Winter)



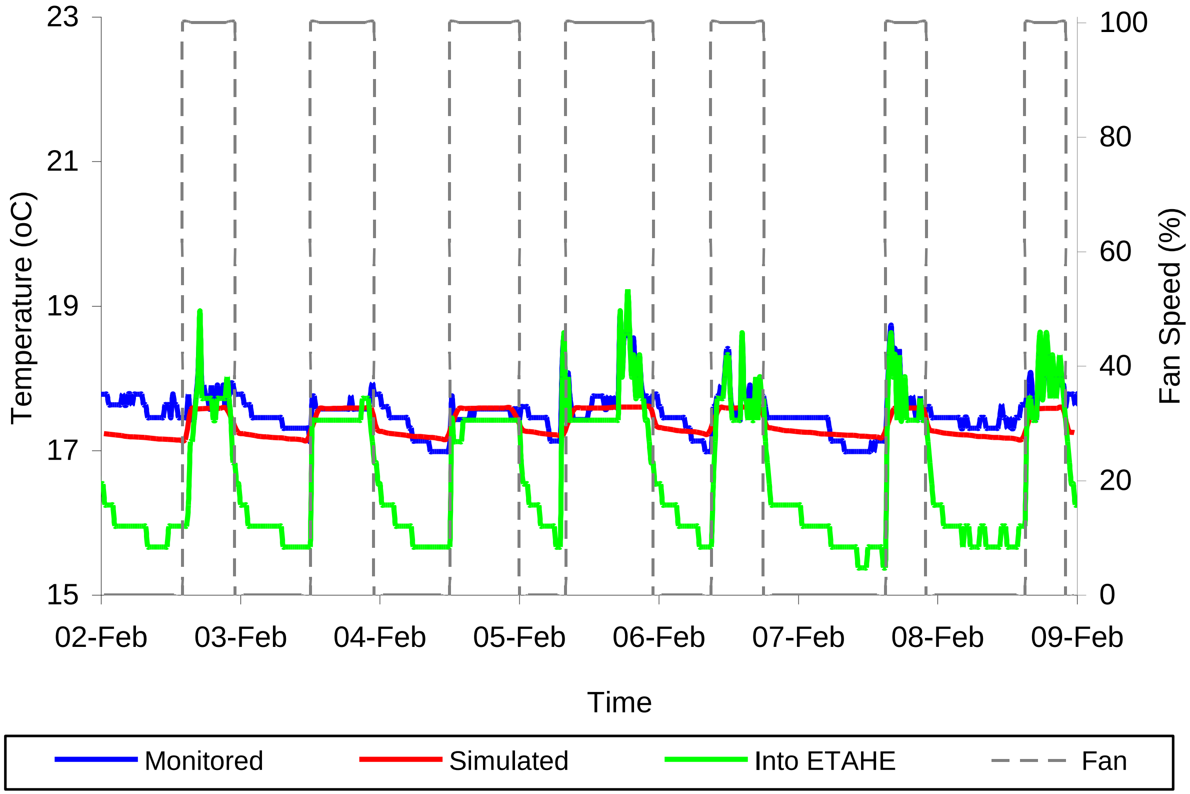
Comparison of Monitored & Simulated Data – Booth's Headquarters (Winter)



