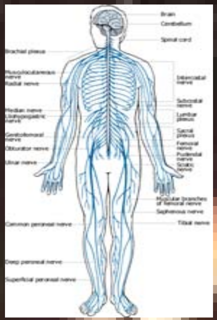
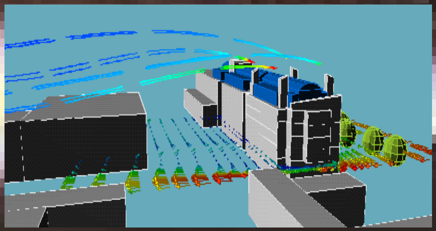
Energy systems modelling

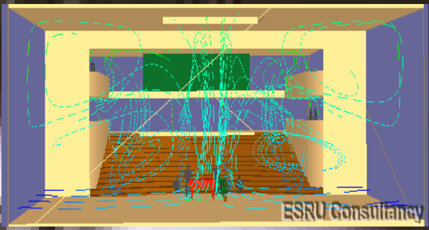


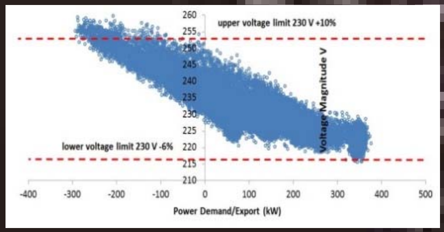
Energy systems are **dynamic**, **non-linear**, **systemic** and **stochastic**.

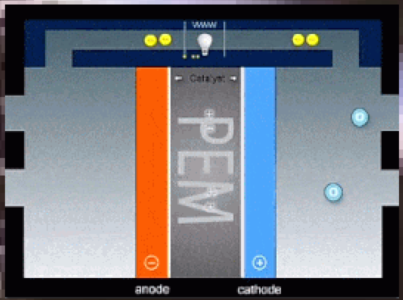
Most decisions are ill-informed.

Simulation supports multi-variate assessments.









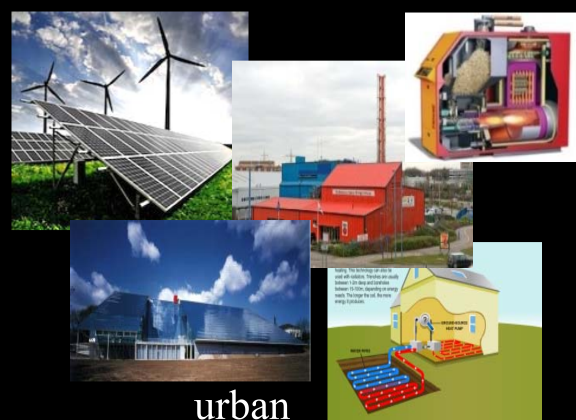
Myriad supply side transition options

fossil fuels

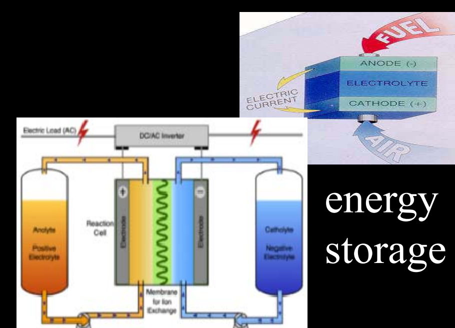
strategic renewables (present)

strategic renewables (future)

nuclear



urban renewables



energy storage

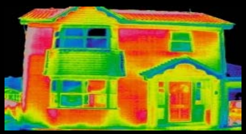
Clean energy transition agendas inextricably link supply and demand issues.

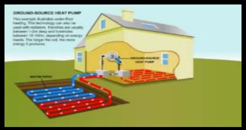
Myriad demand side transition options

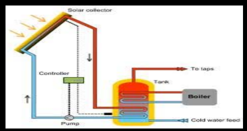
- daylight utilisation
- adaptive facade
- smart control
- demand management
- passive solar devices
- heat recovery
- ventilation preheat
- switchable glazing
- selective films
- advanced insulation

- moveable devices
- breathable walls
- phase change materials
- smart meters & grids
- electric vehicles
- condensing boiler
- heat pumps
- combined heat & power
- tri-generation
- integrated photovoltaics

- desiccant cooling
- evaporative cooling
- electricity to heat
- smart space/water heating
- urban wind power
- biomass/biofuel heating
- culvert heating/cooling
- district heating/cooling
- energy storage
- fuel cells and hydrogen





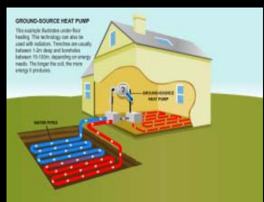


Trends: growing diversity & complexity; scale extension; linking of energy, environment, wellbeing and productivity; life cycle assessment including uncertainty and risk; retrofit planning; policy development.

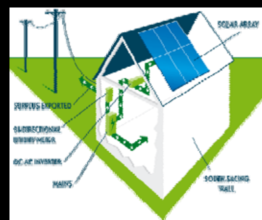
Virtual prototyping is required to select from competing possibilities.

