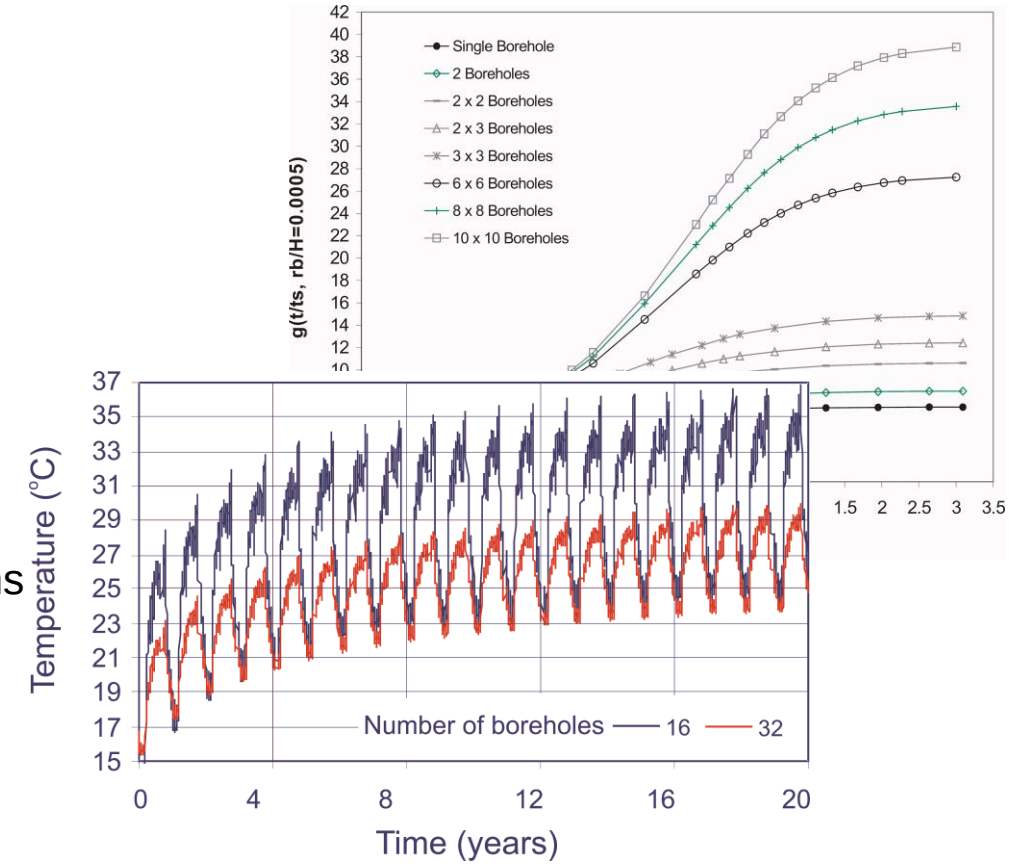
CIBSE Application Manual AM11 'Building Performance Modelling'

Chapter 8: Modelling of plant and renewable energy systems

Scope and content of chapter 8…

- Theme 1 – modelling methods for plant and controls
  - Review of established methods
  - Using simplified control functions
  - Steady-state equipment modelling
  - Dynamic plant and controls modelling
- Theme 2 – embedded renewable energy systems
  - Photovoltaic systems
  - Solar thermal
  - Urban wind
  - Ground source heat pumps



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Chapter 8: Modelling of plant and renewable energy systems

