

eViz: Energy Visualisation for Carbon Reduction

Sabine Pahl & Pieter de Wilde

eViz final event

September 2015

1. The eViz Project

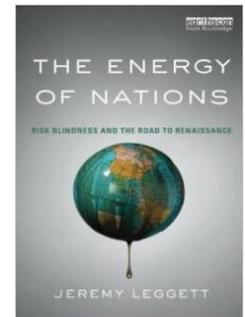


- CO₂ emissions from energy generation & use – large contribution to climate change
- 40% of the UK's energy use and carbon emissions comes from buildings (heating, lighting, use, DCLG, 2014)
- Other issues (Fuel poverty, energy security, Energy & Health, fossil fuels / carbon asset “bubble”?)

Solutions?

Reduce energy demand

Increase energy efficiency



1. The eViz Project



3.5 year EPSRC funded multi-centre study to investigate how we can reduce energy demand in buildings by transforming people's understanding and behaviour through energy visualisations



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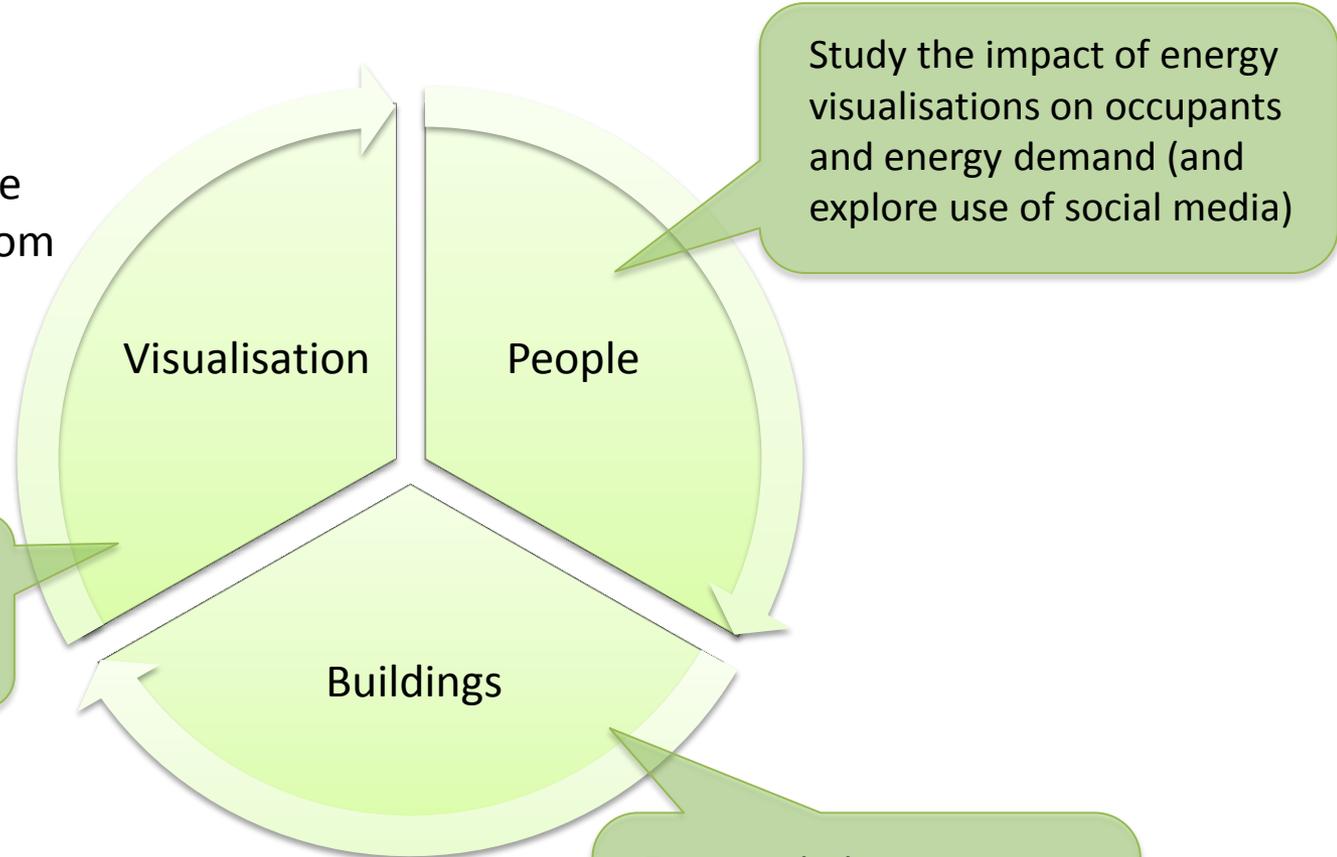
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BATH



1. eViz Tasks



eViz brings together researchers from psychology, building sciences, computer science and data visualisation – from four UK universities



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Examine behaviour in buildings by collecting and analysing building energy use data

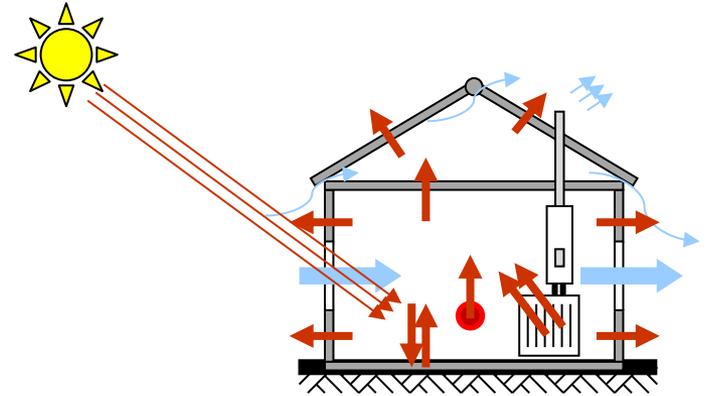
1. eViz Questions



- How can we improve energy demand reduction by taking into account human behaviour and understanding?
- How can we ensure quality and integrity of technical data underlying visuals?
- What visuals attract and engage people?
- How can we use visuals to increase energy efficiency, and what constraints can we anticipate?
- What should we do differently / do next?

1. The eViz Project
2. The role of behaviour and understanding
Sovereign Housing, Diary study, EEE/app
Mental models, Social media
3. Visualising energy
 1. Why visualisation?
 2. eViz examples
VR flat, PCC study,
Viz lab study, Thermal imaging
4. Conclusions
5. Future directions







Close that door!!!

If only it were that simple:

- $T_i > T_a$
- $vp_i > vp_e$
- $ppm_i > ppm_{max}$
- cp values
- pre-cooling
- ... the boy's game?

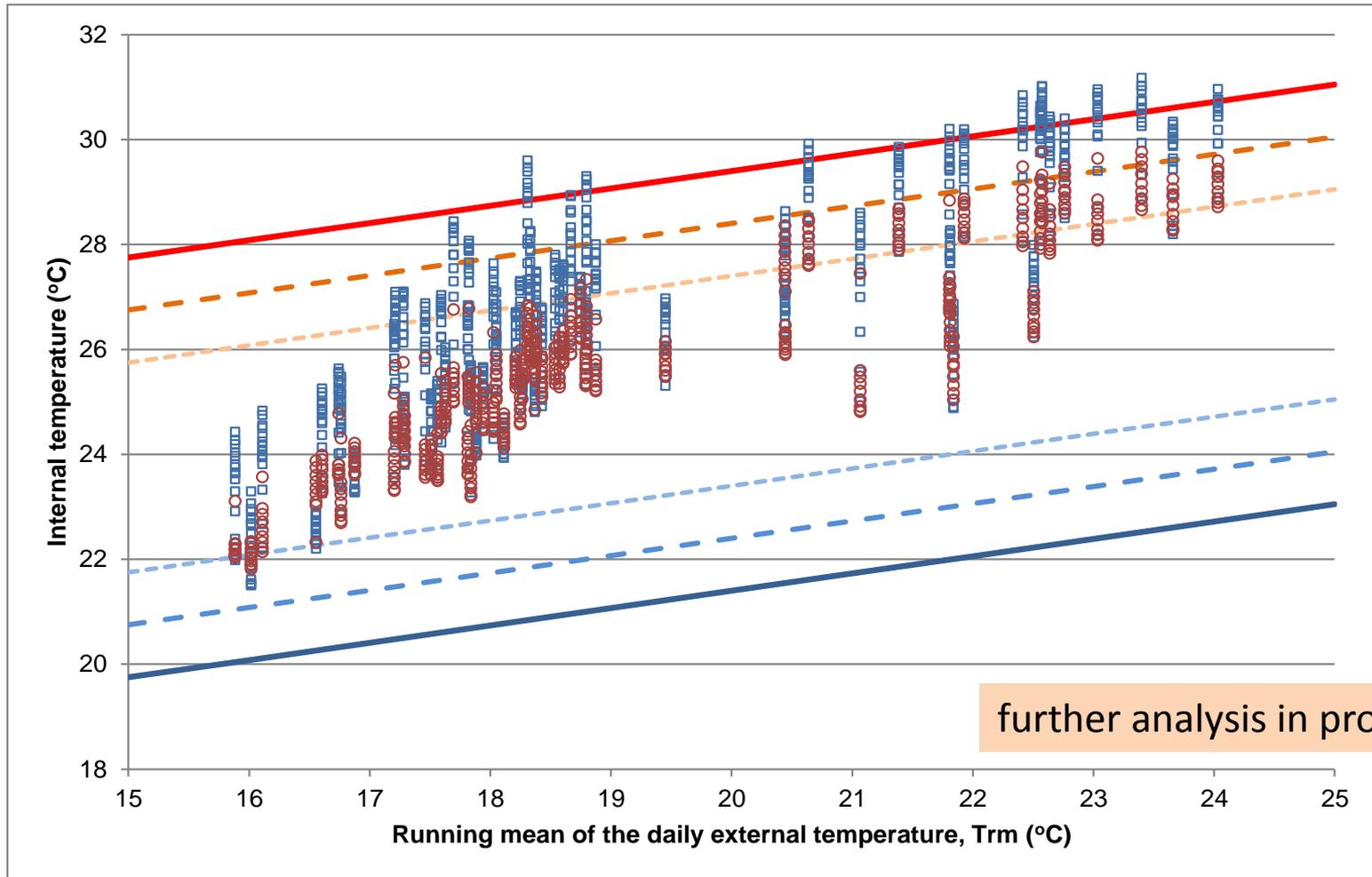
Can we simulate this?