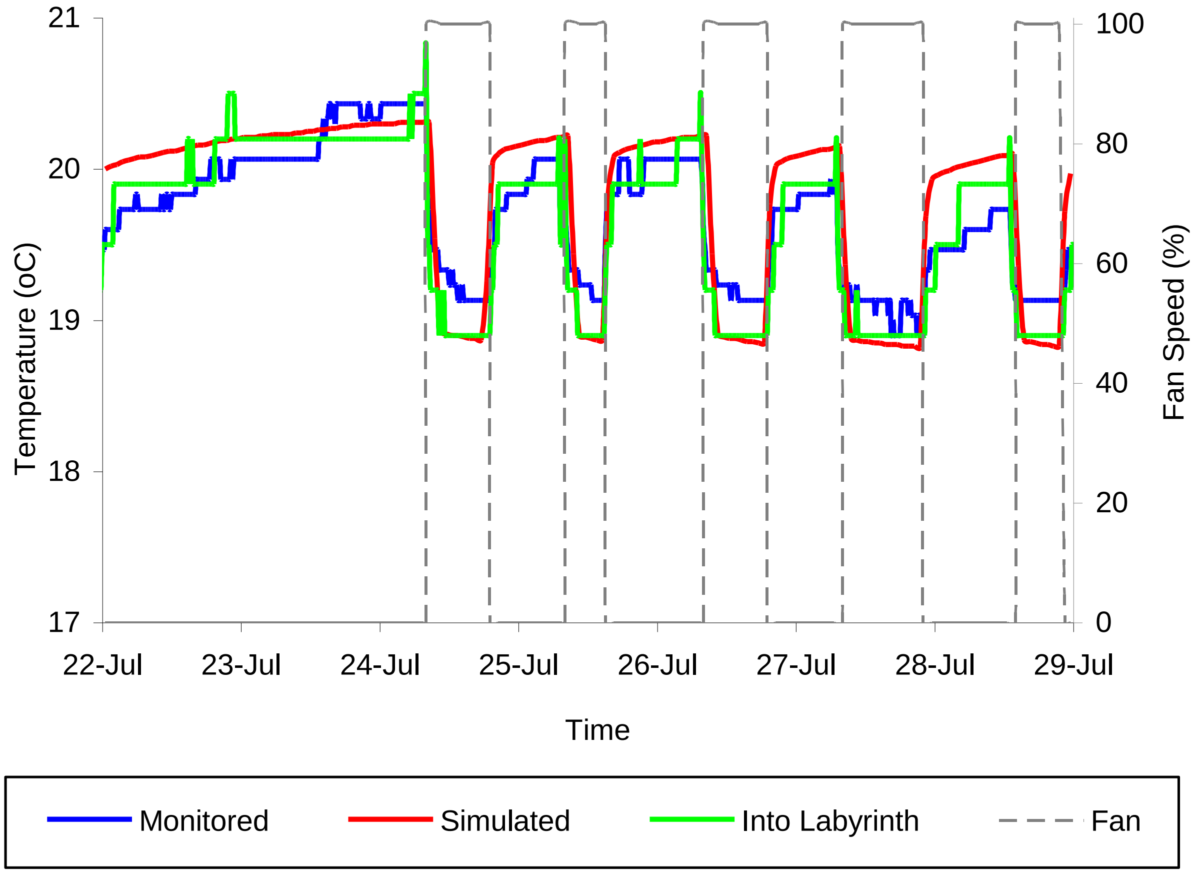
Comparison of Monitored & Simulated Data – The Lowry ETAHE (Summer)



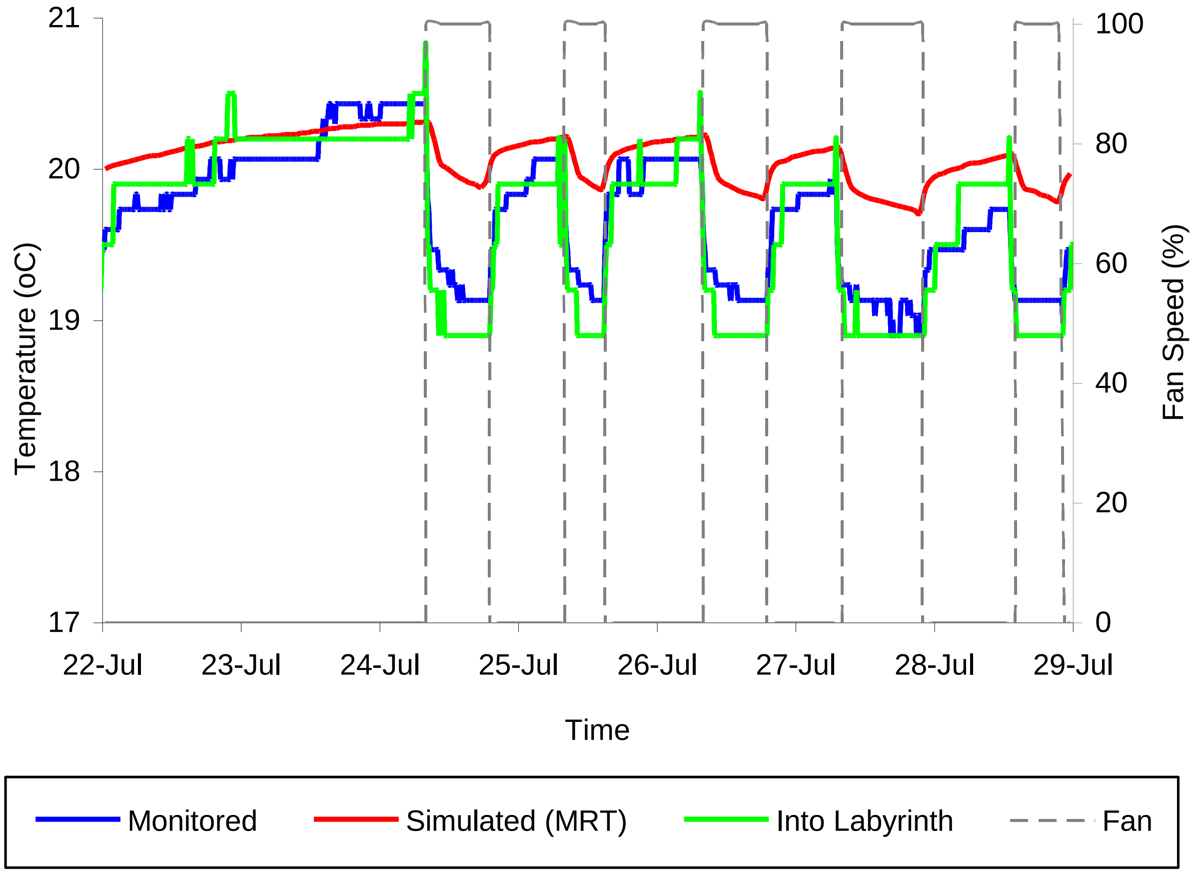
Comparison of Monitored & Simulated Data – The Lowry ETAHE (Winter)