Emphasis of chapter 8…

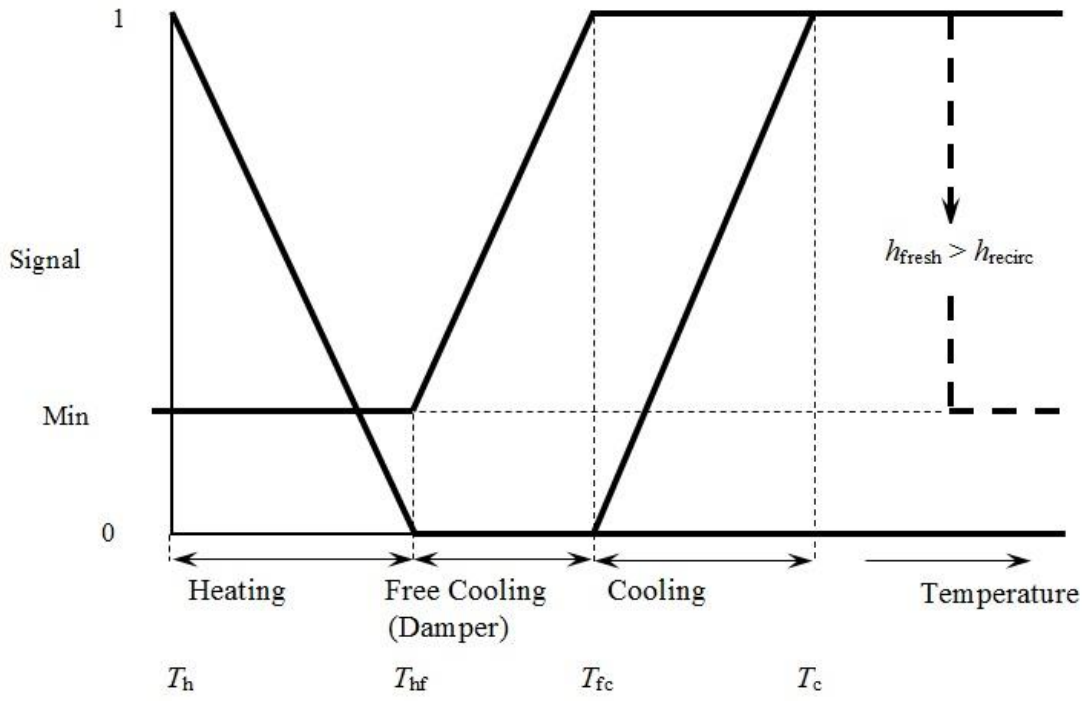
- Plant, controls and renewable systems often the 'Cinderella' part of BPS programs
- At the very least they seldom present with any degree of rigour and detail
- Our philosophy was to present details of modelling methods backed up with examples to help would-be modellers to develop their own tools
- Users of this chapter can therefore have a go at developing their own algorithms to deal with bespoke equipment modelling problems

Table 8.1 Examples of computer programs with extended plant and controls modelling capabilities

Name	Developer/vendor	Environment	Plant modelling features
APACHE	IES, UK	Part of a standalone program	Control laws and simple steady state components
BECON	Hong Kong Polytechnic University & Cardiff University	Plugin to HTB2	'Catalogue fit' and steady state plant model library
CARNOT	Solar Institute, Juelich, Germany	Matlab-Simulink blockset	Dynamic state and stead state components
DesignBuilder	DesignBuilder Software Ltd, UK	Frontend to EnergyPlus	Limited access to EnergyPlus components.
DOE-2	Lawrence Berkeley National Laboratory, USA	Standalone program	Steady state components

Theme 1 – simplified modelling using control functions

- The plant is not modelled – energy and ventilation flows are modelled using band-limited deviations from set points
- Seasonal energy prediction; outline control strategies; summertime overheating with free cooling
- Example across – the classical 3-channel control sequence



Theme 1 (continued) – modelling using steady-state plant components

- Describes how plant components can be modelled in the steady-state due to fast response compared with building envelope
- Examples include heat exchanger effectiveness method and 'catalogue-fitted' models of fans, chiller and heat pumps
- Examples of calculation algorithms in the form of pseudo code are given

Box 8.1: Pseudo code for simple explicit heat exchanger model

Inputs: m_h, m_c, c_h, c_c, AU, T_{hi}, T_{ci}

$C_h = m_h * c_h$

$C_c = m_c * c_c$

$C = \min(C_h, C_c) / \max(C_h, C_c)$

$NTU = AU / \min(C_h, C_c)$

$E = (1 - \exp(-NTU * (1 - C))) / (1 - C * \exp(-NTU * (1 - C)))$

IF $C_h < C_c$ THEN:

$T_{ho} = T_{hi} - E * (T_{hi} - T_{ci})$

$q = C_h * (T_{hi} - T_{ho})$

$T_{co} = T_{ci} + Q / C_c$

ELSE:

