Empirical Validation of Dynamic Thermal Simulation Programs

- **What was done in IEA EBC Annex 58?**
- **Other initiatives**
- **Inclusion in new Annex work programme?**

Paul Strachan, Energy Systems Research Unit, University of Strathclyde, Glasgow

Brussels workshop 18th and 19th April 2016

IEA ECB Annex 58

Identified several high quality test buildings with the necessary levels of instrumentation and control, plus documented building and systems details

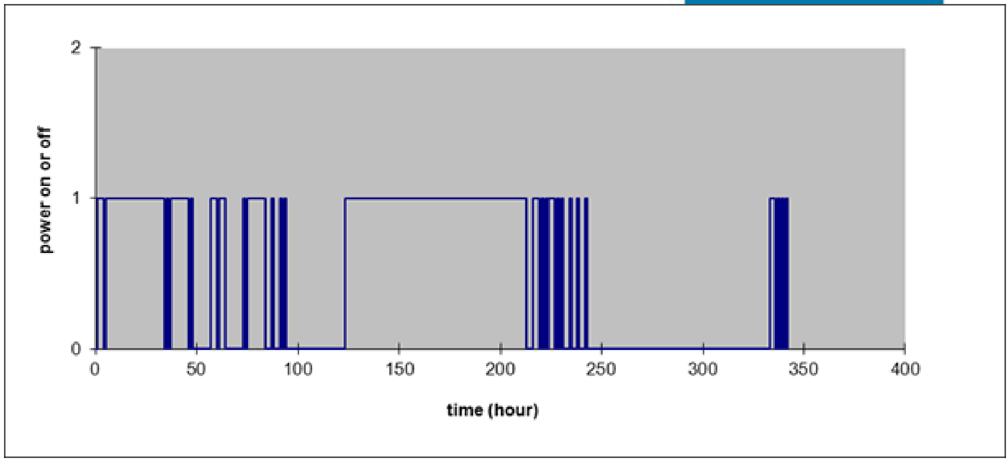
Twin houses: Holzkirchen, Germany
Fraunhofer Institute for Building Physics