Myriad confounding issues

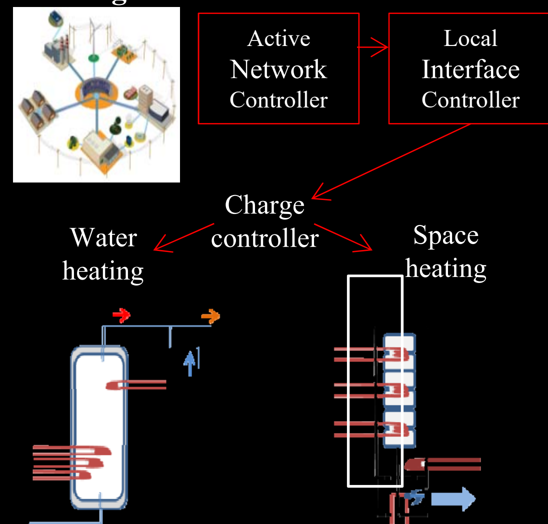
Electrification of heat



Net-zero energy

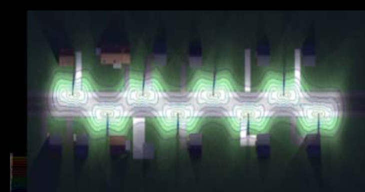


Smart grid



District heating/ power

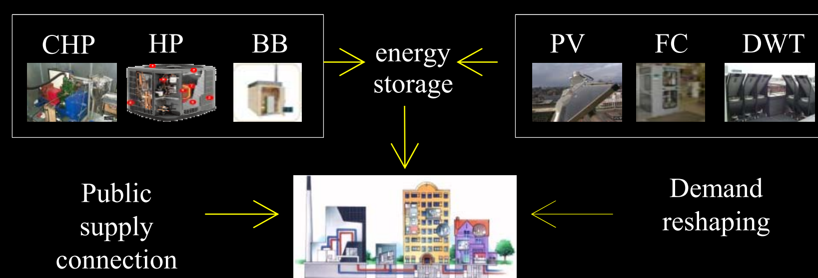
Smart districts



Electric vehicle charging

Embedded RES

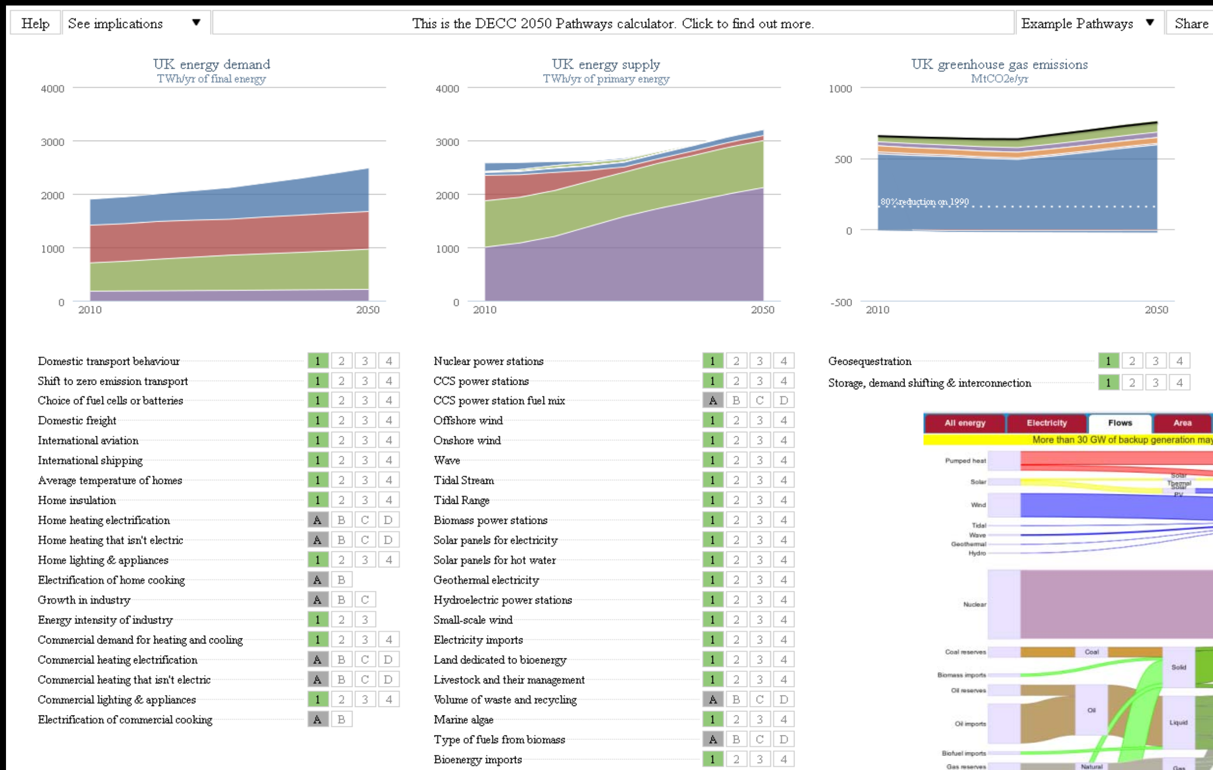
Energy service companies

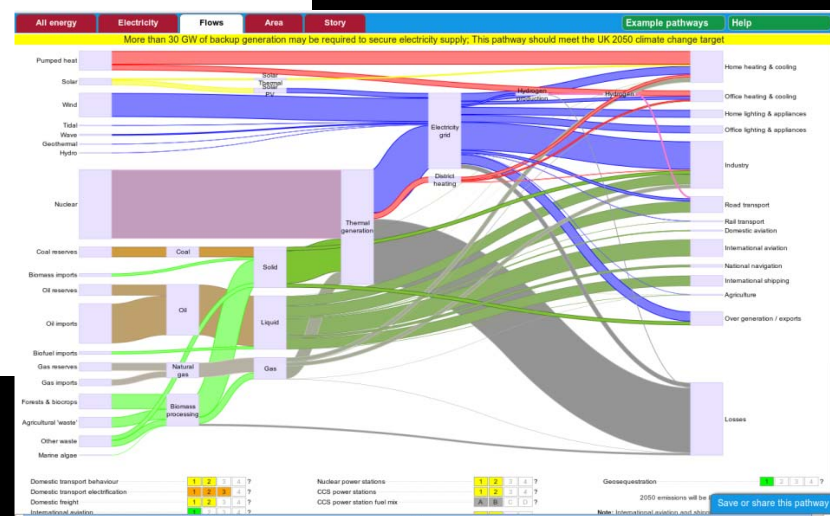


Cost reduction
Wellbeing
Fuel poverty
Air quality
Hybrid systems
Smart control
Network impacts
Comms resilience
Supply resilience
New business models
Legislation compliance
Unintentional impacts
Stochastic influences
Work practices
Policy conflicts

Requires whole system thinking and agreement on analysis scenarios and criteria.

Model type 1: government statistics (e.g. 2050 Calculator)