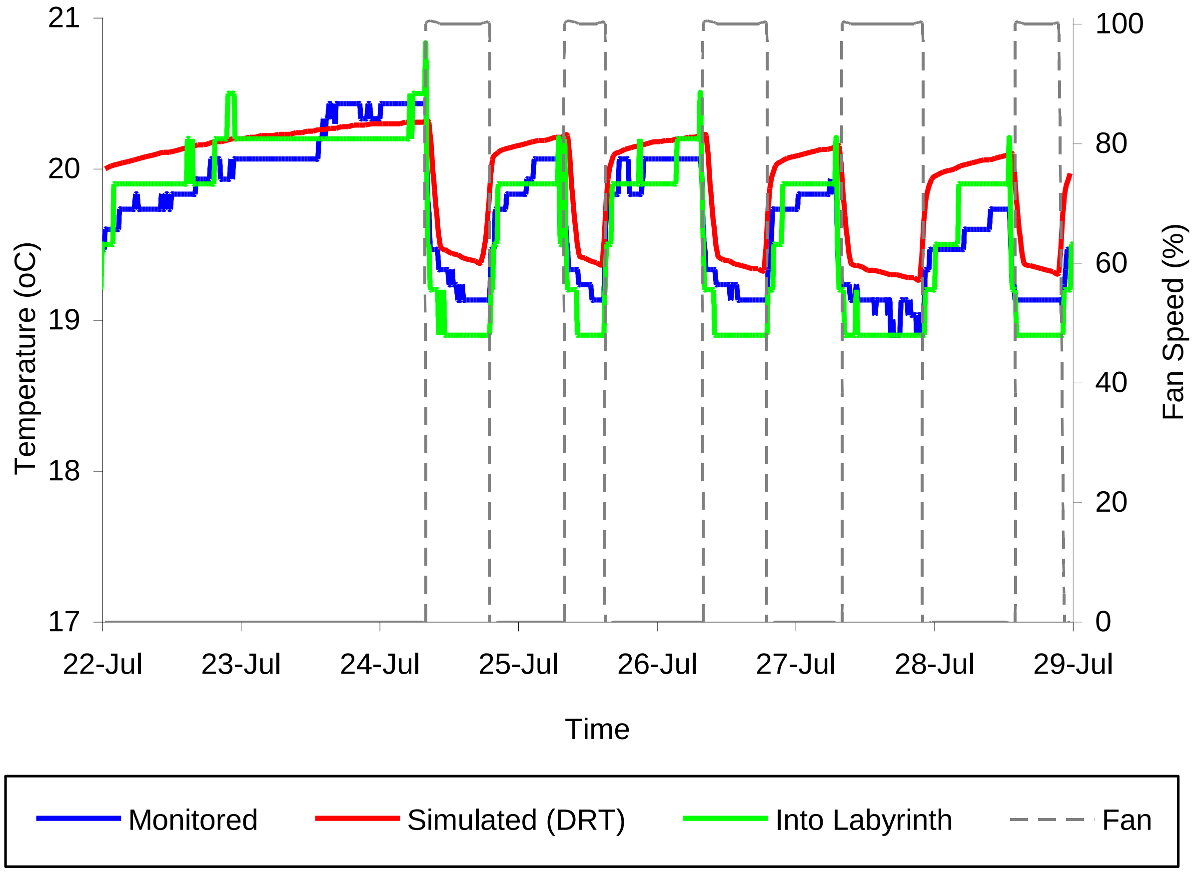
Comparison of Monitored & Simulated Data – The Lowry Labyrinth (Summer)