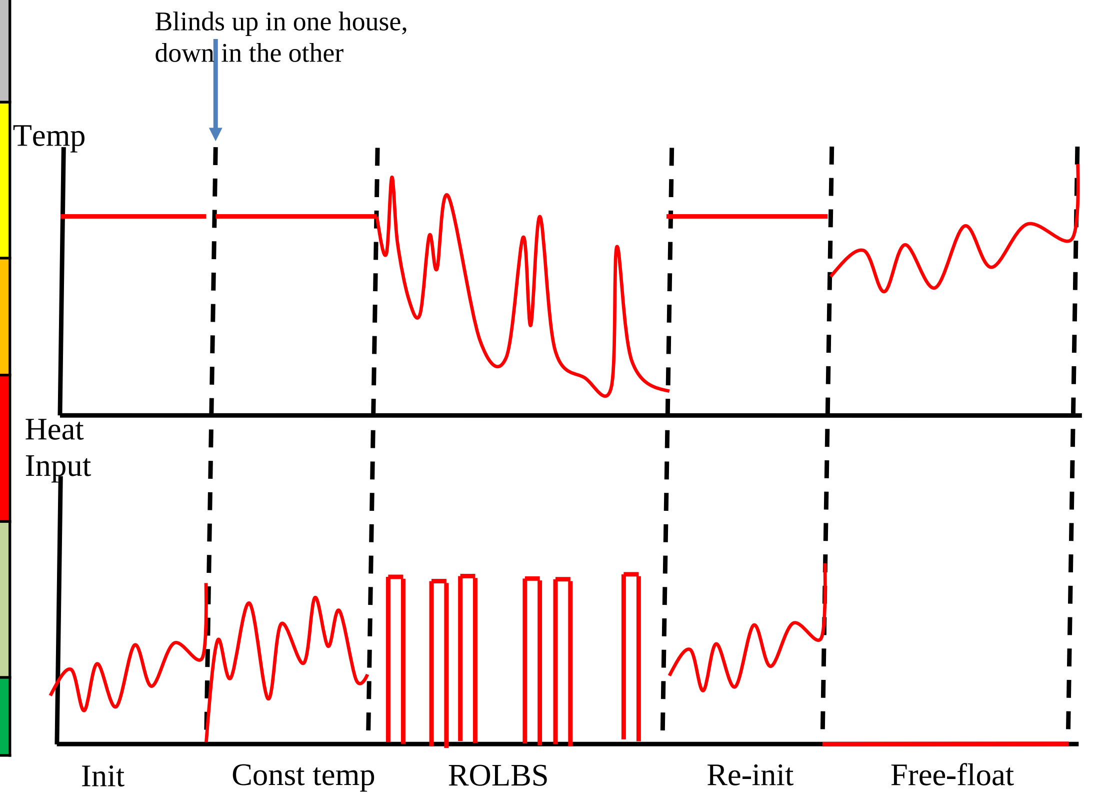
University of Strathclyde Engineering




Experimental schedule

		Twinhouse O5	Twinhouse N2
Days 1-20	Initialisation – constant temperature 30°C in all spaces (with adjustments and data losses corresponding the minute book)	Blinds down	Blinds down
Days 21-22	Initialisation – constant temperature 30°C in all spaces	Blinds down	Blinds down
Days 23-29	Constant temperature – 30°C in all spaces	Blinds up	Blinds down
Days 30-44	ROLBS sequence in living room. No heat inputs elsewhere.	Blinds up	Blinds down
Days 45-50	Re-initialisation – constant temperature 25°C in all spaces.	Blinds down	Blinds down
Days 51-61	Free-float	Blinds up	Blinds down