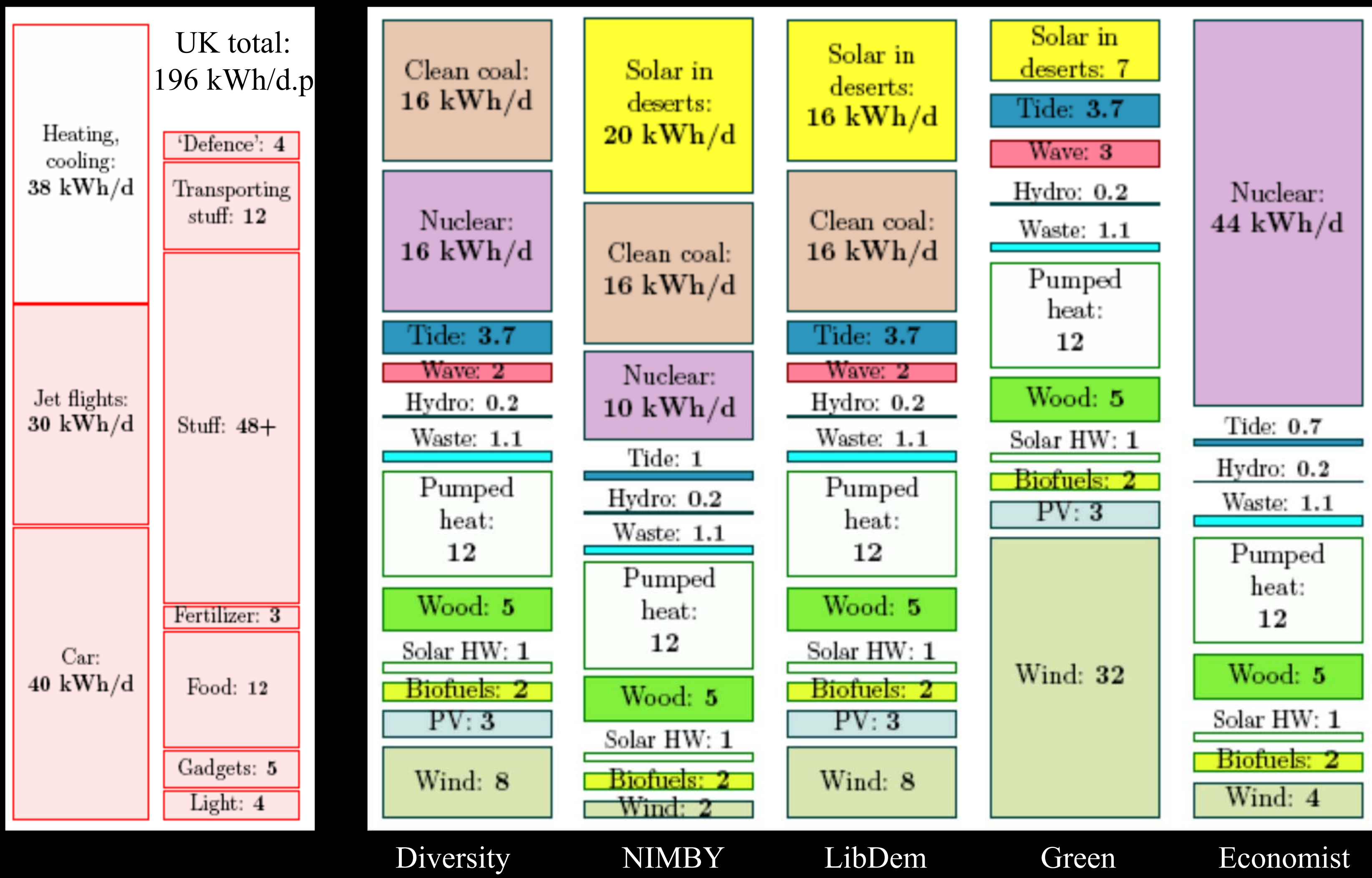


*(**2050-calculator**-tool.decc.gov.uk/)*

China: http://2050pathway.chinaenergyoutlook.org/
India: http://indiaenergy.gov.in/
South Korea: http://2050.sejong.ac.kr/
Taiwan: http://my2050.twenergy.org.tw
South Africa: https://www.environment.gov.za (link middle left of homepage)
Belgium: http://www.climatechange.be/2050/ and also Wallonia (a region of Belgium): http://www.wbc2050.be
Japan: http://www.2050-low-carbon-navi.jp/web/en/ (english) http://www.2050-low-carbon-navi.jp/web/jp/index.html (Japanese)
Draft version for Indonesia: http://calculator2050.esdm.go.id/
Draft version for Thailand: http://122.155.202.232/

Sustainable energy options

Source: MacKay, www.withouthotair.com



Issues: new technology vs. lifestyle change; political imperative; balance of options; supportive legislation.

Model type 2: performance tracking via 'big data'

Queries:
- ❑ energy use profiling;
- ❑ heat-to-power ratios;
- ❑ district heating feasibility;
- ❑ daylight/solar/wind access;
- ❑ fuel poverty distribution;
- ❑ carbon maps.

metered data

database of actual & future consumption

remote monitoring

scenario simulation

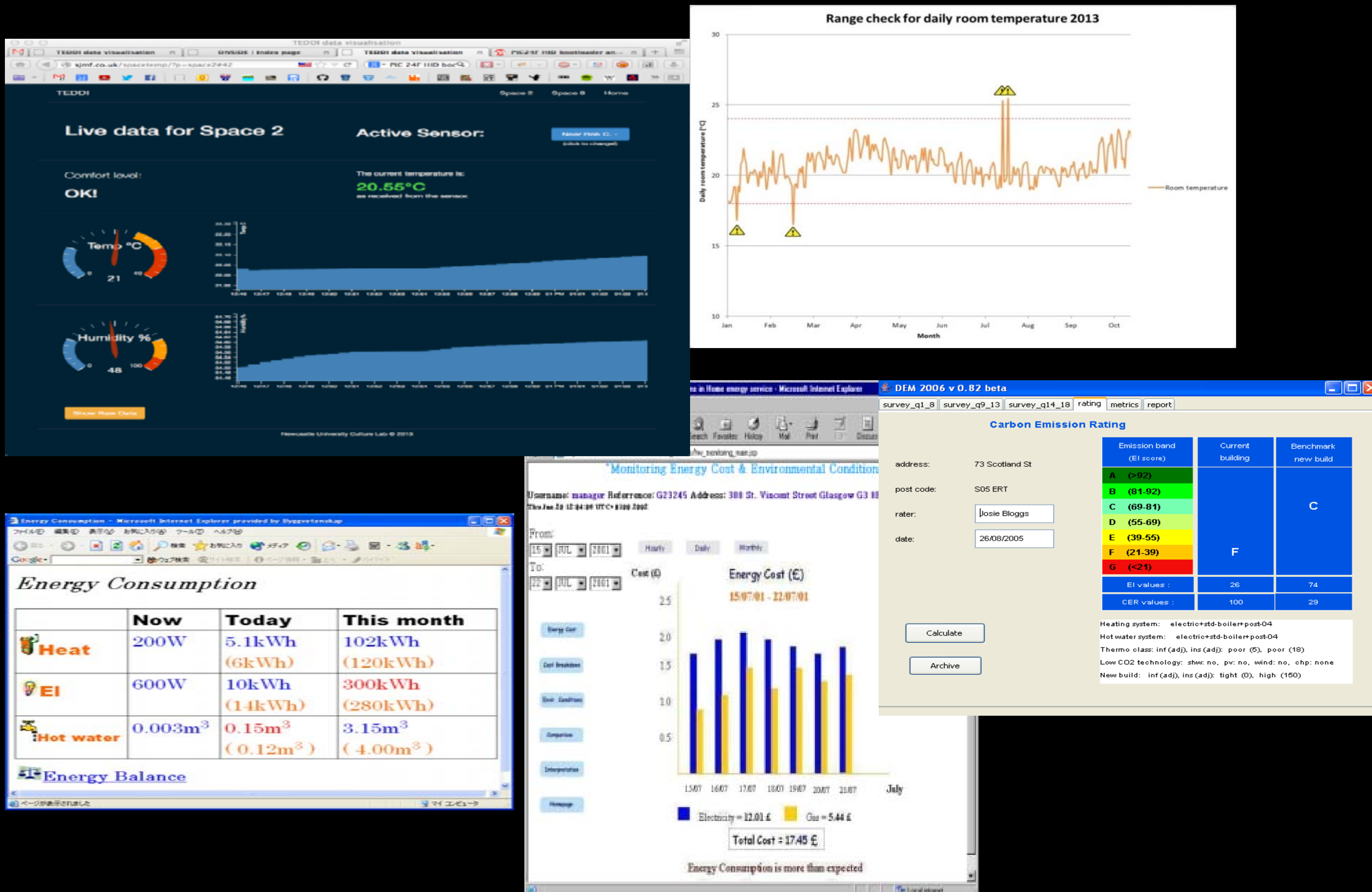
e-Service delivery:
- ❑ alarms & alerts;
- ❑ conditions monitoring;
- ❑ local & aggregate control;
- ❑ health services;
- ❑ information.