$T_{co} = T_{ci} - E * (T_{hi} - T_{ci})$

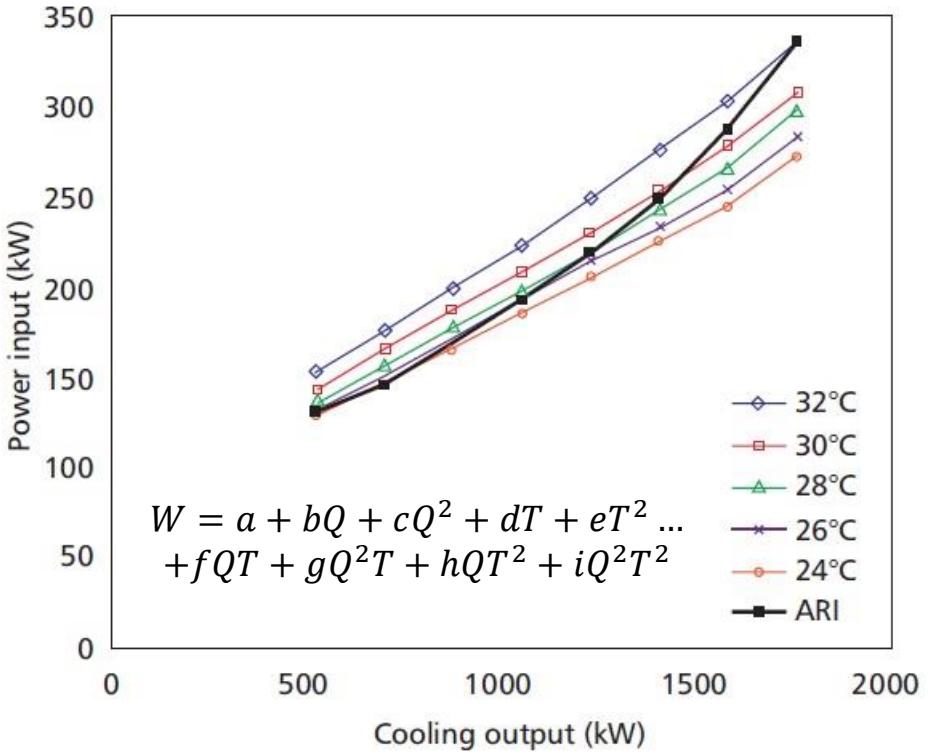
$q = C_c * (T_{co} - T_{ci})$

$T_{ho} = T_{hi} + q / C_h$

ENDIF

Theme 1 (continued) – 'catalogue-fit' models

- The example shows fitting to manufacturers data for a screw compressor-driven chiller
- Manufacturers are obliged to submit these details to meet BS-EN and ANSI/AHRI standards
- Similar detailed performance data widely available for heat pumps, fans, pumps and CHP modules, etc



Theme 1 (continued) – dynamic modelling of plant and controls

- Approaches to more complex fully dynamic models are described
- The example here shows block diagram modelling used to investigate alternative controlled responses of radiator and underfloor heating
- These modelling methods offer the ultimate in detail and rigour at the expense of complexity and computational effort – very much for niche problem-solving