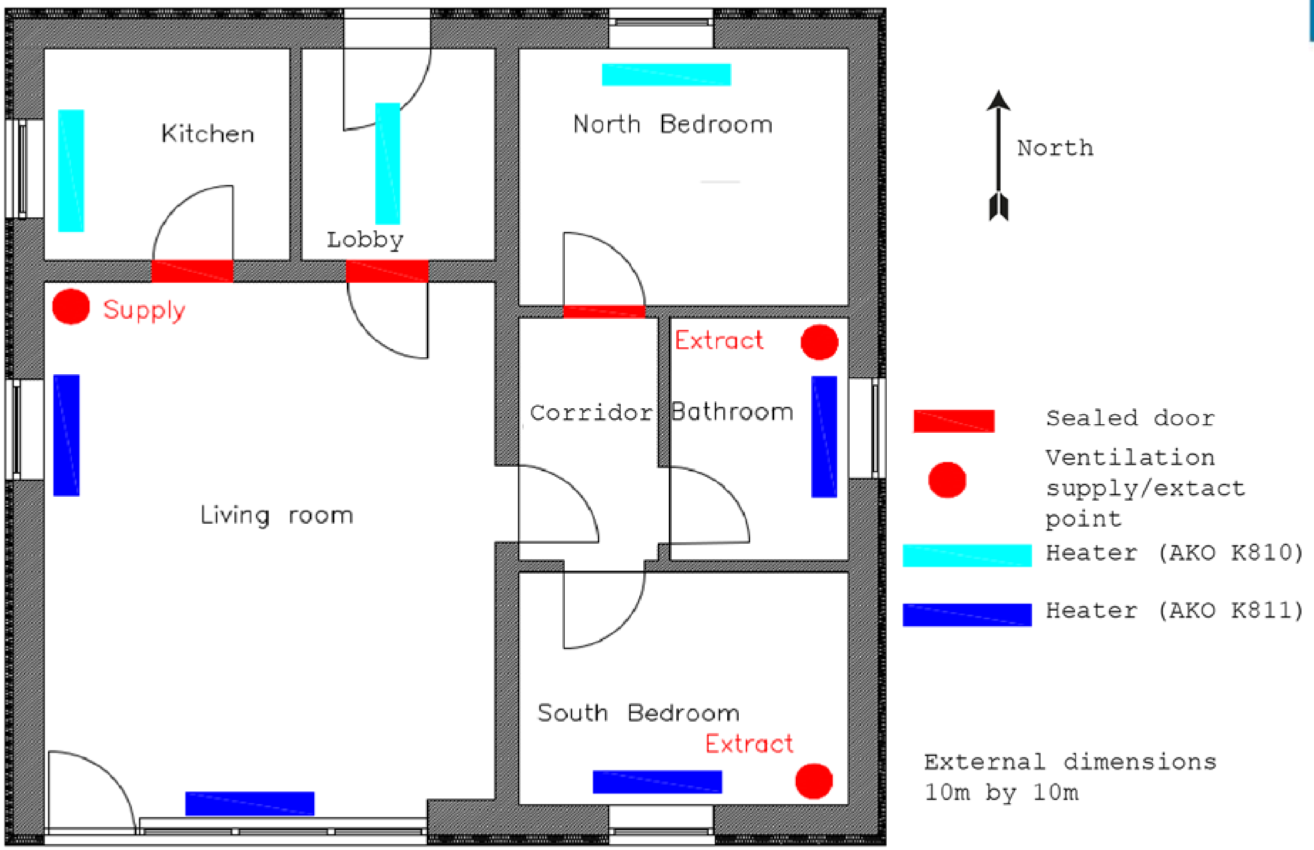




Empirical Validation Procedure

1. Experimental design (properties/sensors/test schedule ...)
2. *Experiment*
3. Blind validation – using measured climate data and operational schedules but without knowledge of internal conditions
4. *Analysis – between programs and predictions vs experiment*
5. Refine models – document changes
6. *Final analysis and archiving of high quality data sets*

Ventilation/ Heating



Climate and Building data collected at 1 min intervals – supplied to modelling teams with both 10 min and 1 hour averages

Experiments

Experiment 1: August/September 2013

- Side-by-side experiment, blinds up/down

Experiment 2: April/May 2014

- 1 house only
- Increased magnitude of heat injections
- Also used for a common exercise for system identification
- Maintain constant temperature in all boundary zones (north rooms/ attic and cellar)
- Some additional sensors