information for government, local authorities, institutions, industry, utilities, citizens and others

consumption/emissions monitoring; city profiling; property classification; trend analysis; action planning; equipment monitoring/control; post-occupancy impact assessment; target attainment

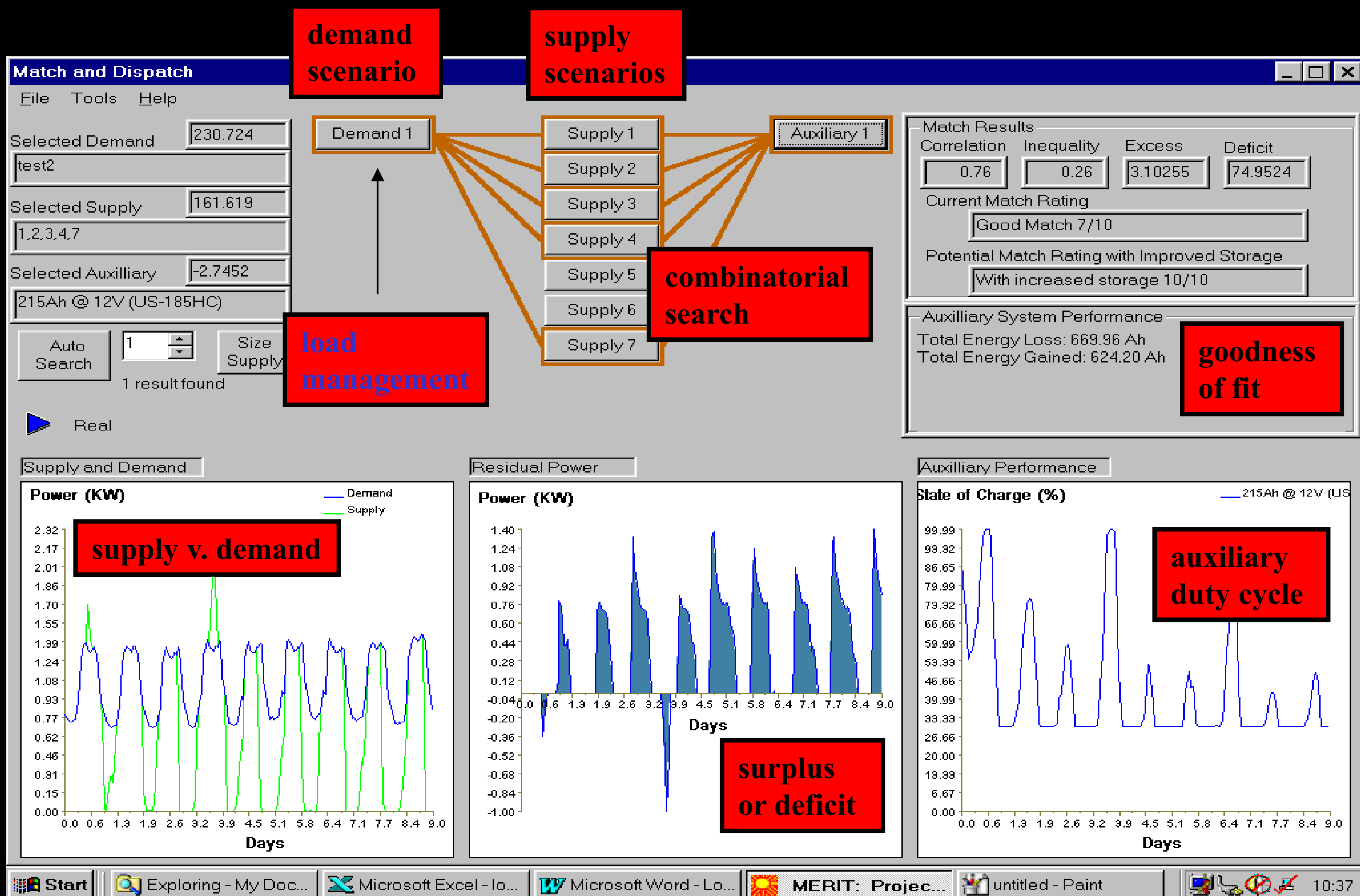
Issues: resilient comms; cybersecurity; consumer participation; ESCo growth; service quality assurance.

eServices



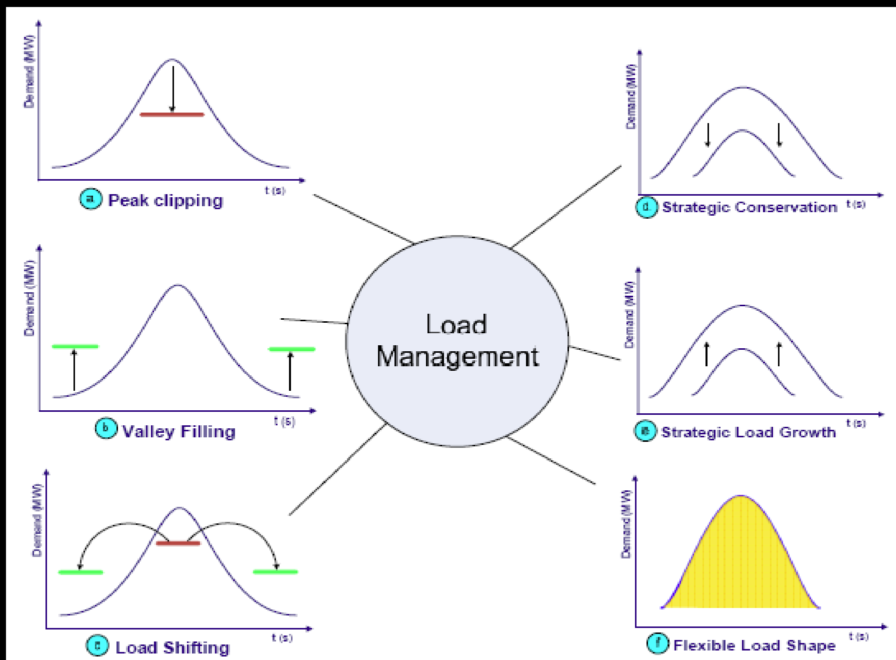
EnTrak (https://www.strath.ac.uk/research/energysystemsresearchunit/applications/entrak/)