... yes...CFD+...?

How much energy saved?

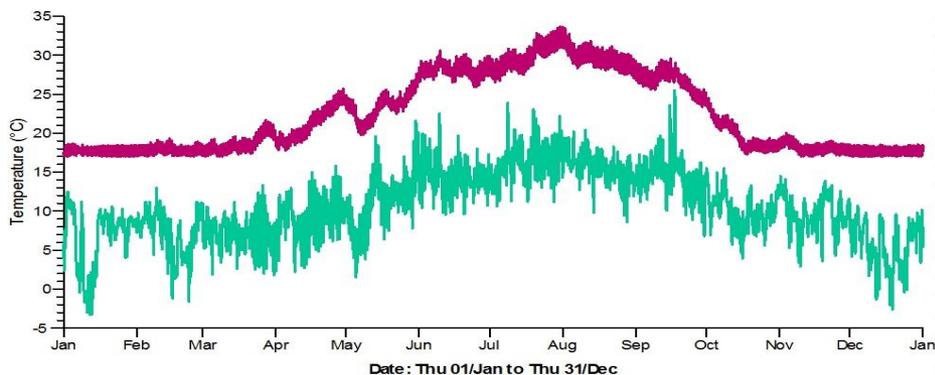
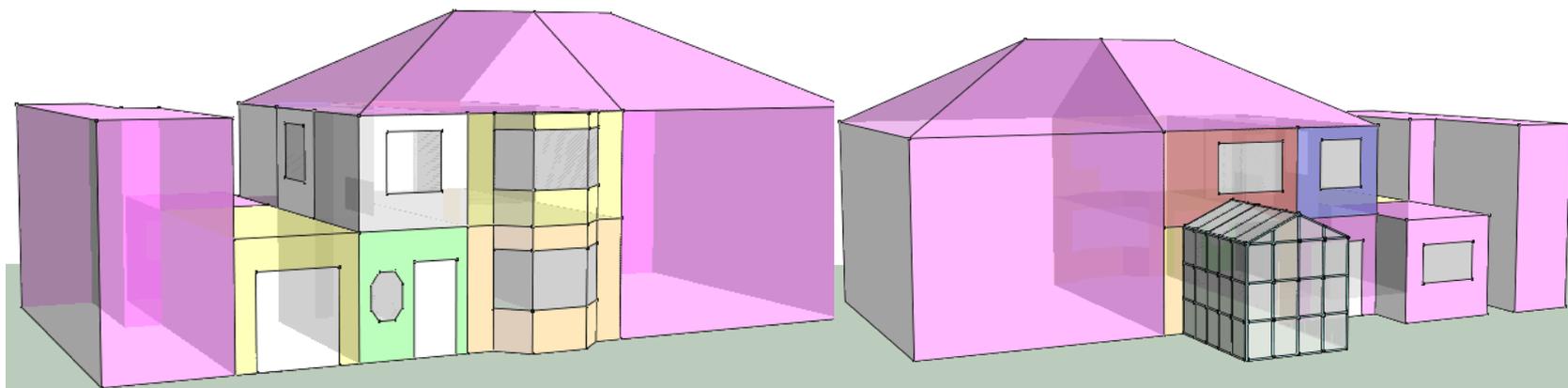
...blimp on annual metering...?

Sovereign Housing



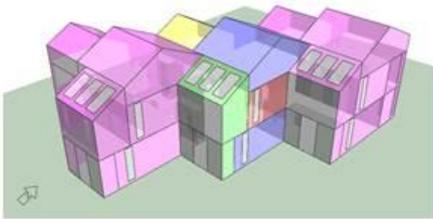
BSEN15251 thresholds and the hourly temperatures measured in the living room and bedroom of Flat 2: a warmer home

IES Simulations



— Mean radiant temperature: Living Room (goodhews.ap) —
— Dry-bulb temperature: CamborneEWY.fwt (CamborneEWY.fwt)

Dr. Neveen Hamza, Dr. Islam Abuhela and Miss Qian Zi



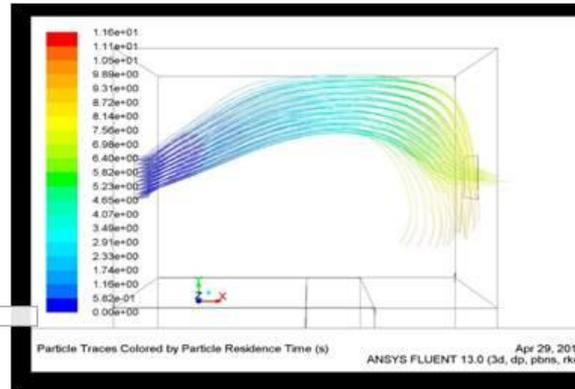
Studying users behaviours in Code 6 homes

Running CFD models in ANSYS 13 to determine wind velocity and natural ventilation wind flow patterns in Birmingham apartment model

Formatting the CFD outputs to Particle Vector analyses to show

- Position of each particle in 3D axis
- Velocity of Each particle in 3D
- Particle temperature (K)
- Particle Density
- Particle mass

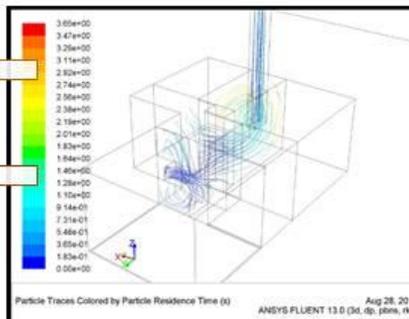
Sending Particle and CFD visualizations to the Team in Birmingham university to superimpose on the Birmingham Flat model



CFD analysis of air flow in living room (plan view)



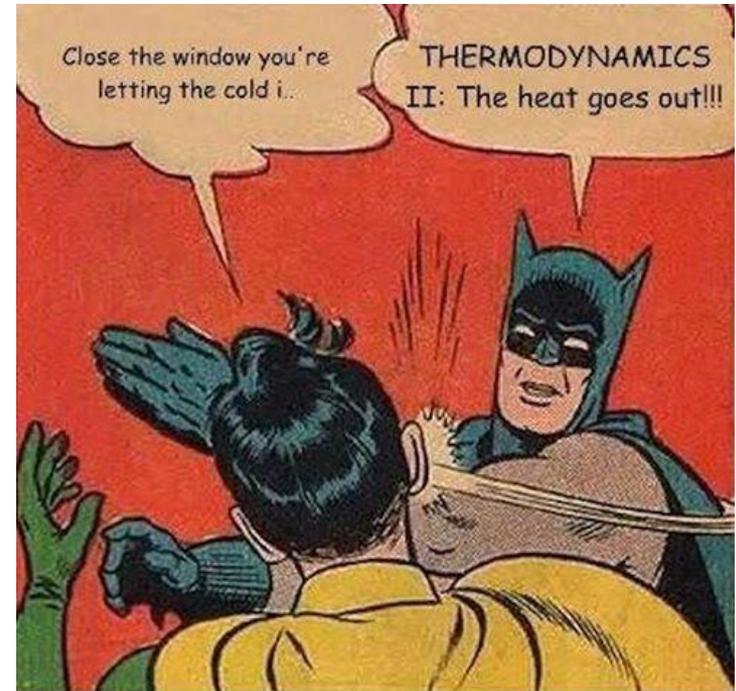
CFD analysis of air flow in living room (axonometric view)



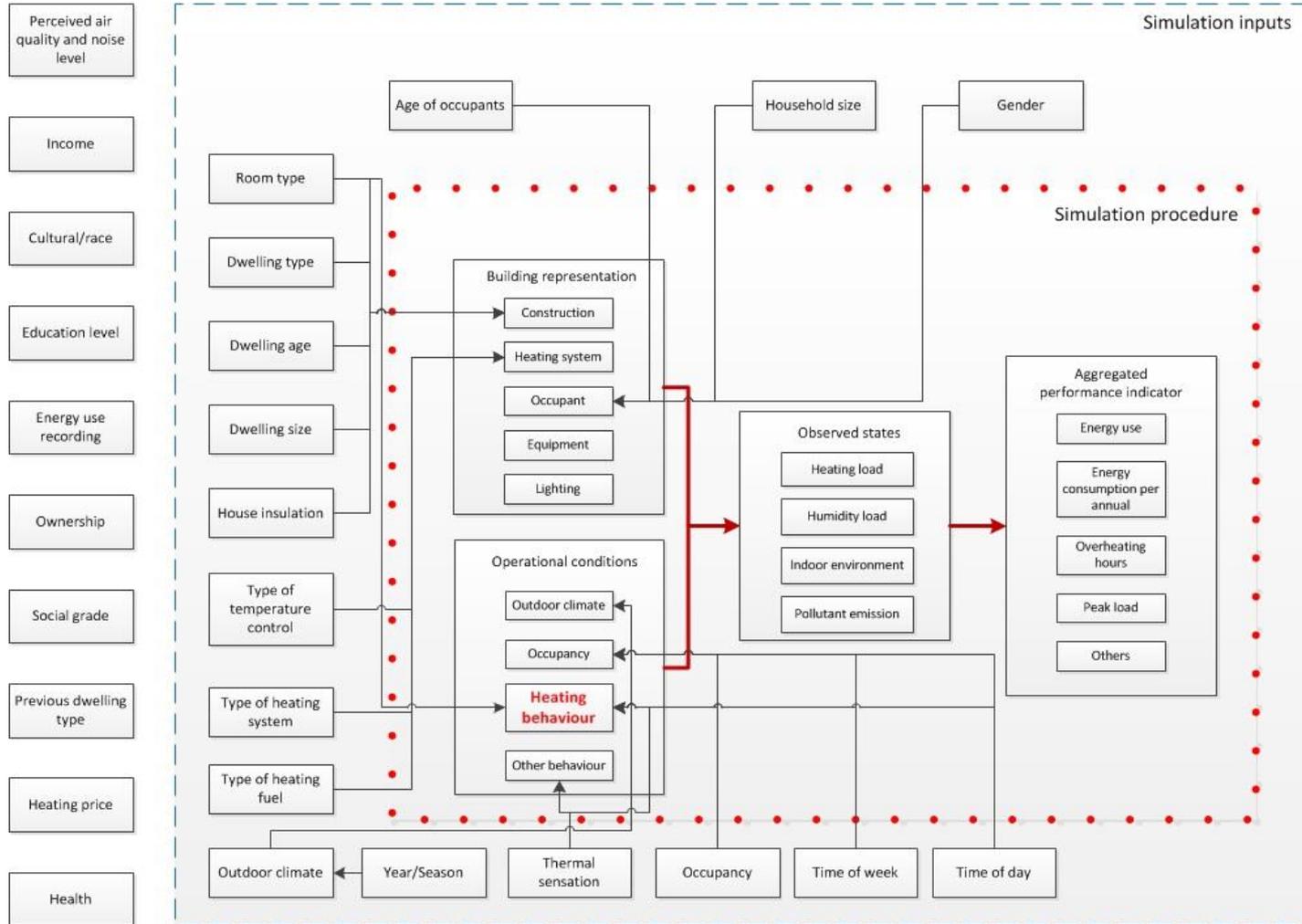
CFD analysis of air flow between corridor and kitchen hood extraction