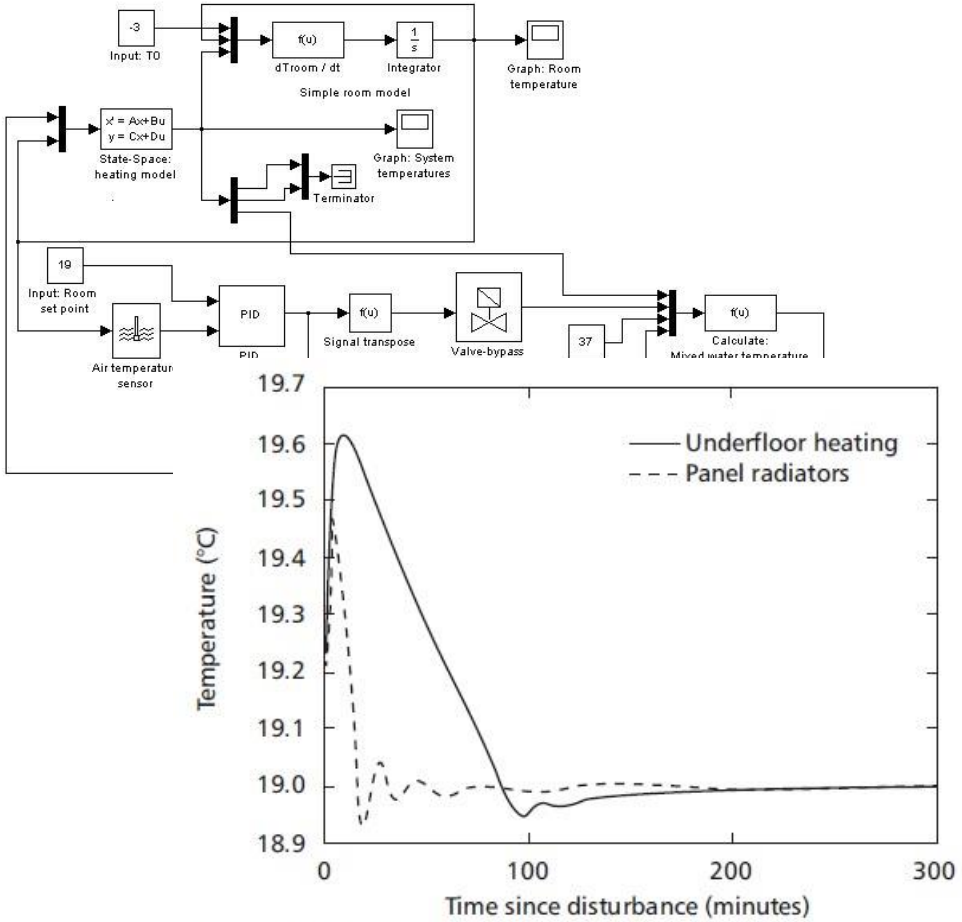


Figure 8.9 Simulated closed loop heating response to a sudden increase in casual heat gain (P+I control)

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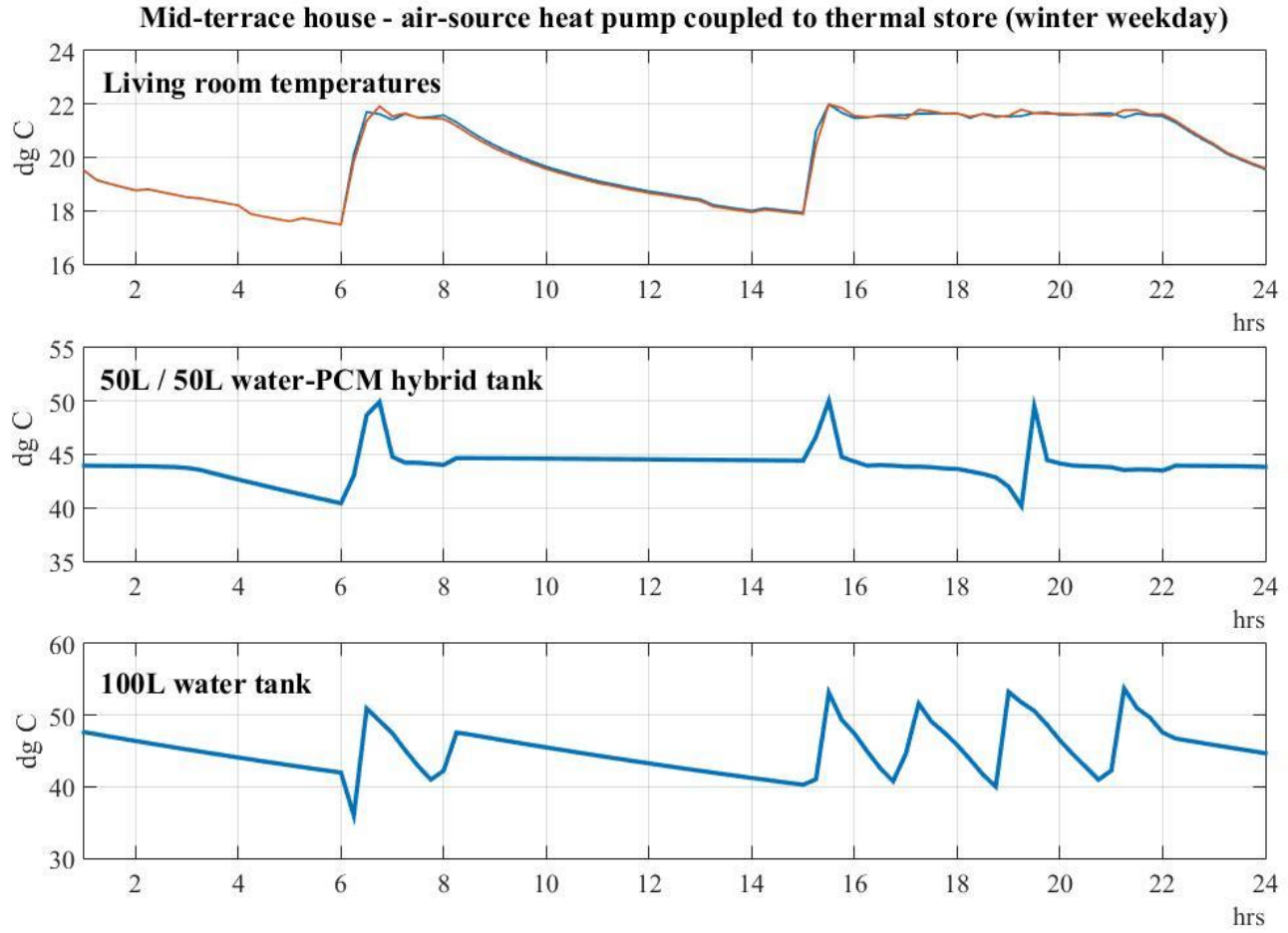
Examples: Comparative simulation of air-source heat pump and phase-change store…