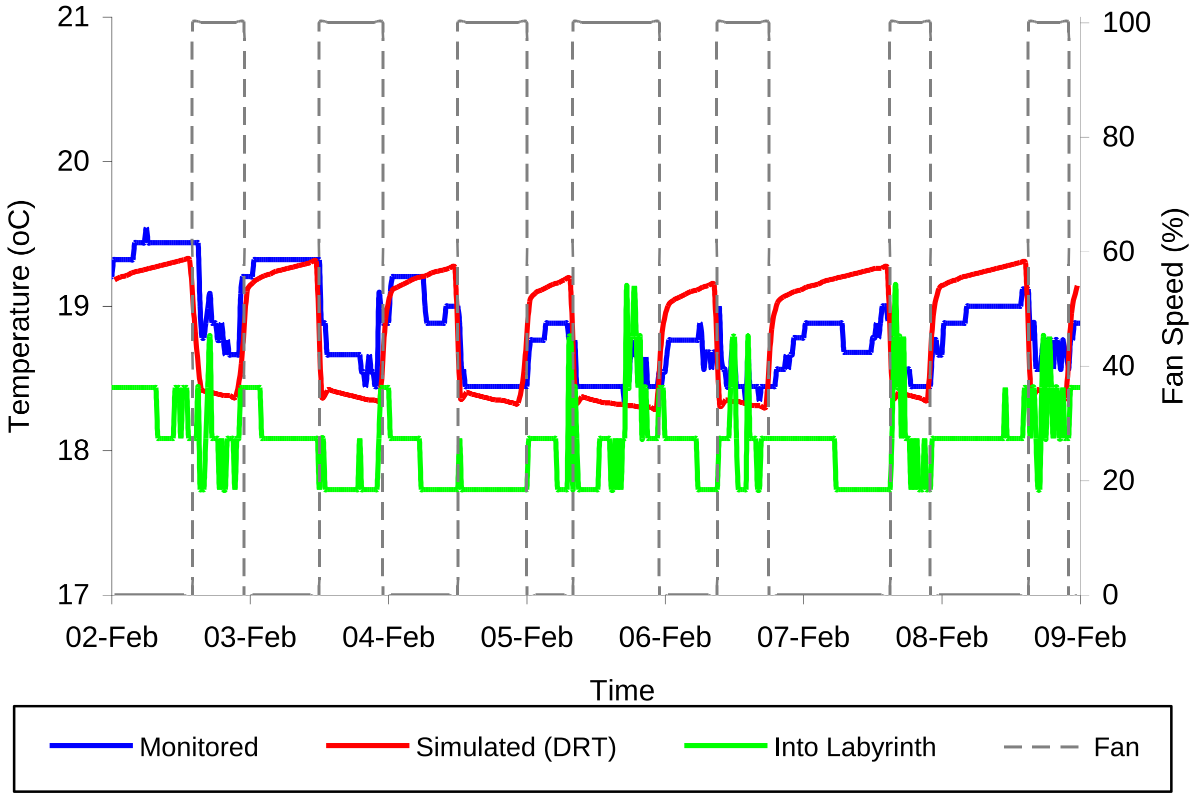
Comparison of Monitored & Simulated Data – The Lowry Labyrinth (Summer)