Particle Residence Time (s)	Particle X Position (m)	Particle Y Position (m)	Particle Z Position (m)	Particle X Velocity (m/s)	Particle Y Velocity (m/s)	Particle Z Velocity (m/s)	Particle Diameter (m)
0.00E+00	5.20E+00	-3.00E+00	1.90E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-06
1.56E-04	5.20E+00	-3.00E+00	1.90E+00	-1.07E+00	-3.27E+00	-2.00E+00	1.00E-06
2.29E-03	5.20E+00	-3.01E+00	1.90E+00	-1.07E+00	-3.27E+00	-2.00E+00	1.00E-06
4.37E-03	5.20E+00	-3.01E+00	1.89E+00	-9.84E-01	-3.29E+00	-2.01E+00	1.00E-06
6.44E-03	5.19E+00	-3.02E+00	1.89E+00	-9.06E-01	-3.31E+00	-2.03E+00	1.00E-06
8.49E-03	5.19E+00	-3.03E+00	1.88E+00	-8.28E-01	-3.33E+00	-2.04E+00	1.00E-06
1.06E-02	5.19E+00	-3.03E+00	1.88E+00	-7.51E-01	-3.34E+00	-2.06E+00	1.00E-06
1.26E-02	5.19E+00	-3.04E+00	1.87E+00	-6.75E-01	-3.36E+00	-2.07E+00	1.00E-06
1.47E-02	5.19E+00	-3.05E+00	1.87E+00	-5.99E-01	-3.38E+00	-2.08E+00	1.00E-06
1.51E-02	5.19E+00	-3.05E+00	1.87E+00	-5.95E-01	-3.38E+00	-2.10E+00	1.00E-06
1.72E-02	5.19E+00	-3.06E+00	1.86E+00	-5.95E-01	-3.38E+00	-2.10E+00	1.00E-06
1.96E-02	5.19E+00	-3.07E+00	1.86E+00	-5.53E-01	-3.37E+00	-2.11E+00	1.00E-06
2.22E-02	5.18E+00	-3.07E+00	1.85E+00	-5.05E-01	-3.36E+00	-2.12E+00	1.00E-06
2.39E-02	5.18E+00	-3.08E+00	1.85E+00	-4.10E-01	-3.34E+00	-2.14E+00	1.00E-06

- Many assumptions in daily life, some right, some wrong: need for education(gently!)
- Monitoring: a lot of noise, hard to capture the effect of single events/actions



Complexity



- Interaction with general public does not allow to do long simulations in the background (3 minute wait for computer run)
- Fast feedback based on a training an algorithm: Artificial Neural Network (ANN)
- Two products:
 - EEE (Energy Efficiency Educator – running on PC)
 - eViz APP (running on Android Phone)

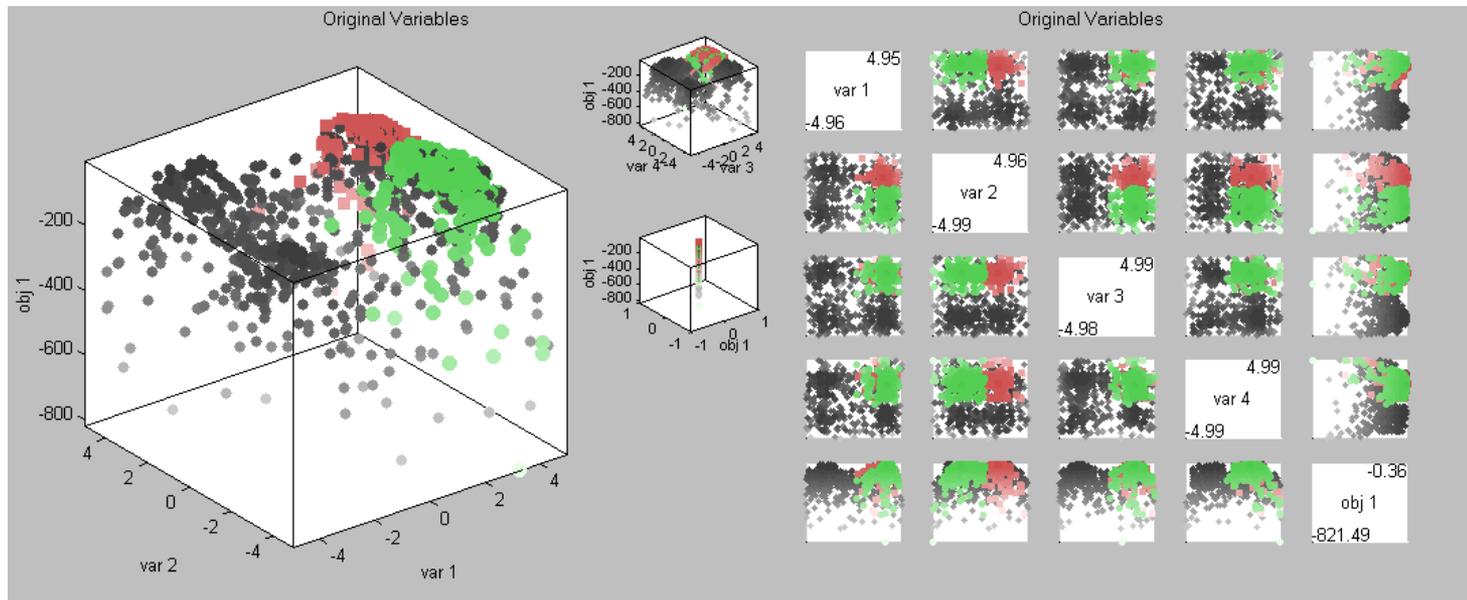
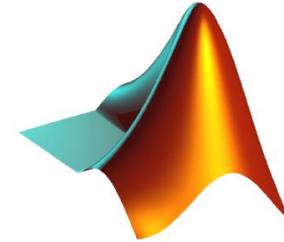
Input for E+ simulations and ANN

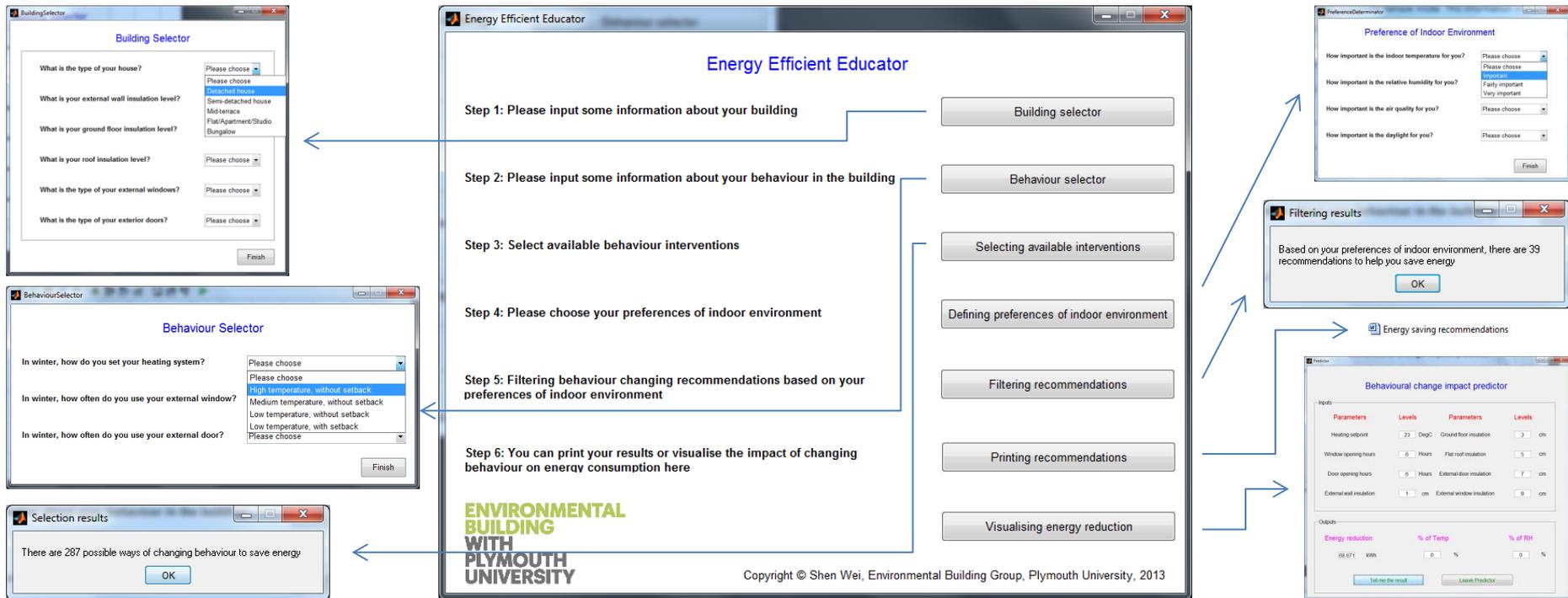
Training data	Testing data
Thermostat setting: 25°C, 23°C, 21°C, 19°C, 17°C, 15°C	Thermostat setting: 24°C, 22°C, 20°C, 18°C, 16°C, 14°C
Window opening time: 6H, 5H, 4H, 3H, 2H, 1H	Window opening time: 5.5H, 4.5H, 3.5H, 2.5H, 1.5H
Window opening time: 6H, 5H, 4H, 3H, 2H, 1H	Window opening time: 5.5H, 4.5H, 3.5H, 2.5H, 1.5H
External window insulation: without, with one layer	External window insulation: without, with one layer
Ground floor insulation: without, with one layer	Ground floor insulation: without, with one layer
Flat roof insulation: without, with one layer	Flat roof insulation: without, with one layer
External door type: single, double	External door type: single, double
External window type: single, double	External window type: single, double