Model type 3: matching supply and demand

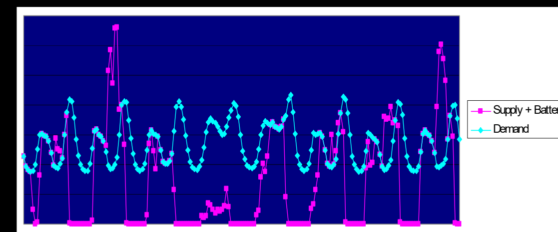


Merit (https://www.strath.ac.uk/research/energysystemsresearchunit/applications/merit/)

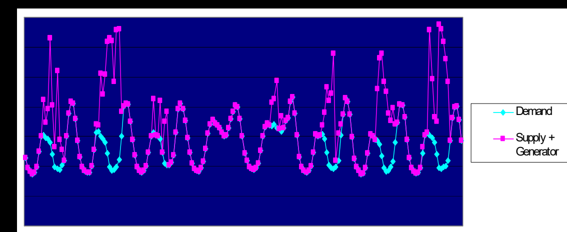
Demand management/response

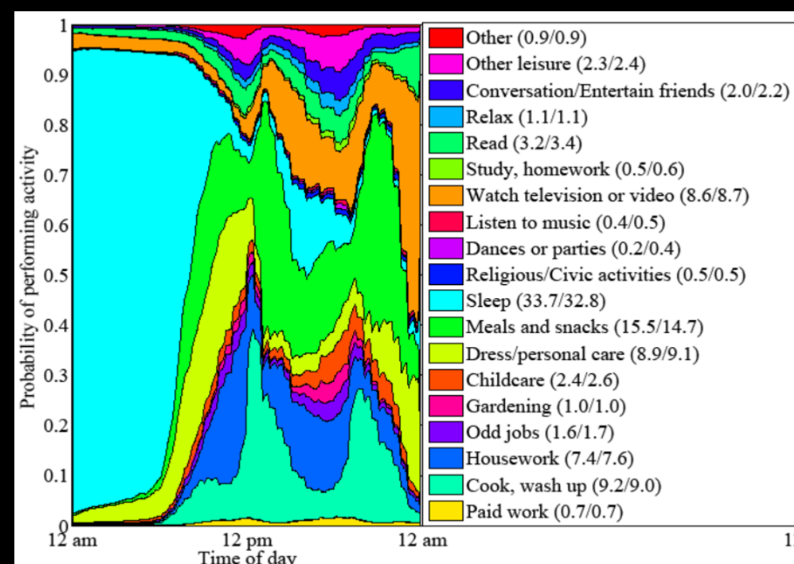


62%



81%

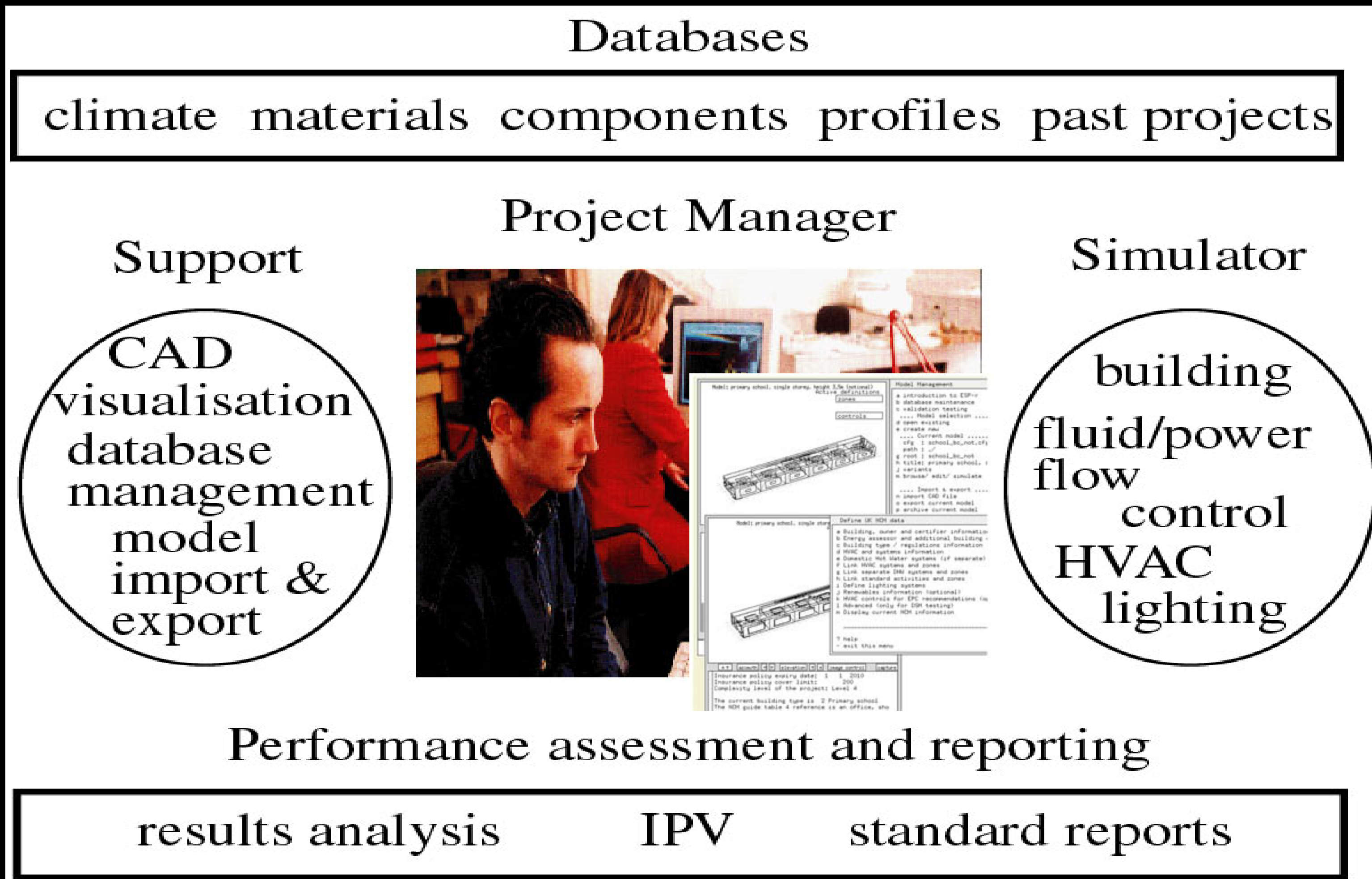




(Robinson, 2012)

Issues: active network control; user needs and expectations; who benefits; unintentional impacts; tariff complexity; understanding building physics.