Submitted Modelling Results

Experiment 1 Phase 1 ("blind")
- 21 datasets
- 13 organisations
- 11 programs

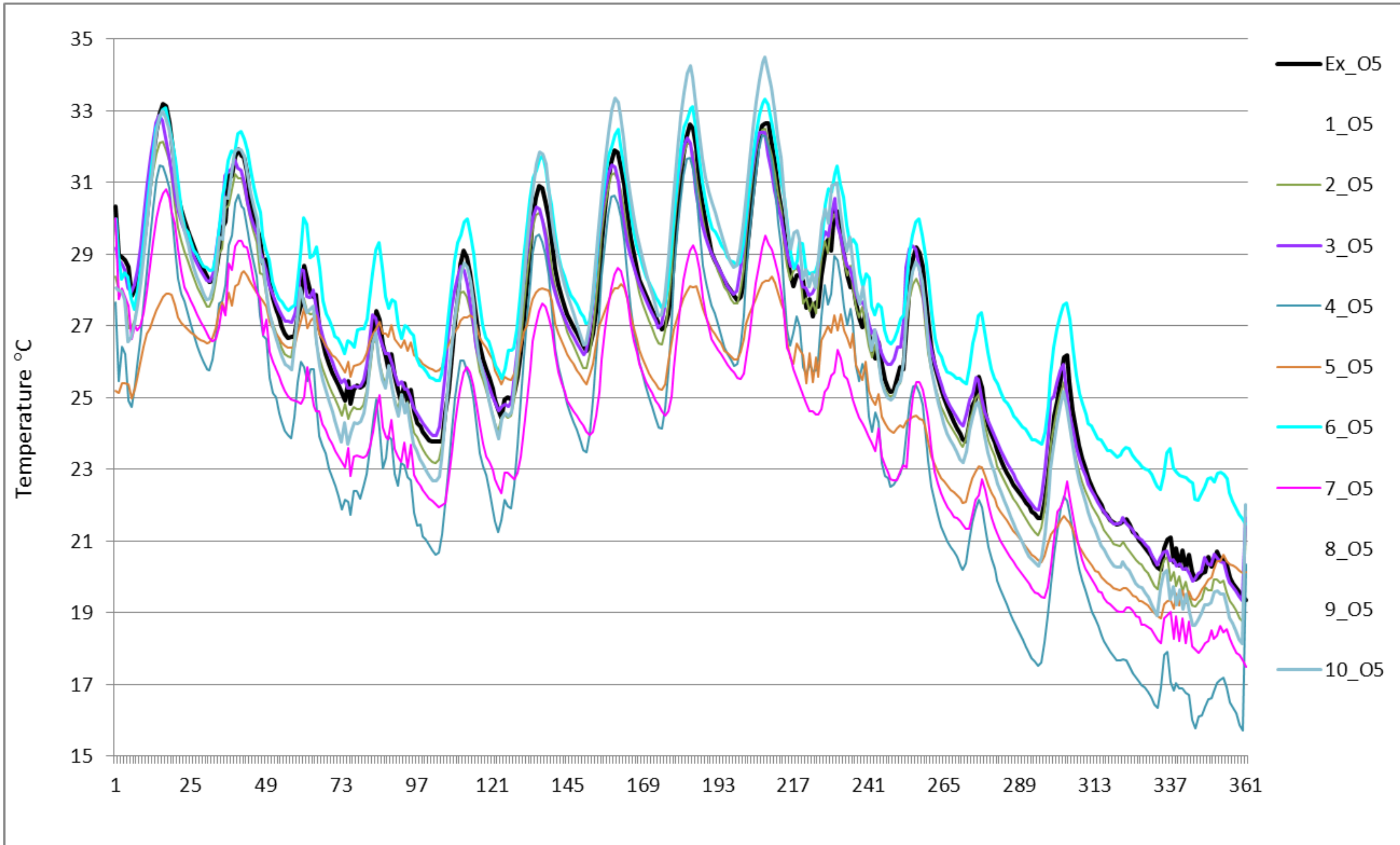
Experiment 1 Phase 2
- 18 datasets
- 16 organisations
- 12 programs

Experiment 2
- 13 datasets
- 12 organisations
- 10 programs

CIEMAT
CTU Prague
DTU
Equa
Fraunhofer
HFT Stuttgart
Hong_Kong_City Univ
IES
Leuven
Liege
Politecnico di Milano
RWTH Aachen
Univ Gent
Univ Innsbruck
Univ Strathclyde

TRNSYS	4
Modelica	4
EnergyPlus	2
ESP-r	2
EES	2
Matlab	2
INSEL	2
eQuest	1
IDA-ICE	1
Wufi	1
IESVE	1
Dynbil	1

Living room temperature: ROLBS sequence: (some) predictions + experimental data House O5



Experiment 1, Temperature, Magnitude

ANNEX 58 TWIN HOUSE MEASURED AND SIMULATED DATA

TEMPERATURE COMPARISONS

Green = <1°C
Yellow = 1><2°C
Orange = 2<>4°C
Red = >4°C

Period 2	Constant 30 C	168	hrs
Period 3	ROLBS	361	hrs
Period 4	Constant 25 C	144	hrs
Period 5	Free running to 2	240	hrs