6911 cases

6880 cases

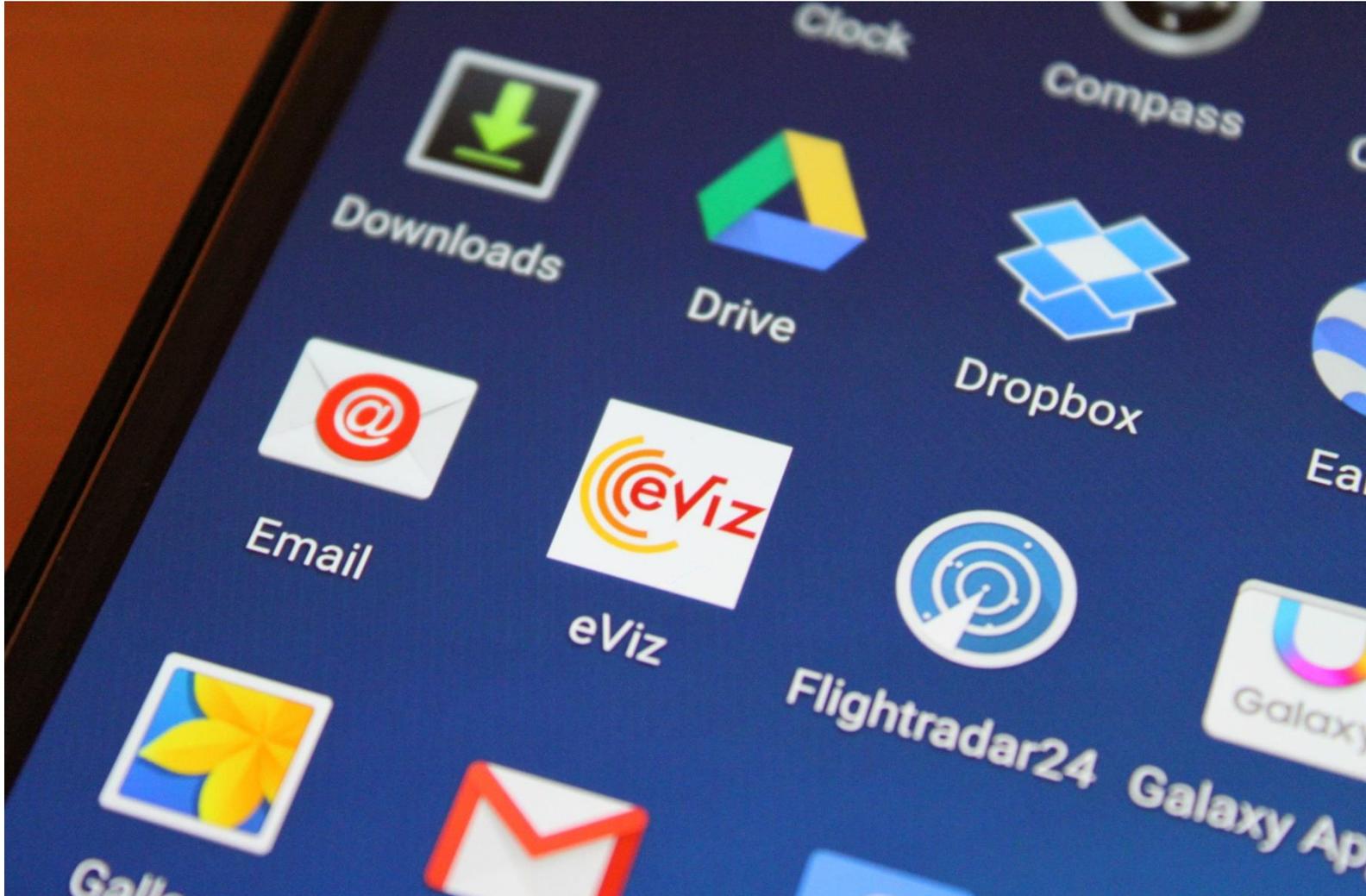
- Matlab environment
- EnergyPlus
- IVCGA



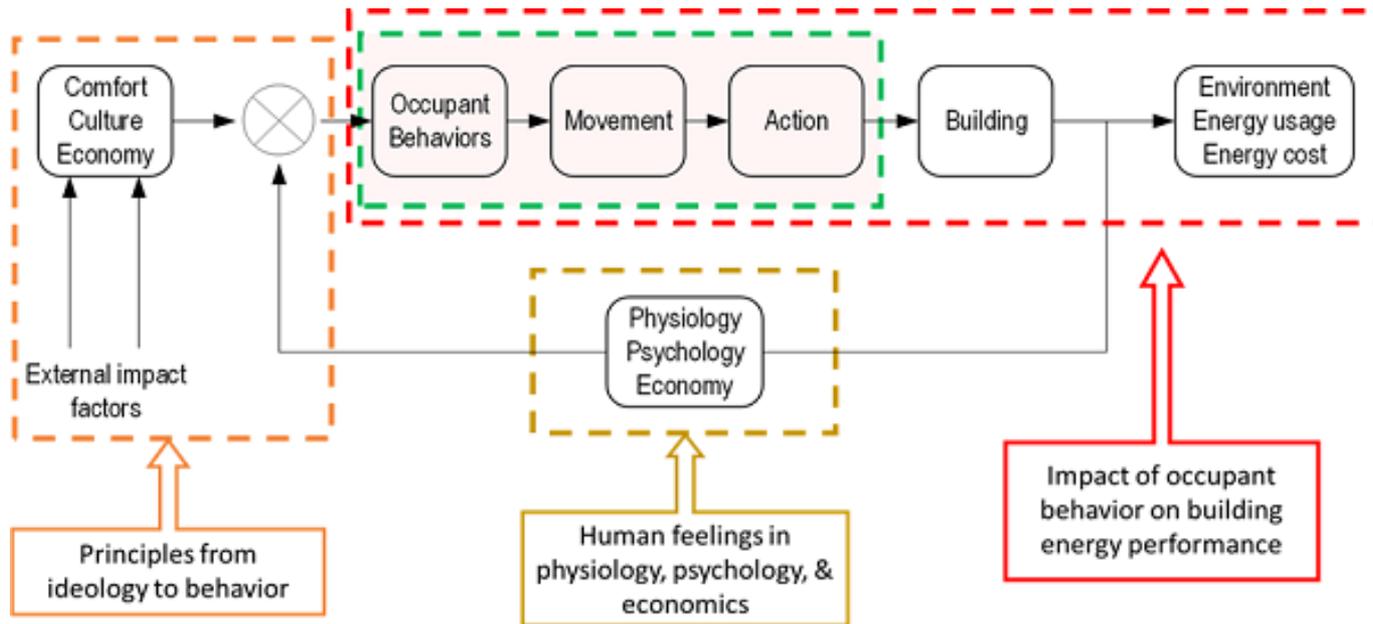


Wei, S., Goodhew, J., Rafiq, Y., Pahl, S., & De Wilde, P. (2015). Energy efficiency educator – early stages of an interactive tool to help reduce heating energy demand in residential buildings. *Proceedings from the European Council for an Energy Efficient Economy 2015*, France.

eViz APP



Definition and Simulation of Occupant Behavior in Buildings

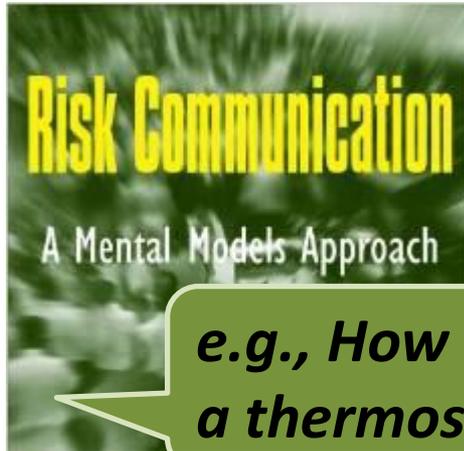




... are they really? Might there be other parts of the system that could be described as 'buggy'?

It's important to consider people – their mental models; their behaviour and understanding – and to build people-focused systems and interfaces

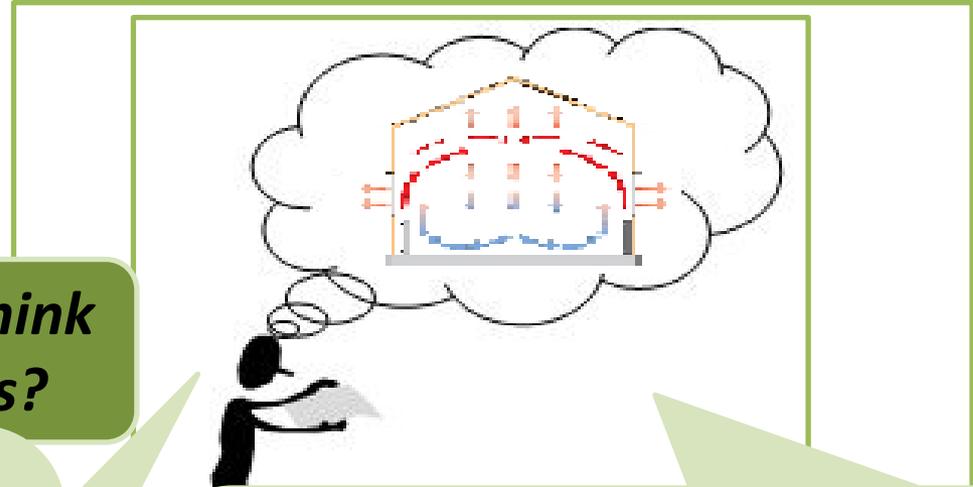
Mental Models



e.g., How do you think a thermostat works?

“The thermostat sends a signal to the boiler which means that the boiler will not cut out when it reaches 15°C, it will cut out when it reaches 20°C”.