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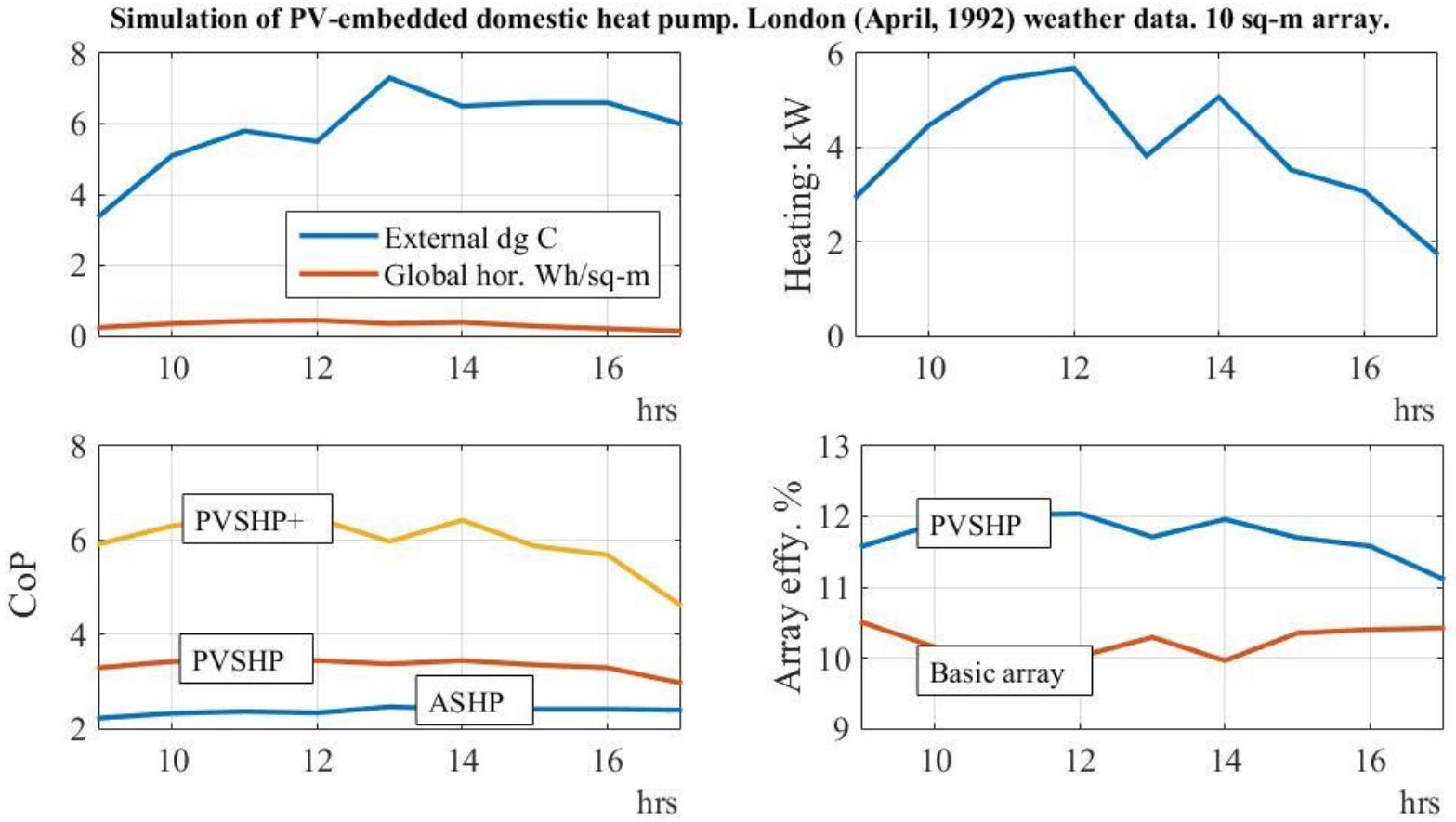
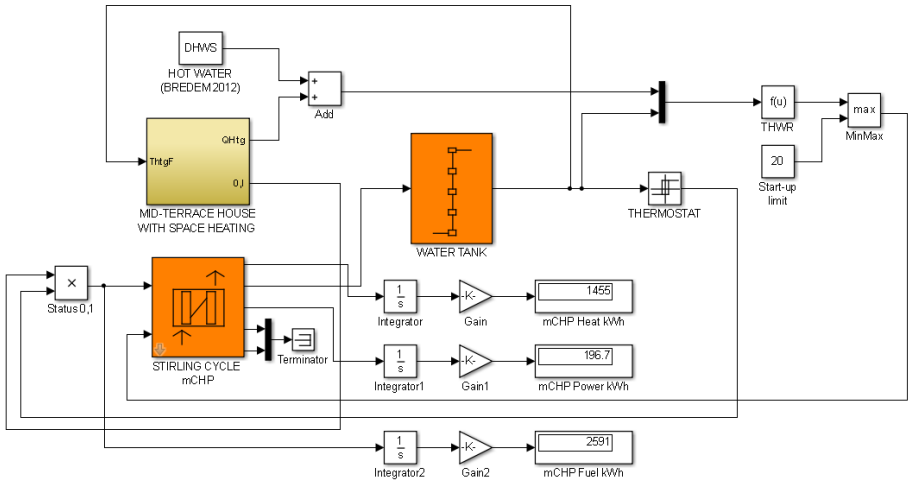