Magnitude Fit

AvAbsDiff to Experiment

		Sim 1	Sim 2	Sim 3	Sim 4	Sim 5	Sim 6	Sim 7	Sim 8	Sim 9	Sim 10	Sim 11	Sim 12	Sim 13	Sim 14	Sim 15	Sim 16	Sim 17	Sim 18	Sim 19	Sim 20	Sim 21
O5 LRT	Per 3	2.2	0.5	0.4	2.5	1.9	1.2	2.4	4.3	1.7	0.8	0.7	1.2	0.7	1.2	1.3	2.4	2.0	4.8	2.6	10.8	1.2
O5 LRT	Per 5	1.5	0.5	0.4	2.9	0.9	0.8	1.7	4.1	1.2	1.0	0.6	0.6	0.6	1.0	1.1	0.9	1.4	3.6	2.5	3.8	0.8
N2 LRT	Per 3	1.9	0.9	0.4	2.5	2.9	0.4	1.8	4.8	3.5	0.9	1.0	0.4	0.5	1.6	0.8	0.8	0.7	2.2	2.2	6.0	1.4
N2 LRT	Per 5	1.7	0.8	0.4	2.5	2.7	0.4	1.0	3.5	3.4	1.4	1.0	0.3	0.4	1.5	0.8	1.2	0.6	1.3	2.1	3.8	1.5
N2-O5 LRT	Per 3	2.0	0.5	0.5	0.4	4.5	0.9	0.7	2.2	3.6	0.7	1.5	0.9	0.5	1.5	0.6	3.2	1.5	2.7	0.5	5.0	1.3
N2-O5 LRT	Per 5	1.4	0.5	0.4	0.5	3.3	0.6	0.7	1.5	4.1	0.4	1.1	0.5	0.5	1.1	0.6	2.0	1.2	2.3	0.5	2.6	1.5
O5 SBDT	Per 3	1.4	0.4	0.9	1.4	2.2	1.9	1.5	7.4	0.8	0.9	1.5	1.8	1.5	0.6	1.6	3.0	2.3	4.1	2.1	11.4	0.8
O5 SBDT	Per 5	0.9	0.3	0.5	1.3	2.0	1.5	0.7	5.4	0.8	0.3	0.8	1.5	1.2	0.5	0.9	1.8	1.3	3.2	1.7	3.8	0.8
N2 SBDT	Per 3	3.2	0.5	0.6	1.7	3.6	1.0	1.1	5.5	3.4	1.4	0.6	1.0	0.8	0.4	1.0	1.7	0.6	1.7	1.9	6.2	0.8
N2 SBDT	Per 5	1.9	0.6	0.6	1.3	4.3	1.2	0.5	4.1	3.5	0.8	0.6	1.1	0.9	0.4	0.5	1.6	0.4	1.1	1.5	3.5	0.6
N2-O5 SBDT	Per 3	1.8	0.7	0.8	0.3	3.1	0.9	0.4	2.0	3.3	0.5	2.0	0.8	0.7	0.9	0.6	1.6	1.7	2.4	0.3	5.3	1.6
N2-O5 SBDT	Per 5	1.2	0.6	0.5	0.2	2.3	0.5	0.4	1.6	3.7	0.6	1.4	0.4	0.4	0.6	0.4	1.3	1.3	2.1	0.2	2.3	1.4
O5 KITT	Per 3	1.7	1.4	1.0	0.8	2.5	2.9	0.5	3.8	1.1	2.9	1.9	2.7	2.9	0.8	2.2	4.7	3.0	3.4	1.8	7.6	1.8
O5 KITT	Per 5	1.1	0.8	0.7	0.9	2.9	2.3	0.5	3.6	1.6	1.3	1.3	1.9	2.3	0.7	1.6	2.2	1.7	2.7	1.0	5.3	1.3