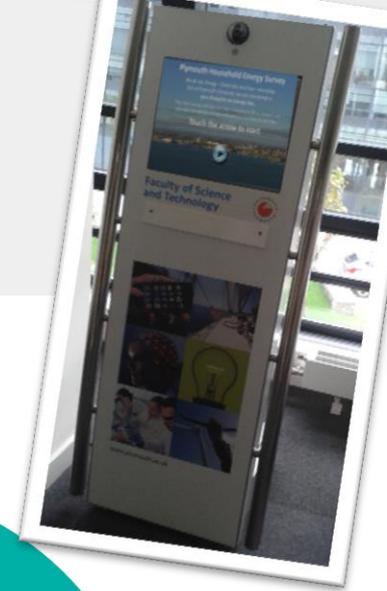
= FEEDBACK MODEL (n= 12)



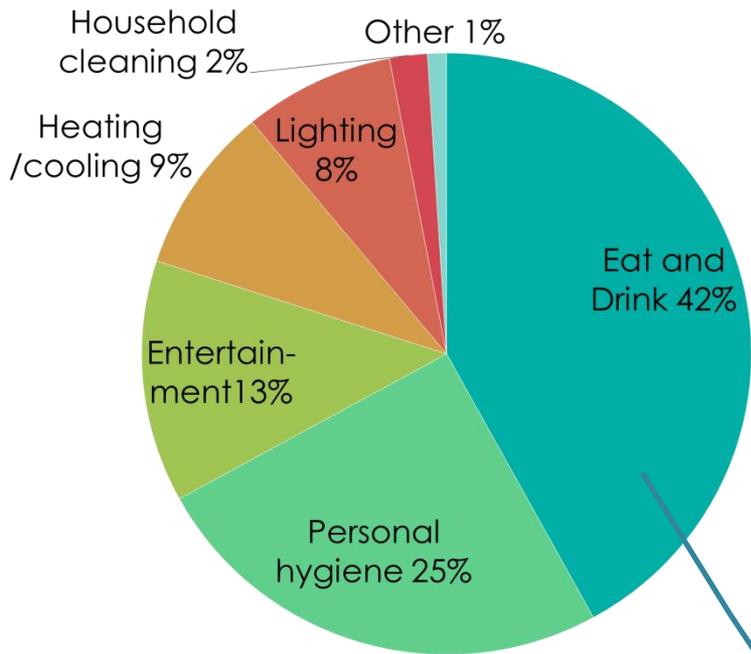
“When you turn it up, it’s a bit like a gas hob, you turn it up, more gas comes out. Maybe there is a valve that opens to let more heat through”.

= VALVE MODEL (n= 12)

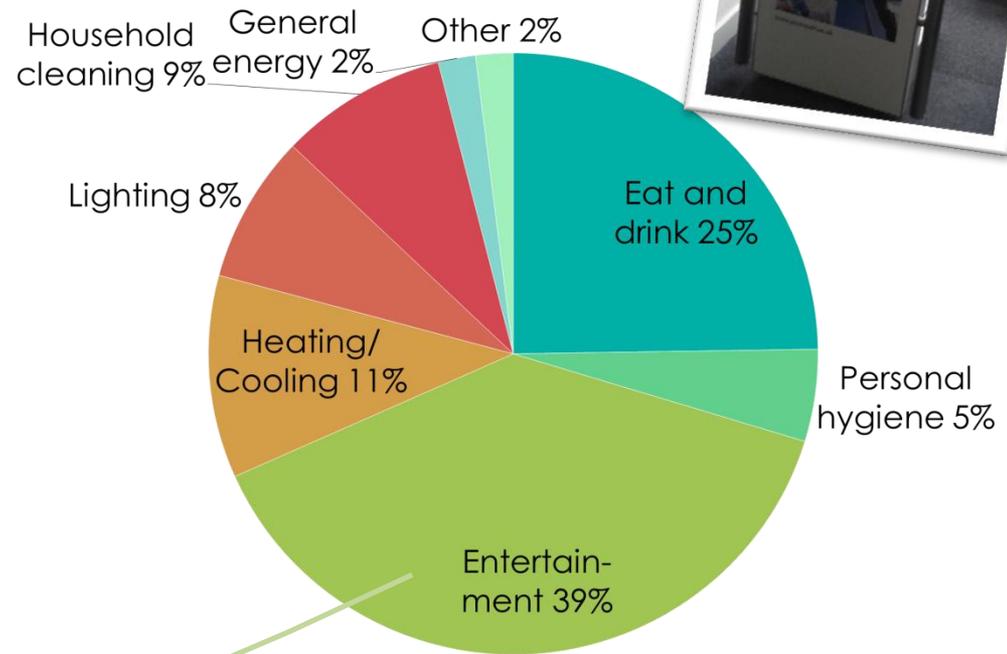
Energy understanding regarding daily behaviours



Morning

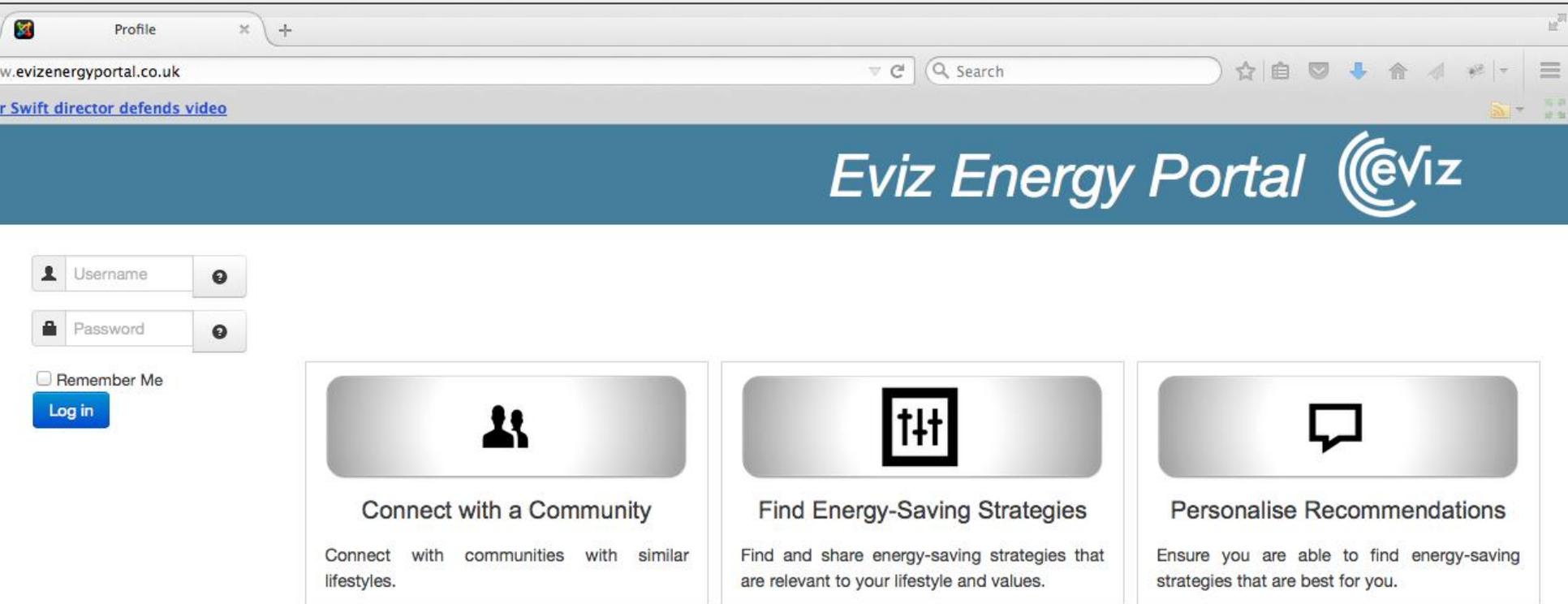


Evening



People think the **Kettle** consumes most energy in the morning

People think the **Television** consumes most energy in the evening



The screenshot shows a web browser window with the URL www.evizenergyportal.co.uk. The page features a blue header with the text "Eviz Energy Portal" and the eViz logo. Below the header, there is a login section with a "Username" field, a "Password" field, a "Remember Me" checkbox, and a "Log in" button. To the right of the login section, there are three feature cards: "Connect with a Community" (with a person icon), "Find Energy-Saving Strategies" (with a lightbulb icon), and "Personalise Recommendations" (with a speech bubble icon). Each card includes a brief description of the feature.

Screenshot of Login Page

Users are able to create, share and interact with energy-saving strategies that are relevant and personalised to their own values and lifestyle.

Hi Rachel,

[Log out](#)

[HOME](#)

[PROFILE](#)

[STRATEGIES](#)

[COMMUNITIES](#)

Strategy

Strategy Title

Batch Cooking

Strategy Description

... write a short description of your strategy here

Supported Values

- Health and Wellbeing
- Hobbies
- Family and Friends
- Career
- Nature
- Food and Drink

Lifestyle Label

easy × kitchen ×
time-saver ×

Strategy Image

[Browse...](#) No file selected.

[Submit](#) or

[Cancel](#)



Screenshot of Strategy Input Form

Users contribute their own energy-saving strategies and associate this information with their values and lifestyle -> *user-generated content*

Eviz Energy Portal



Cooking in Batches

Written by Gilly

Category:

Uncategorised

Published: 03 September 2015

Hits: 20



Vote 5

Rate

Cooking in Batches

Values

[Health and Wellbeing](#), [Food and Drink](#)

Batch cooking by cooking in larger quantities and saving two or three meals in the freezer works really well for me.



[Next >](#)

Comments

Partial screenshot of Strategy Display Page

Users search for and organise strategies according to individual and community values.

Users can interact with other community members to vote, discuss, rank and save strategies to their personal strategy collections.

Burrows et al., (2015).
Proceedings from INTERACT'15

Burrows et al., (2014).
Proceedings from BEHAVE'14

Burrows et al., (2014).
Proceedings from
PERSUASIVE'14

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2. The role of behaviour and understanding
Sovereign Housing, Diary study, EEE/app
Mental models, Social media
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2. Why Visualisation?