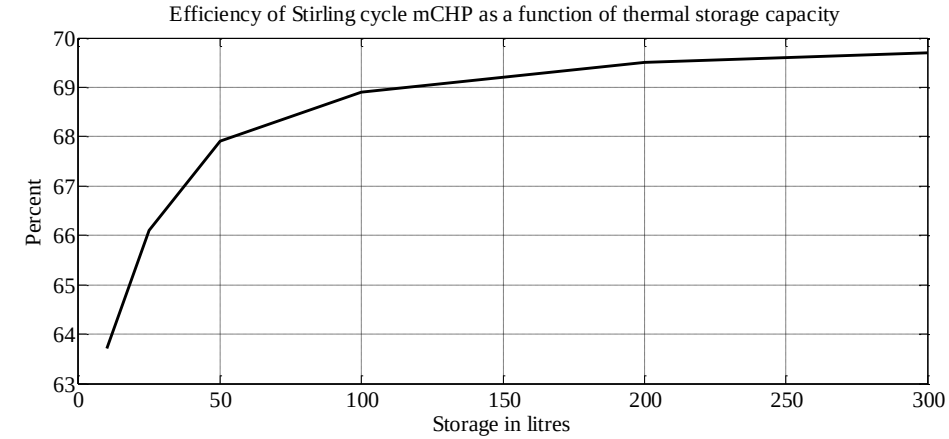
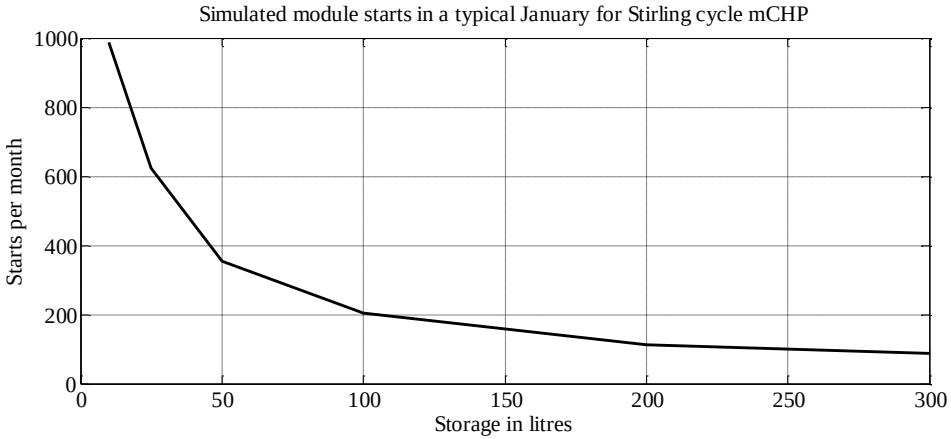
Examples: Photovoltaic-embedded heat pump simulation…