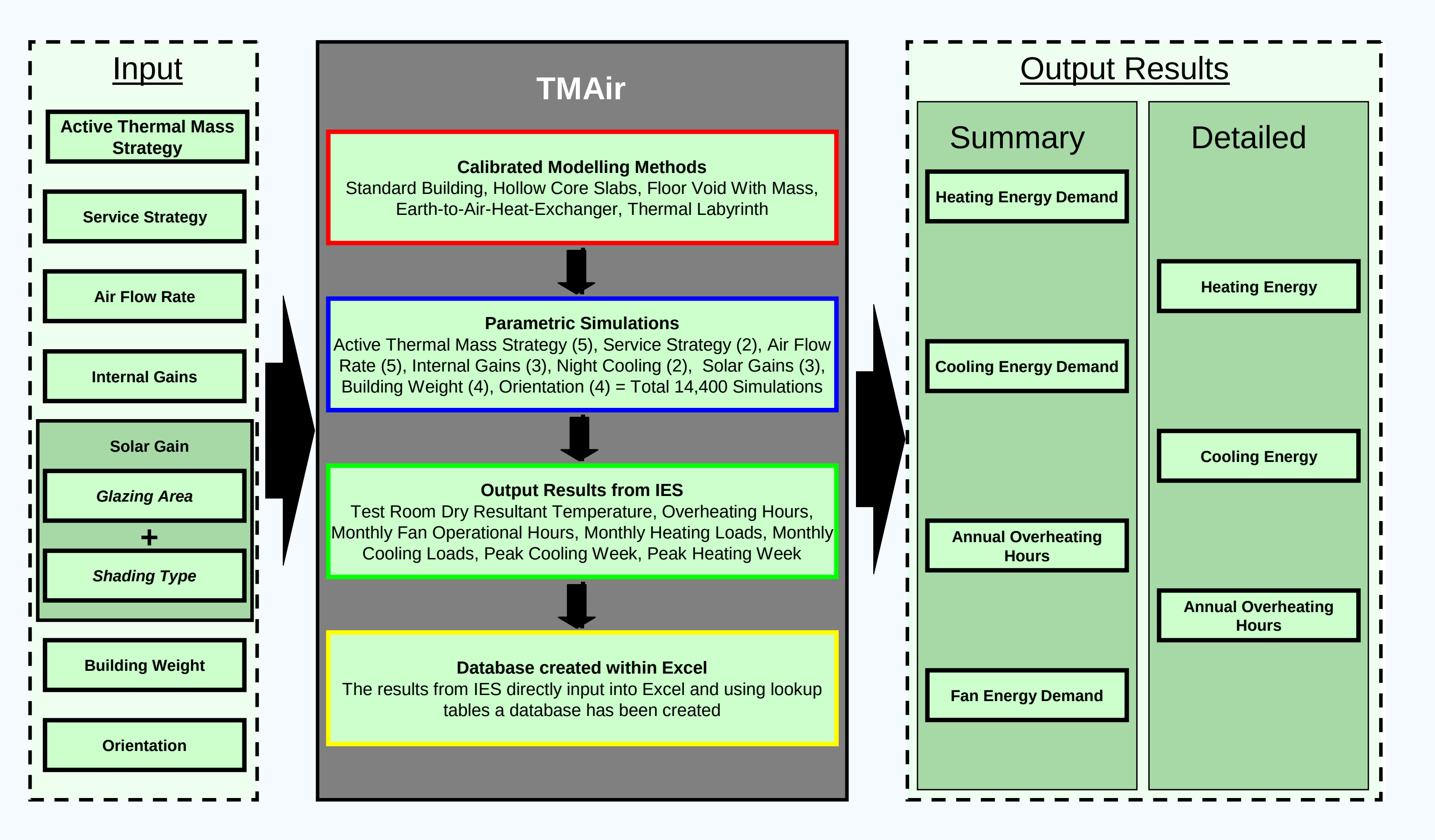
Comparison of Monitored & Simulated Data – The Lowry Labyrinth (Summer)



Comparison of Monitored & Simulated Data – The Lowry Labyrinth (Winter)



Development of a Concept Design Tool



Input

- **Active Thermal Mass Strategy**
- **Service Strategy**
- **Air Flow Rate**
- **Internal Gains**
- **Solar Gain**
  - ***Glazing Area***
  - +
  - ***Shading Type***
- **Building Weight**
- **Orientation**

TMAir

Calibrated Modelling Methods
Standard Building, Hollow Core Slabs, Floor Void With Mass, Earth-to-Air-Heat-Exchanger, Thermal Labyrinth

Parametric Simulations
Active Thermal Mass Strategy (5), Service Strategy (2), Air Flow Rate (5), Internal Gains (3), Night Cooling (2), Solar Gains (3), Building Weight (4), Orientation (4) = Total 14,400 Simulations

Output Results from IES
Test Room Dry Resultant Temperature, Overheating Hours, Monthly Fan Operational Hours, Monthly Heating Loads, Monthly Cooling Loads, Peak Cooling Week, Peak Heating Week

Database created within Excel
The results from IES directly input into Excel and using lookup tables a database has been created

Output Results

Summary

- **Heating Energy Demand**
- **Cooling Energy Demand**
- **Annual Overheating Hours**
- **Fan Energy Demand**

Detailed

- **Heating Energy**
- **Cooling Energy**
- **Annual Overheating Hours**