From the psychology and social science literature



50%
of the brain
used for visual
processing



70%
of the sensory
receptors are
in the eyes



100ms
to get a
sense of the
visual scene

<http://blog.crew.co/6-things-know-brain-learns/>
Image credit: Amit Kapoor

Important for attention, interest, memory, elaboration and emotion (cognition & motivation; Holmes & Mathews, 2010)

Can provide cues for action; potential to facilitate new behaviours that break habits

Visuals

Can be linked to tailoring, feedback and goal setting

Communicate messages quickly and powerfully (Sheppard, 2005)

Overcome language or knowledge barriers (O'Neill & Smith, 2014)

Condense complex information (Nicholson-Cole, 2005)

Pahl et al., under review

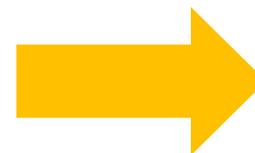
2. Why Visualisation?



- Energy is abstract and invisible to the end user
- Unlike petrol gauge in our car or store of food
- Energy use is not 'primary' behaviour
- Difficult to understand how much energy we use
- Energy use is not easily connected with actions

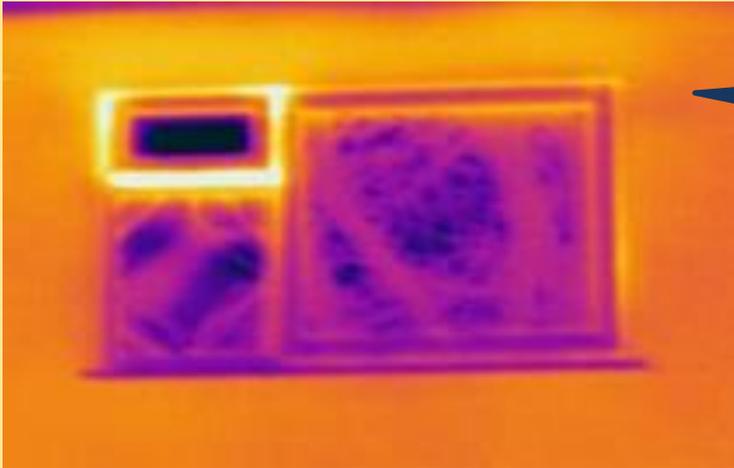
Increased interest in 'making the invisible visible'

E.g. smart meter roll out



2. Why Visualisation?

Energy visualisation



Immediate reaction

What a terrible waste! I ought to close that window

Later consequences

Cue: Householder opens window

Must remember to close it in a minute – that looked bad

Cue: Heating starts up

I wonder if the windows are open upstairs – vivid image

End result:
Energy demand reduced

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Virtual Reality Flat



We developed an interactive virtual reality tool for people to explore and interact with. There are different 'modules'

Virtual Reality Flat

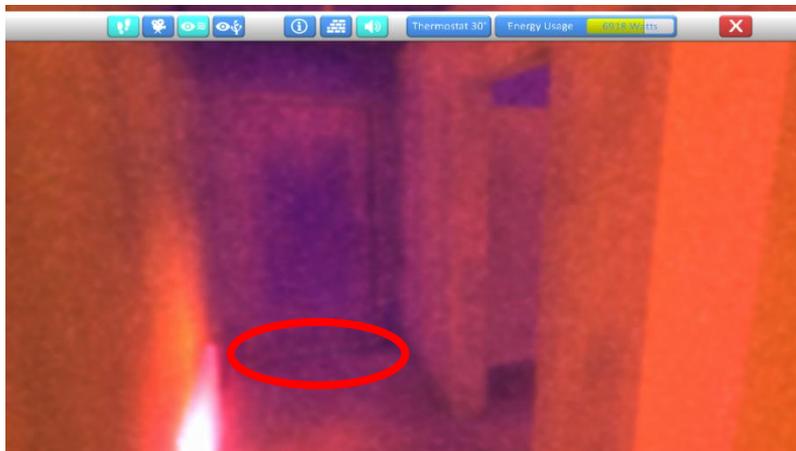


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For example, an avatar is shown and users of the VR tool are asked to help him save energy



Virtual Reality Flat

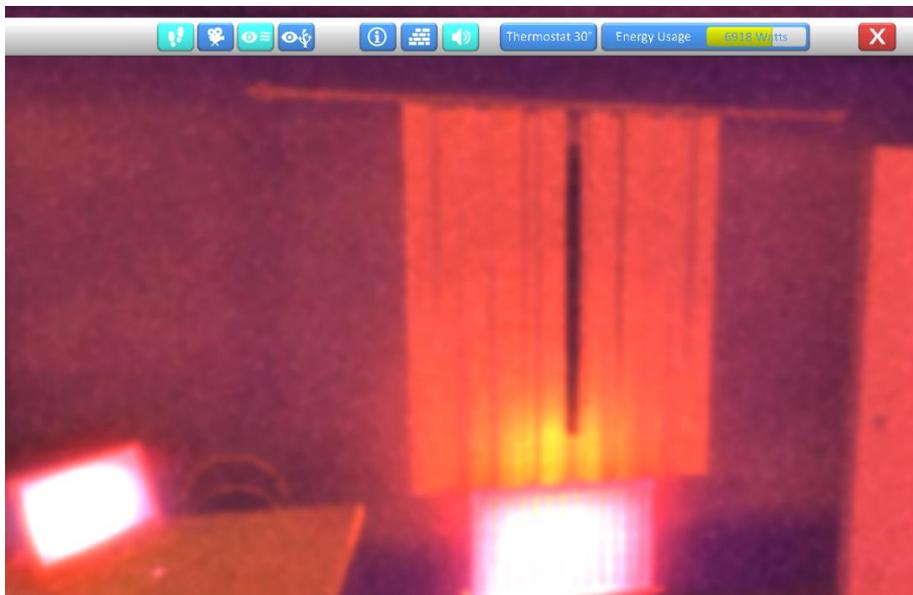
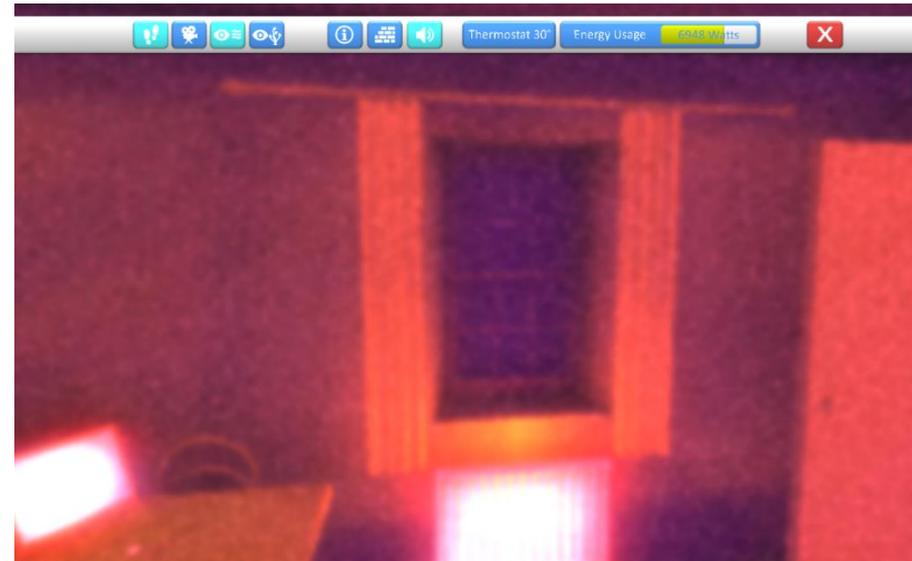


For example, a thermal imaging representation shows heat escaping and the effect of action taken against such heat escape, here adding a draught excluder to close a gap at an external door.

Stone et al., (2014).
Boomsma et al., (in revision)

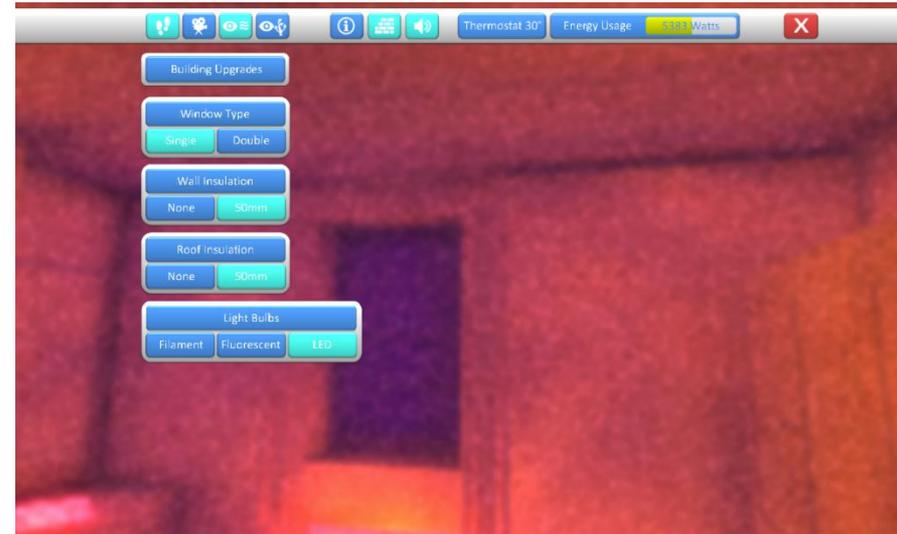
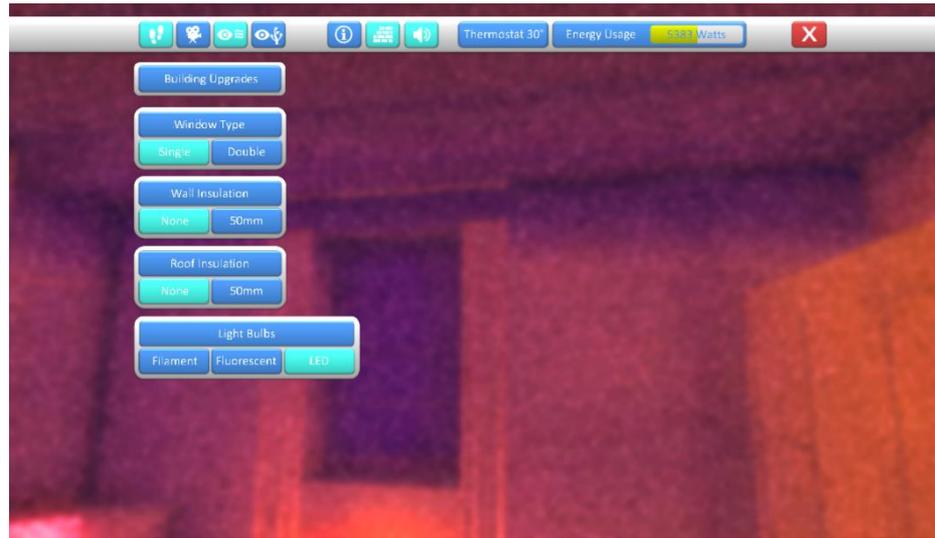


Virtual Reality Flat



Thermal imaging can also represent different actions surrounding windows and curtains.