Examples: Stirling cycle mCHP – simulated reductions in module starts through storage…

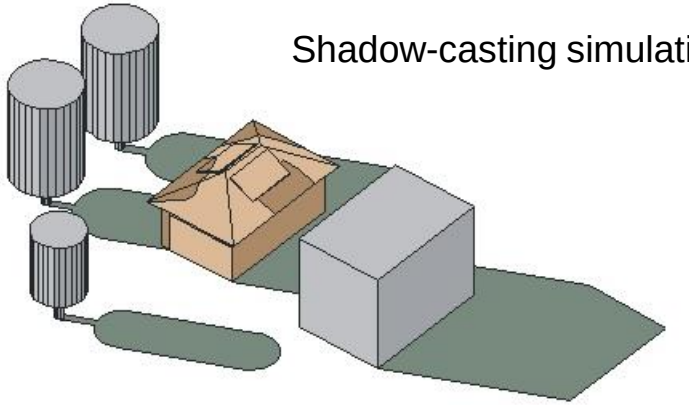




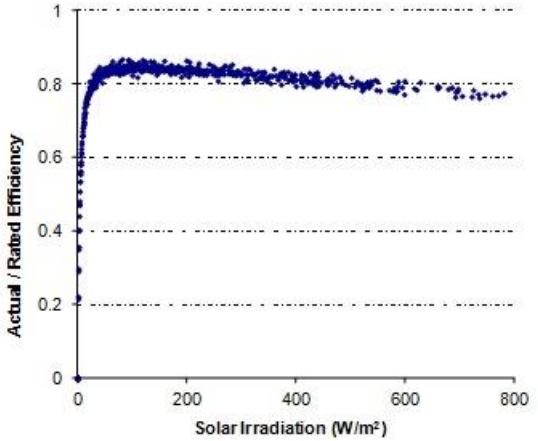


Theme 2 – solar renewables

- We review the approaches to modelling photovoltaic modules and power-conditioning systems
- Some BPS programs can simulate both shadow-casting onto PV surfaces as well as self-shading
- ISO 9459-5 procedure for solar collector performance is considered as are alternative analytical methods where manufacturer's information is limited



Shadow-casting simulation

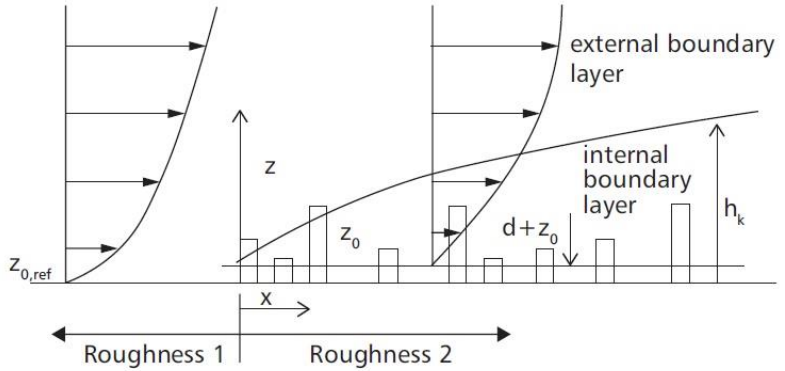


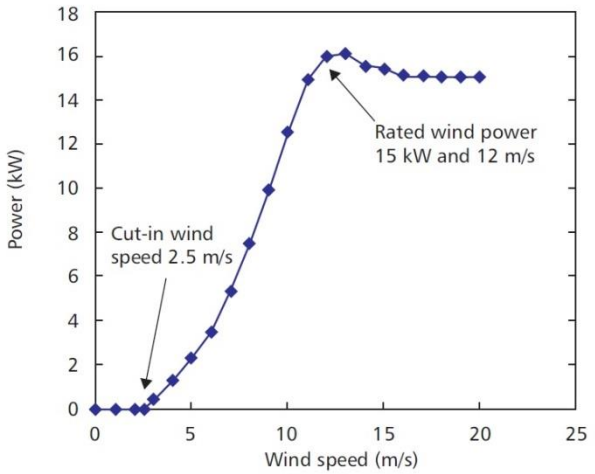
Single diode PV model including inverter