Model type 4: energy systems simulation



https://www.strath.ac.uk/research/energysystemsresearchunit/applications/esp-r/

Simulation predicates

Energy processes are dynamic

Continuity:
$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

X – Momentum:
$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}=-\frac{\partial p}{\partial x}+\frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}\right]$$

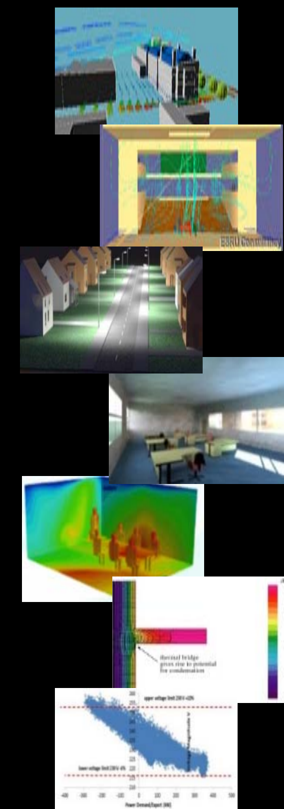
Y – Momentum:
$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho v^2)}{\partial y}+\frac{\partial(\rho vw)}{\partial z}=-\frac{\partial p}{\partial y}+\frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum
$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho w^2)}{\partial z}=-\frac{\partial p}{\partial z}+\frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}\right]$$

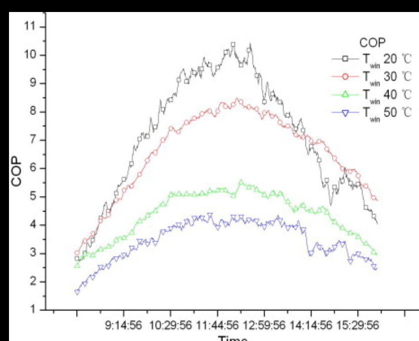
Energy:
$$\frac{\partial(E_T)}{\partial t}+\frac{\partial(uE_T)}{\partial x}+\frac{\partial(vE_T)}{\partial y}+\frac{\partial(wE_T)}{\partial z}=-\frac{\partial(up)}{\partial x}-\frac{\partial(vp)}{\partial y}-\frac{\partial(wp)}{\partial z}-\frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right]$$
$$+\frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\tau_{xx}+v\tau_{xy}+w\tau_{xz})+\frac{\partial}{\partial y}(u\tau_{xy}+v\tau_{yy}+w\tau_{yz})+\frac{\partial}{\partial z}(u\tau_{xz}+v\tau_{yz}+w\tau_{zz})\right]$$

Overall problem is systemic

Capital/ running/ maintenance cost
Thermal/ visual comfort
Emissions/ air quality
Network interaction/ power quality
Demand/ supply matching
Adaptability/ resilience



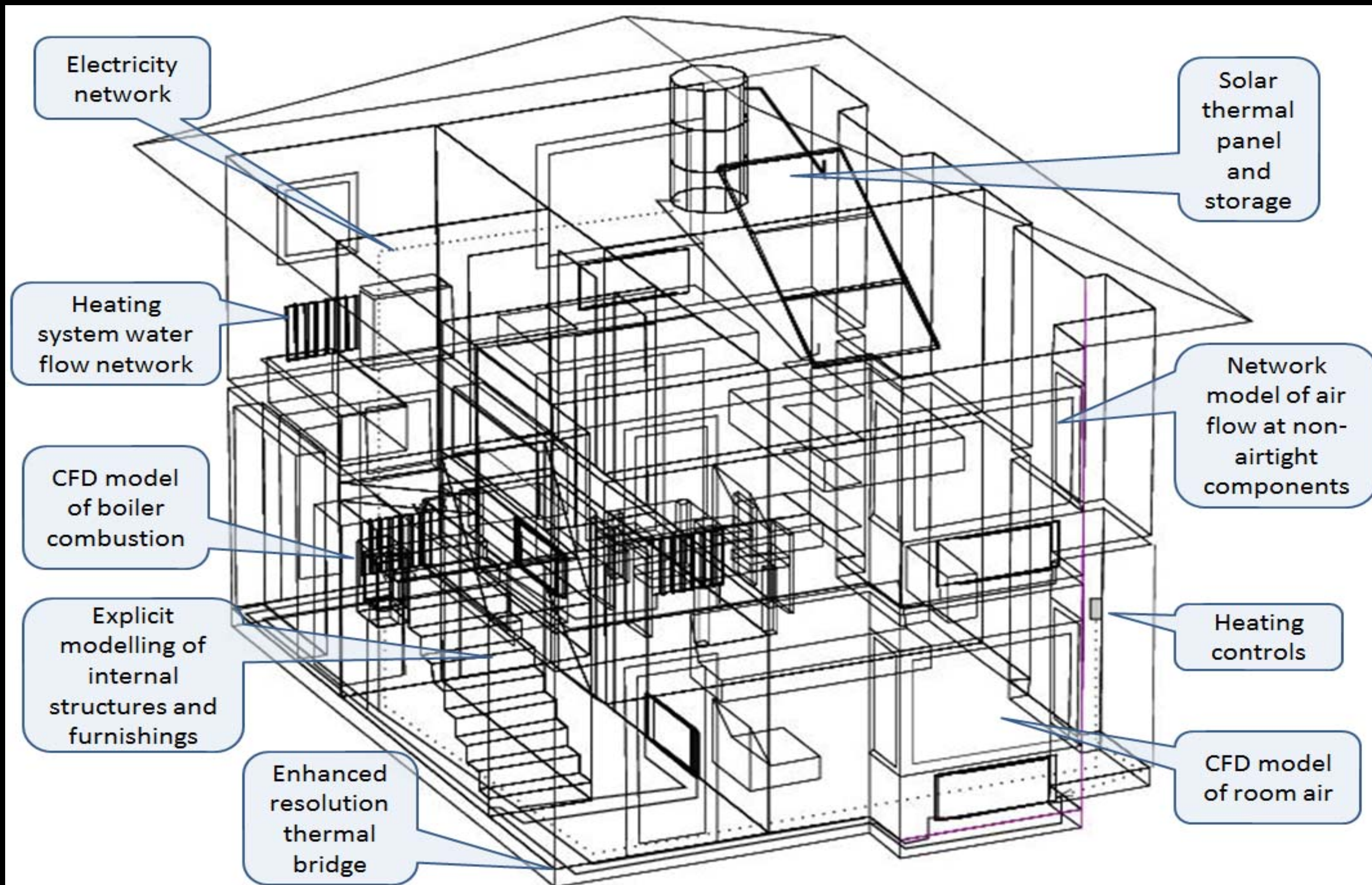
Defining data are non-linear



Influences are stochastic

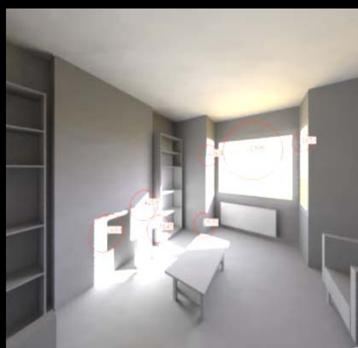
Violation of these predicates leads to a calculation tool, not simulation for reality emulation.