N2 KITT	Per 3	2.0	0.8	0.7	0.6	4.7	2.5	0.5	2.3	2.3	0.9	1.1	2.4	3.3	0.7	1.7	1.4	2.3	2.6	1.2	6.5	1.1
N2 KITT	Per 5	1.2	0.5	0.5	0.9	4.4	2.2	0.8	3.3	3.3	1.0	0.7	1.9	2.8	0.7	1.4	0.8	1.1	1.8	0.7	5.5	0.7
N2-O5 KITT	Per 3	0.3	0.6	0.5	0.2	2.3	0.4	0.4	5.7	1.6	2.5	2.9	0.4	0.4	0.3	0.5	3.4	0.7	1.0	0.6	1.5	0.8
N2-O5 KITT	Per 5	0.1	0.4	0.3	0.1	1.5	0.2	0.4	6.3	1.7	2.2	1.9	0.3	0.5	0.2	0.3	2.2	0.6	0.9	0.4	0.6	0.6
O5 NBDT	Per 3	4.0	0.3	0.7	1.3	2.4	1.7	0.9	6.0	0.3	1.4	0.3	1.4	1.3	0.5	1.9	3.4	2.0	1.8	0.2	6.4	0.4
O5 NBDT	Per 5	2.8	0.3	0.4	1.0	3.0	1.5	0.4	4.7	1.1	0.5	0.3	1.0	1.2	0.5	1.4	1.5	1.2	1.7	0.1	3.8	0.3
N2 NBDT	Per 3	3.3	0.3	0.5	1.0	4.0	1.7	0.5	4.9	1.8	1.1	0.5	1.6	2.2	0.5	1.6	0.8	1.3	1.2	0.2	4.8	0.4
N2 NBDT	Per 5	2.3	0.2	0.3	0.6	4.2	1.7	0.4	3.9	2.7	0.3	0.2	1.3	2.0	0.5	1.2	0.8	0.6	1.0	0.2	4.0	0.3
N2-O5 NBDT	Per 3	0.7	0.1	0.3	0.3	1.6	0.2	0.7	1.3	1.6	0.4	0.8	0.2	0.9	0.1	0.3	2.6	0.7	0.7	0.1	2.2	0.2
N2-O5 NBDT	Per 5	0.6	0.2	0.2	0.4	1.2	0.3	0.5	0.9	1.6	0.3	0.4	0.4	0.8	0.1	0.3	1.6	0.7	0.7	0.1	0.8	0.2
Fixed Temp periods																						
AvAbsDiff																						
O5 LRT	Per 2	0.4	0.4	0.4	0.5	4.4	0.3	0.5	0.5	0.5	0.4	0.4	0.4	0.6	0.5	0.4	0.7	1.2	0.9	1.0	1.3	0.6
O5 LRT	Per 4	0.3	0.2	0.2	0.2	3.8	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.3	0.2	0.5	0.5	0.5	0.8	5.0	0.2
N2 LRT	Per 2	0.2	0.2	0.2	0.2	0.5	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.4	0.4	0.2	0.6	0.6	0.2	0.9	0.4	0.2
N2 LRT	Per 4	0.2	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.5	0.4	0.2	0.7	0.6	0.2	0.9	3.6	0.2