Theme 2 – urban wind

- We review building *integrated*, building *mounted* and building *augmented* wind turbine options
- Effective wind speed – boundary layer considerations in open terrain and urban environments
- Wind turbine power curves

Changing terrain boundary layer for urban wind device simulations

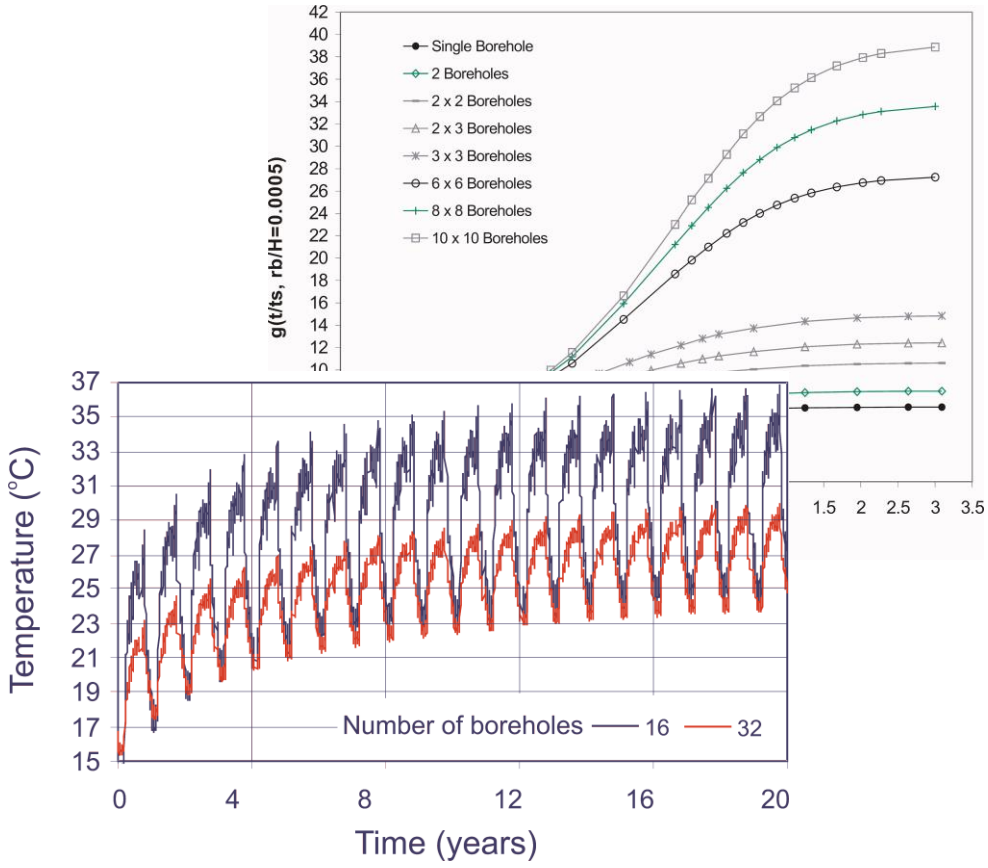




Power curve for a typical urban wind turbine

Theme 2 – ground source heat pumps

- We review the various methods available including key references…
  - Analytical models
  - Two-dimensional numerical models
  - Response factor (*g*-function) models
  - Three-dimensional numerical models
- The trade-off between accuracy and computational effort is discussed
- These are long time-horizon problems – far longer than the time horizon of interest in most routine BPS investigations



g-functions for alternative array patterns (top); 20-year GSHP simulation (bottom)

Chapter 8 – summary and conclusions

- Plant, controls and embedded renewable treatments in many established BPS programs are still under development
- Rigour and detail are patchy
- In many cases, users will need to develop their own bespoke algorithms and tools to build on preliminary results obtained from an established BPS program
- Some approaches for the development of such are presented in this chapter and applications for these approaches are discussed
- The chapter is underpinned by 63 references giving sources of further reading and help for users