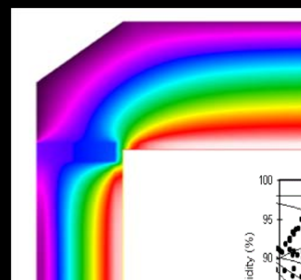
High resolution modelling of exemplar cases

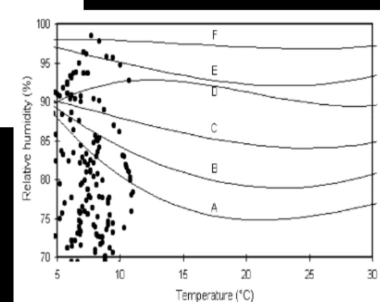


Performance outcomes address real world issues

glare and daylight

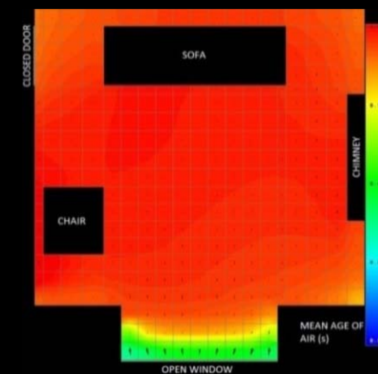




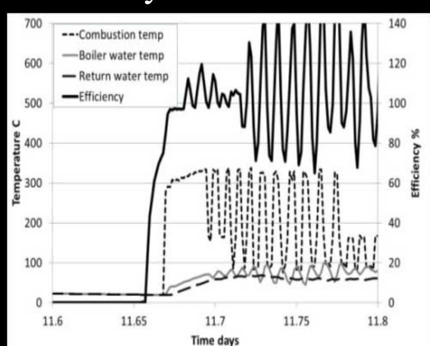


thermal bridges & mould growth

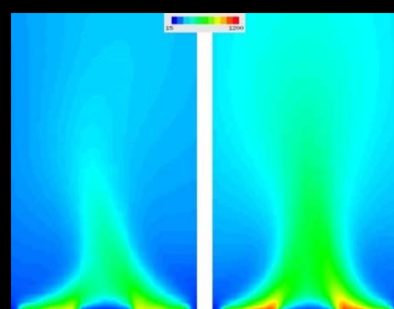
mean age of air

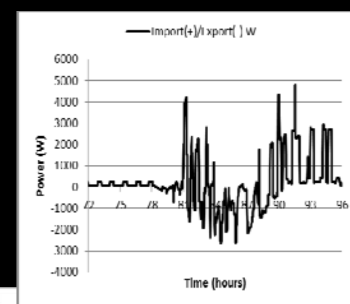


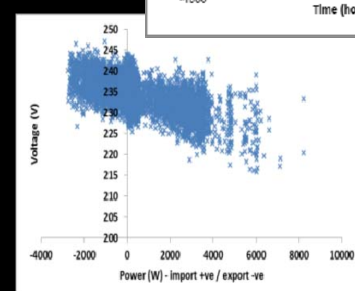
control dynamics



clean combustion



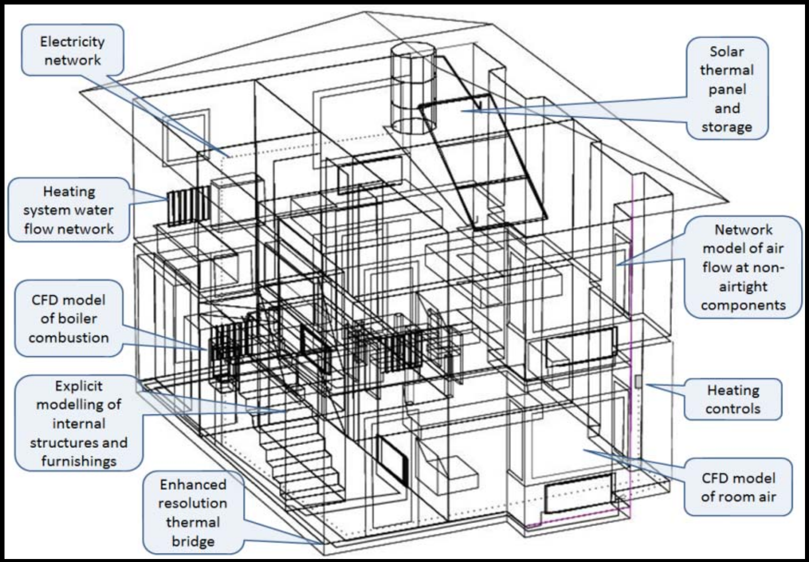




power quality

Energy benchmarking

- High resolution model created.
- Simulations undertaken to quantify potential best outcome.
- Benchmarks formulated for all house types.

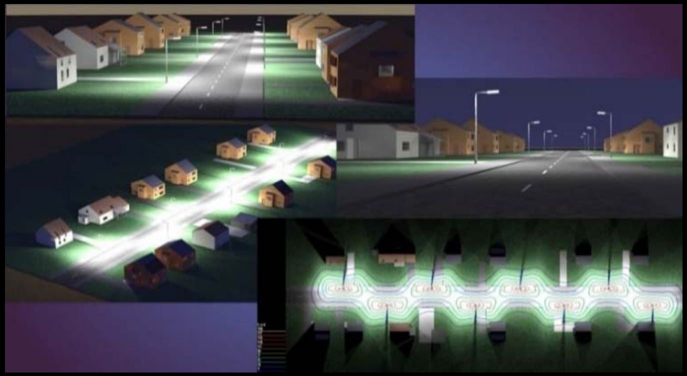


	Pre-upgrade (kWh)	Post-upgrade (kWh)
January	1,766	1,519
February	1,413	1,218
March	1,224	1,054
April	1,156	994
May	662	567
June	246	212
July	30	24
August	123	94
September	492	399
October	796	667
November	1,380	1,170
December	1,660	1,418
Annual	10,948	9,336
Gas consumption*	13,516	11,526
Annual saving*	—	£84