Experiment 1, Temperature, Magnitude, Phase 2

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Magnitude Fit

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O5 LRT	Per 3	1.0	0.4		1.3	0.8	2.2	0.4	3.4		0.8	0.3					1.0		0.6	2.5	0.4	1.1
O5 LRT	Per 5	0.4	0.4		1.8	0.7	1.4	0.3	3.1		1.3	0.3					0.7		0.4	2.4	0.4	0.7
N2 LRT	Per 3	0.7	0.6		0.9	0.6	0.6	0.6	2.7		0.8	0.4					0.4		0.5	1.8	0.6	1.3
N2 LRT	Per 5	1.1	0.6		1.0	0.5	0.2	0.5	2.1		1.2	0.5					0.4		0.4	1.8	0.9	1.5
N2-O5 LRT	Per 3	1.6	0.4		0.6	0.5	2.6	0.3	1.0		0.2	0.5					1.0		0.3	0.7	0.7	1.3
N2-O5 LRT	Per 5	1.1	0.4		0.8	0.7	1.2	0.3	1.3		0.2	0.5					0.7		0.3	0.6	0.7	1.3
O5 SBDT	Per 3	2.2	0.4		1.2	0.8	2.6	0.5	7.5		0.4	0.3					1.0		1.4	2.0	1.0	0.5
O5 SBDT	Per 5	1.4	0.3		1.2	0.8	2.0	0.4	5.0		0.3	0.2					0.7		1.0	1.6	0.7	0.5
N2 SBDT	Per 3	23.2	0.2		0.9	0.7	0.6	0.5	5.8		0.3	0.2					0.6		0.6	1.6	0.6	0.9
N2 SBDT	Per 5	18.7	0.3		0.7	1.0	0.9	0.5	3.5		0.6	0.3					0.6		0.5	1.1	1.2	0.6
N2-O5 SBDT	Per 3	25.4	0.5		0.3	0.4	2.5	0.4	1.7		0.5	0.4					0.9		1.3	0.4	1.0	1.3
N2-O5 SBDT	Per 5	20.2	0.4		0.6	0.5	1.1	0.3	1.5		0.4	0.4					1.0		1.1	0.5	1.0	1.1
O5 KITT	Per 3	0.8	0.3		2.0	0.7	0.8	0.4	2.4		0.6	0.5					0.7		0.4	3.4	0.4	1.3
O5 KITT	Per 5	0.5	0.2		1.5	0.5	1.1	0.3	1.6		0.8	0.2					0.5		0.4	3.8	0.4	0.8
N2 KITT	Per 3	0.5	0.5		2.1	0.6	0.6	0.3	2.5		0.6	0.4					0.7		0.4	1.4	0.5	2.0
N2 KITT	Per 5	0.3	0.4		1.4	0.5	1.0	0.3	1.6		0.9	0.2					0.5		0.4	1.3	0.7	0.5
N2-O5 KITT	Per 3	1.2	0.3		0.1	0.3	0.7	0.4	0.4		0.4	0.1					0.4		0.1	1.9	0.2	0.6
N2-O5 KITT	Per 5	0.7	0.2		0.2	0.3	0.2	0.3	0.5		0.2	0.2					0.3		0.1	2.4	0.3	0.3
O5 NBDT	Per 3	1.2	0.1		1.3	0.5	1.1	0.4	5.2		0.5	0.3					2.9		2.1	0.9	0.5	0.6
O5 NBDT	Per 5	1.0	0.1		1.2	0.5	1.2	0.4	3.5		0.2	0.1					1.6		1.0	0.9	0.3	0.4
N2 NBDT	Per 3	0.7	0.2		0.9	0.8	0.7	0.7	4.5		0.6	0.2					1.5		0.9	0.5	0.3	0.6
N2 NBDT	Per 5	0.7	0.2		0.7	1.0	1.2	0.7	2.9		0.2	0.3					0.6		0.5	0.5	0.5	0.5
N2-O5 NBDT	Per 3	0.6	0.1		0.4	0.5	0.5	0.3	0.8		0.1	0.4					1.5		1.4	0.4	0.3	0.2
N2-O5 NBDT	Per 5	0.3	0.1		0.5	0.4	0.2	0.3	0.7		0.1	0.3					1.2		1.3	0.4	0.5	0.1
Fixed Temp periods																						
AvAbsDiff																						
O5 LRT	Per 2	0.3	0.4		0.4	0.4	0.4	0.3	0.3		0.4	0.4					0.5		0.4	1.0	0.3	0.4
O5 LRT	Per 4	0.2	0.2		0.2	0.2	0.2	0.2	0.1		0.2	0.2					0.3		0.2	0.7	0.2	0.2
N2 LRT	Per 2	0.2	0.2		0.2	0.2	0.2	0.2	0.2		0.2	0.2					0.7		0.2	0.3	0.2	0.2
N2 LRT	Per 4	0.2	0.2		0.3	0.2	0.2	0.2	0.2		0.2	0.2					0.7		0.2	0.3	0.2	0.2

Conclusions

University of Strathclyde Engineering

A comprehensive full-scale empirical validation test on an unoccupied real building … a useful resource for program users and developers.