Virtual Reality Flat



Fabric upgrades can be made by a user and feedback is provided via the thermal imaging representation and simple energy use feedback
Current work is focusing on access to the tool via a smart in a VR 3D headset

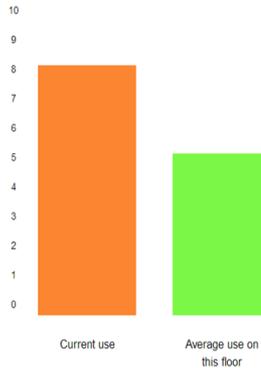
KNOW YOUR FLOOR



Interested in the electricity use on your floor?

Know Your Floor - Floor 1

Is your floor using less electricity than usual?



Electricity use on your floor
 Now 8.38 kW
 Usually 5.55 kW
 Last update 11 Mar 2014 12:15

Usual use is the average use at this time and day on your floor over the last 5 months

Hints and tips

Floors 1 and 4

Know Your Floor - Floor 2

Is your floor using less electricity than usual?



Electricity use on your floor
 Now 4.57 kW
 Usually 5.59 kW
 Last update 11 Mar 2014 12:15

Usual use is the average use at this time and day on your floor over the last 5 months

Hints and tips
 Home Time Switch-Off
 Did you know that 200 lights left on all day and night in this building use about 280 kWh a day. So switching the lights off at night could avoid wasting 52,000 kWh - that's over £5,200 a year.

Floors 2 and 3

'Know your floor' A study on the use of visual feedback in a workplace setting

Boomsma et al., (under review) Encouraging energy saving in the workplace

Barriers and lessons

- People were keen but had limited opportunities for savings
- Need for management and context to be responsive:
 1. Other circumstances, e.g., heating
 2. Highly challenging work environment
 3. Open plan offices

“There is no individual control on the radiators, therefore when it's cold we have to use electric heaters and when it's hot we have to have the windows open despite the heating being on.”

“Sometimes people rush out of the meetings with 27 action points and its life or death and they have got to get this child now. They rush out the room and they are not thinking: have I checked the window?”

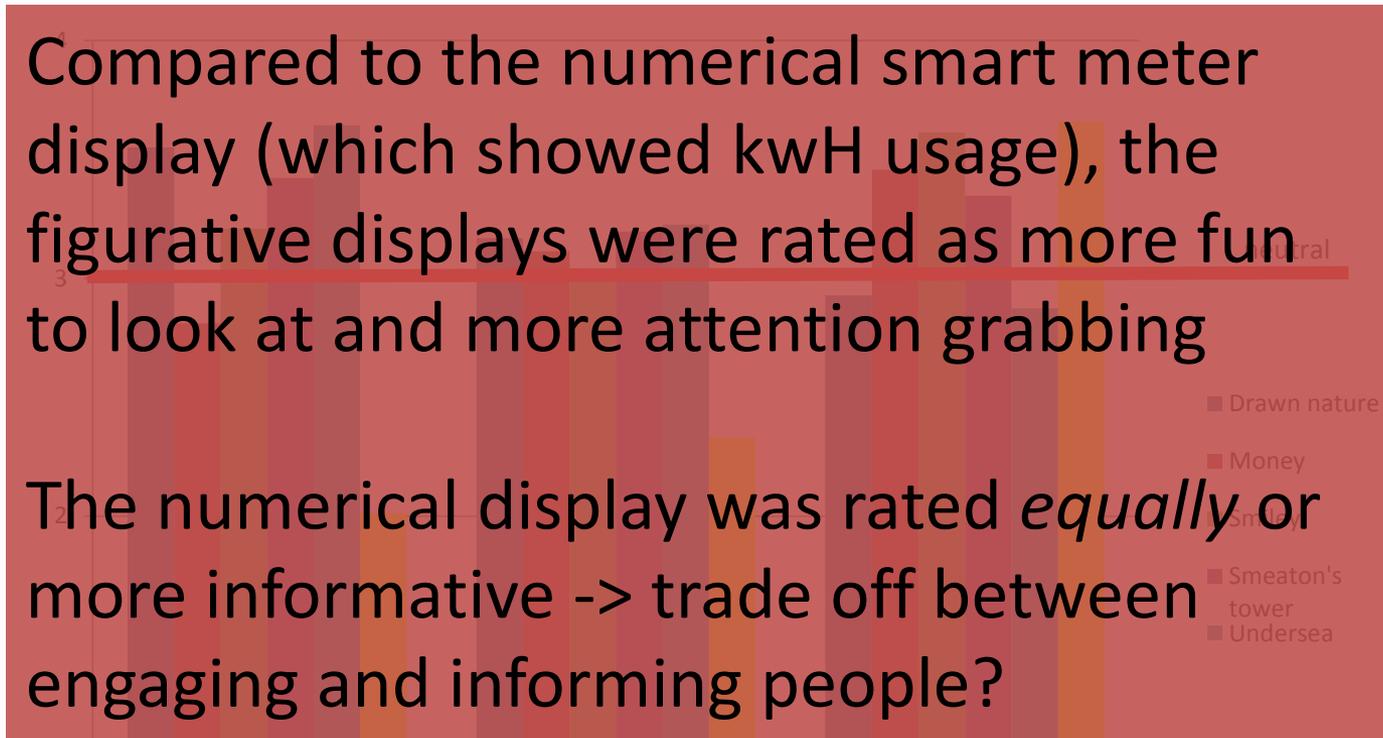
Smart meter displays

How can we maximise the effect of smart meter IHDs?



Smart meter displays

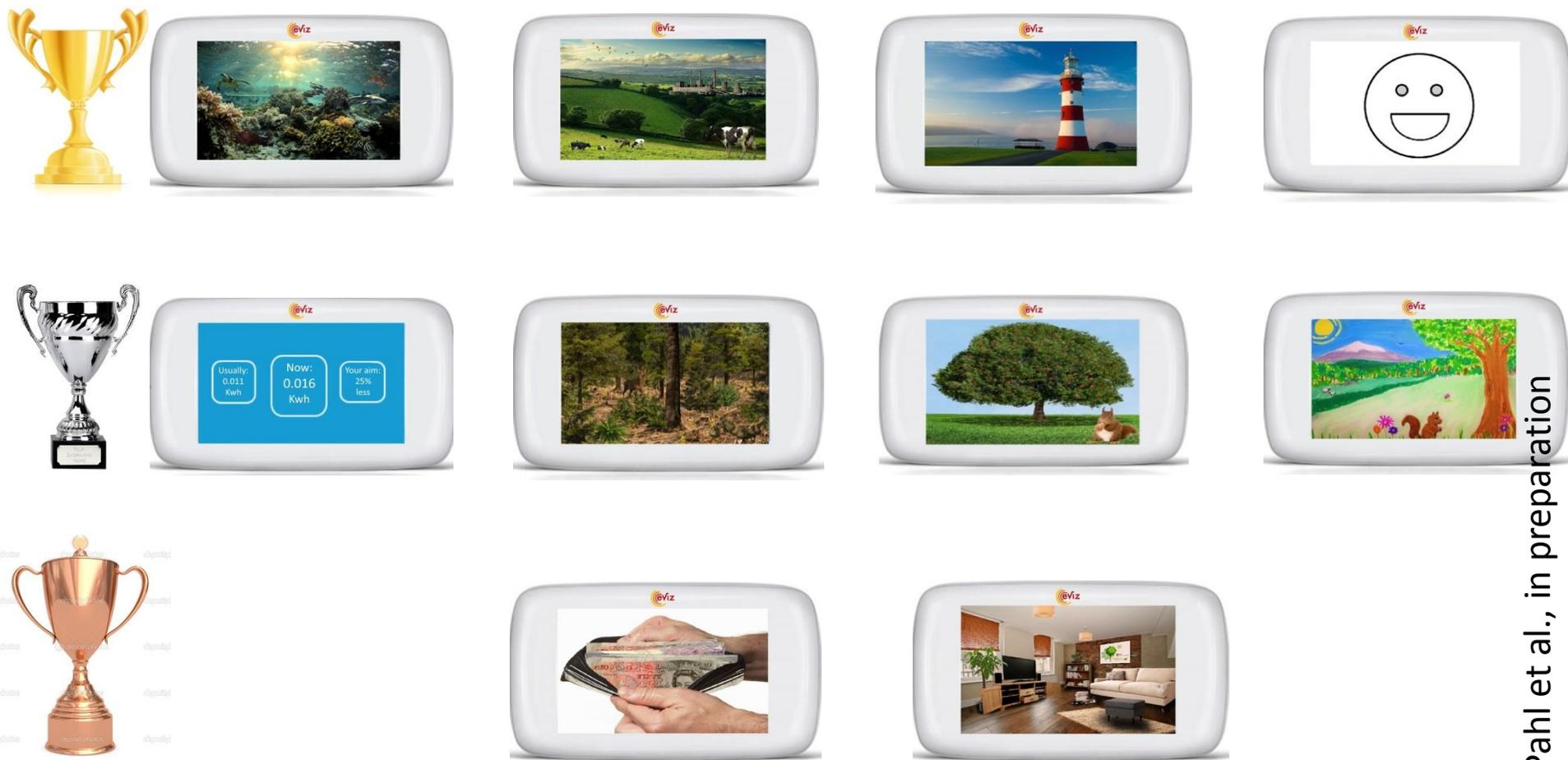
Ratings of selected viz (see previous slides) compared to



1 = strongly disagree to 5 = strongly agree

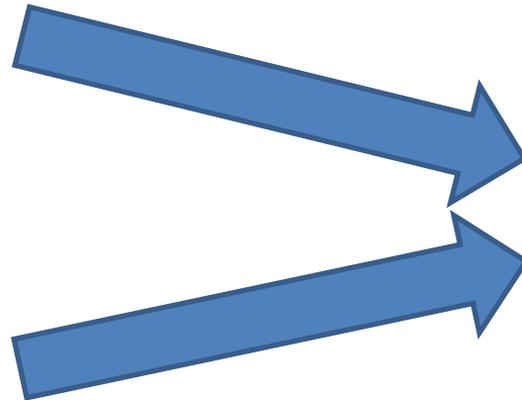
Smart meter displays

Preferences 1-2 weeks later



What's important for people's motivation to save energy when we use smart meter displays?

Two key aspects: FUN and INFORMATION



No influence of age, gender, students vs. general public, bill payer or not; numeracy?
(Based on regression analysis predicting motivation in 80 participants)

Thermal Images



Cold spots on the ceiling – insulation missing?

Gap under external door



- CO₂ emissions reduced by 0.75 tons in TI group; no change in audit or control group (from energy bills)
- TI performed more energy efficiency actions than audit or control
- 20% of householders reported draughtproofing measures in TI group compared to 3% in audit group

So far all tailored / personalised to own home; highly relevant / diagnostic

Does thermal imaging have to be tailored to your own home?

Question of cost and effort

Thermal – Tailored



Report with thermal images of their own home

Thermal – Targeted



Report with thermal images of a typical home, showing issues commonly found in homes in this area

Text - Targeted

DOORS:
Colder air often enters the house via draughts around, at the top and the bottom of an external door. Cold air can enter the house at the point where patio doors meet in the centre. Cat flaps in doors can allow cold air to enter the house

CEILINGS:
Heat escapes and cold air enters the house where loft insulation is of reduced thickness, missing or misplaced. Loft hatches often get forgotten when loft insulation is fitted.

FLOORS AND SKIRTINGS:
Cold draughts can enter the house from the floor and walls at the skirting boards, especially if the ground floor is wooden and suspended.

Report with text only, same information as the thermal-targeted group

**Results after 2 weeks and after 1 year
-- Preliminary analysis --**

Results two weeks after the intervention



- More social sharing and discussion for thermal **tailored** than thermal **targeted** or **text**
- Thermal **tailored** more powerful memory than thermal **targeted**, which was more powerful than **text**
- *Have they done anything already?* Thermal **tailored** more than thermal **targeted** or **text**

Results one year after the intervention

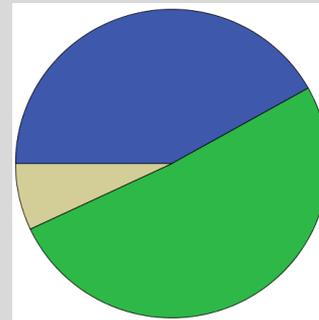
Frequency of energy actions per household:

On average, **tailored**
thermal imaging
led to about twice as
many actions as did
targeted or **control**

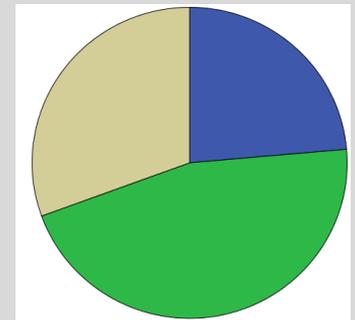
$F(2,112) = 4.66, p = .011; \text{Eta sq} = .08$

Frequency of actions in categories

Targeted &
text



Thermal
tailored



$\chi^2 (2, N = 113) = 9.99, p = .007.$

What were the actions that were most popular, and where were differences between the groups?

Tailored thermal imaging was associated specifically with draught proofing doors and windows, with changing curtains (e.g., adding curtains where there were none before or upgrading to heavier curtains), and with sealing fireplaces (compared to targeted and control)

Both tailored and targeted thermal imaging was associated with loft insulation and improved glazing (compared to control)

Thermal Imaging – illustrative quotes



“That’s amazing actually..... It’s amazing actually the amount of heat that’s coming from this part here look and that door and things”

“The thermographic pictures showed where the problems were”

“That’s it we’re having more insulation”

“Wow that looks dreadful”

“In process of getting external wall insulation- need shown by imaging”

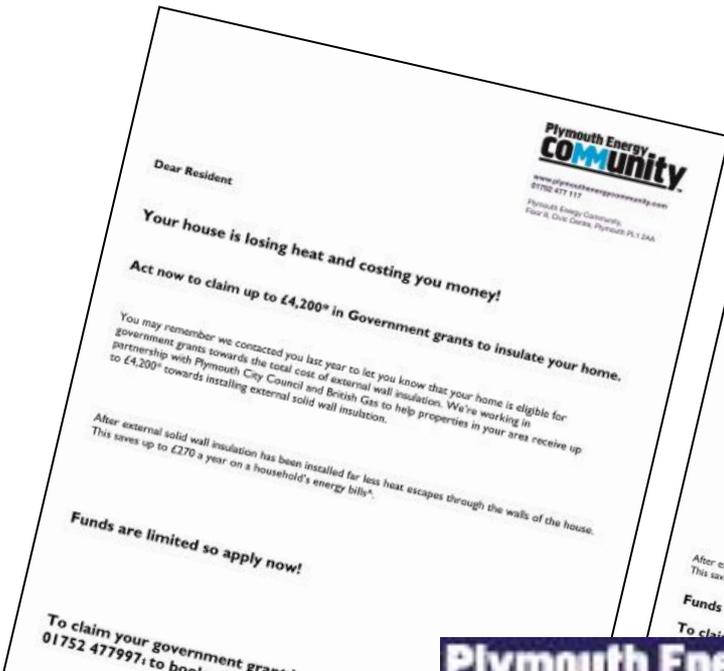
“I’ve got my children to close the curtains at dusk and am investigating some extra insulation in the eave area of the roof.”

“Having been shown where the “cold spots” are, I’m trying to stop them.”

Trial with PCC and BIT



targeting external solid wall insulation



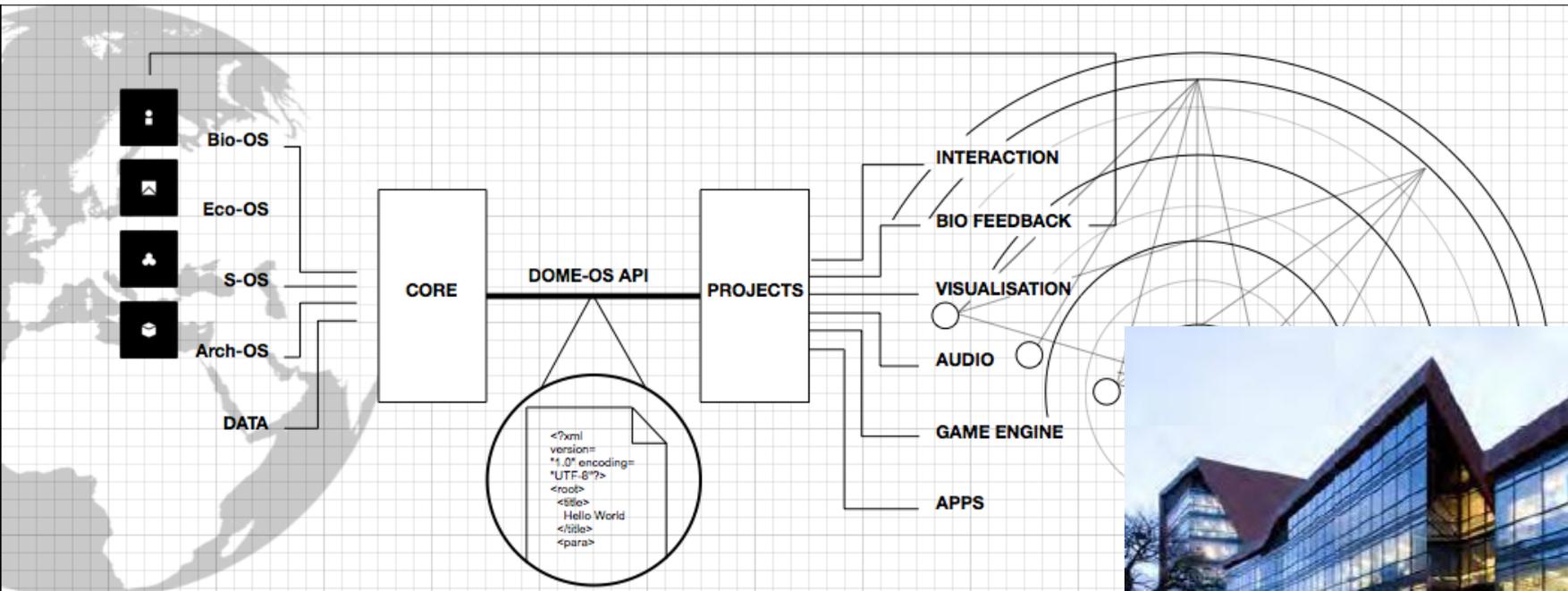
THE
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INSIGHTS TEAM



Immersive eViz movie (in development)



Immersive thermography



1. The eViz Project
2. The role of behaviour and understanding
Sovereign Housing, Diary study, EEE/app
Mental models, Social media
3. Visualising energy
 1. Why visualisation?
 2. eViz examples
VR flat, PCC study,
Viz lab study, Thermal imaging
4. Conclusions
5. Future directions



4. Conclusions

- Different approaches to visualisation
 - a) System and impact of actions (VR flat)
 - b) Current energy use compared to baseline (Social worker study)
 - c) Heat escaping in specific locations in the home (thermal imaging) -> *most evidence so far*
- Key challenge: making energy **meaningful and engaging**, and translating this excitement into **measurable demand reduction**

4. Conclusions

- Work with people/occupants/end users and build any technical solutions around their perceptions, values , concerns & daily tasks
- Motives include financial savings but there are more (avoiding waste, doing the right thing, conforming to the norm)
- Visualisation is powerful but won't work in isolation – need trust, a supportive context
- Unclear how best to integrate diagnostic and engagement tools

5. Future Directions

International collaborations

EnerGAware (H2020 project that started 2015)

IEA Annex 66

IEA DSM task 24

Looking for partners to

- test smart meter viz in situ and assess energy understanding, behaviours and savings
- test tailored and less tailored thermal imaging in different contexts and for different outcomes
- cost-benefit analyses

eden project



Department
of Energy &
Climate Change

energy
saving
trust

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IN PARTNERSHIP WITH  Cabinet Office

regensw
delivering sustainable energy

...and many other partners in our field studies,
our technical office at Plymouth and all the
participants in our studies



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