A well-tested specification and high quality datasets from two experiments (almost 2 months data for each experiment of 1-minutely data from calibrated sensors). Full specifications and experimental datasets in public domain with DOI issued.
Experiment 1: http://dx.doi.org/10.15129/8a86bbbb-7be8-4a87-be76-0372985ea228
Experiment 2: http://dx.doi.org/10.15129/94559779-e781-4318-8842-80a2b1201668

High level of engagement from modellers, so the specification has been thoroughly tested.

Good feedback on outcomes from participating commercial and research organisations.

Conclusions

Some (but certainly not all!) programs have performed very well, even in the blind validation phase of Experiment 1 and free-float period of Experiment 2.

Time and effort was substantial, both by the experimental team, the modellers and the analysis team. And this is a comparatively simple unoccupied building.

User modelling errors even by experienced modellers – on a simple house! Difficult to disaggregate factors such as:

- experience of the modeller
- amount of QA undertaken by colleagues of the modeller
- attention and time devoted to the study by the modeller.

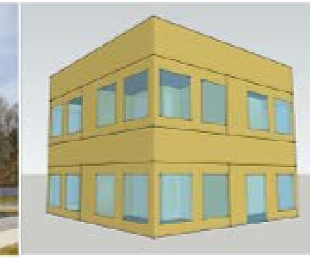
DoE empirical validation study

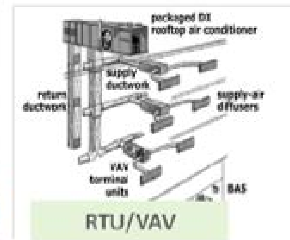
- LBNL, NREL, ORNL, ANL
- Focusing on EnergyPlus validation
- Data sets planned for inclusion in ASHRAE Standard 140

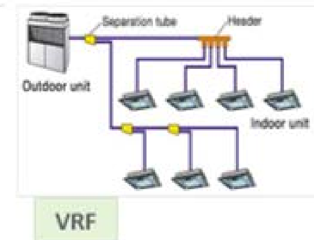
Experimental Facilities – ORNL

ORNL: Flexible Research Platforms (FRP)

- Two buildings:
  - Two story, 5 zones per floor
  - Single story, large zone







Experimental Facilities – NREL

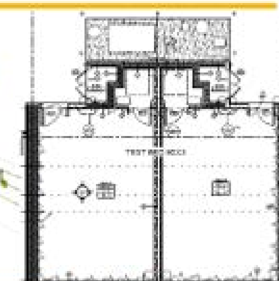
NREL: HVAC test facility

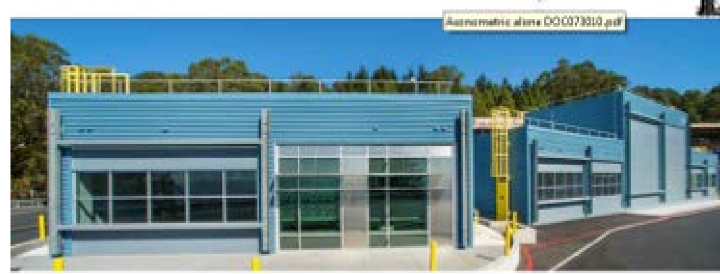
- Performance maps of HVAC components ≤ 10 tons
- Uncertainty < 5%

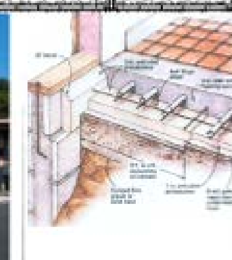
Experimental Facilities - LBNL

LBNL: FLEXLAB

- 4 matched pairs of 20'x30' test cells
- 1 pair of cells rotates
- Reconfigurable south façade
- Radiant slab and panels







New IEA ECB Annex:
Another empirical validation study?

Objectives:

- Similar to IEA Annex 58 – full-scale building, multizone
- Extend experimental set-up to include systems and simulated occupancy

Requirements:

- Need significant resources and time from several teams
- Experimental team with a well-configured experimental facility with detailed specification of building and high levels of instrumentation
- Interest from a good range of modelling teams – commercial, research
- Co-ordinator(s)

Does it fit in with new Annex objectives?