***Based on a typical gas-heated home with an 81% efficient boiler and tariff of 4.21 p/kWh.**

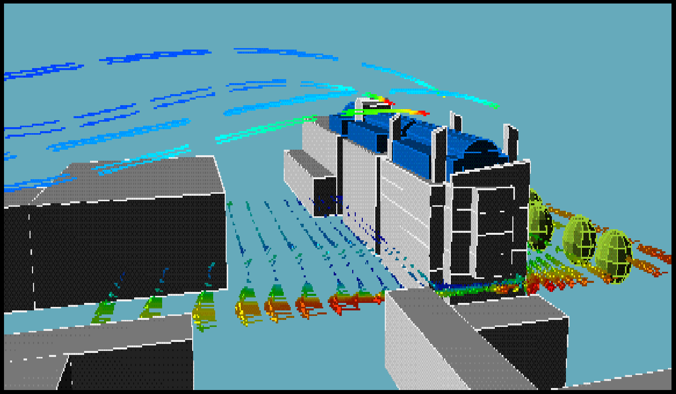
BPS is generally applicable

Smart street lighting

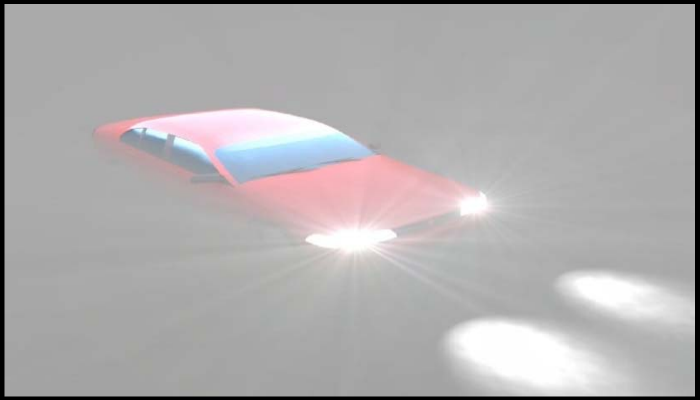


Car park PV for EV charging

Pollution avoidance

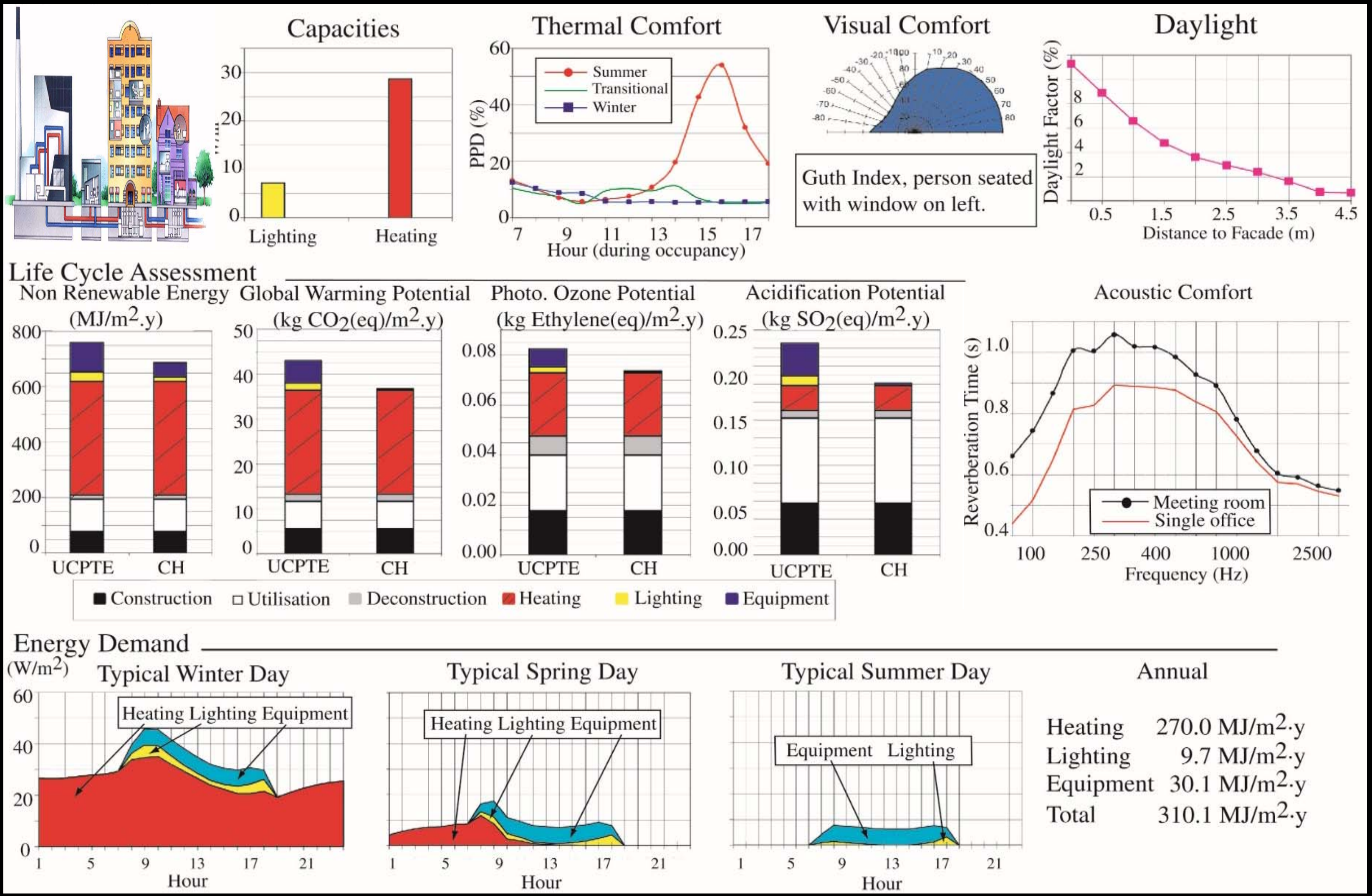


Automobile performance



Issues: validation; accreditation; standard performance assessment methods; education & training.

Integrated performance view



ESP-r: behaviour follows description

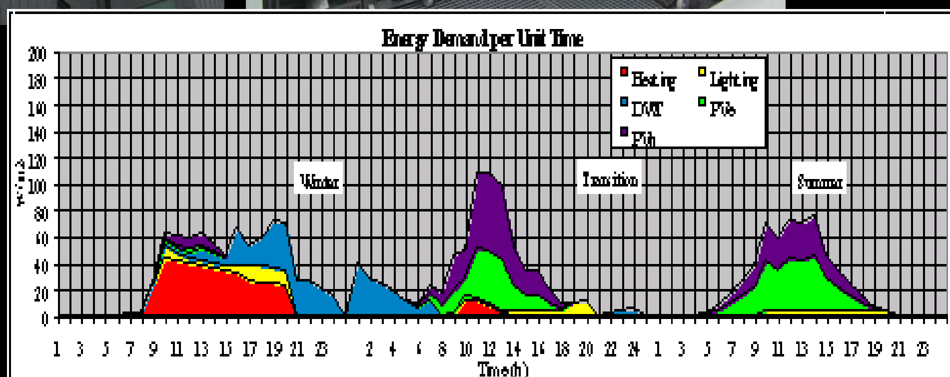
Simulation application: embedded generation

Demand reduction through transparent insulation, advanced glazing and smart control.

PV: 0.7 kW_e

DWT: 0.6 kW_e

PV hybrid: 0.8 kW_e / 1.5 kW_h



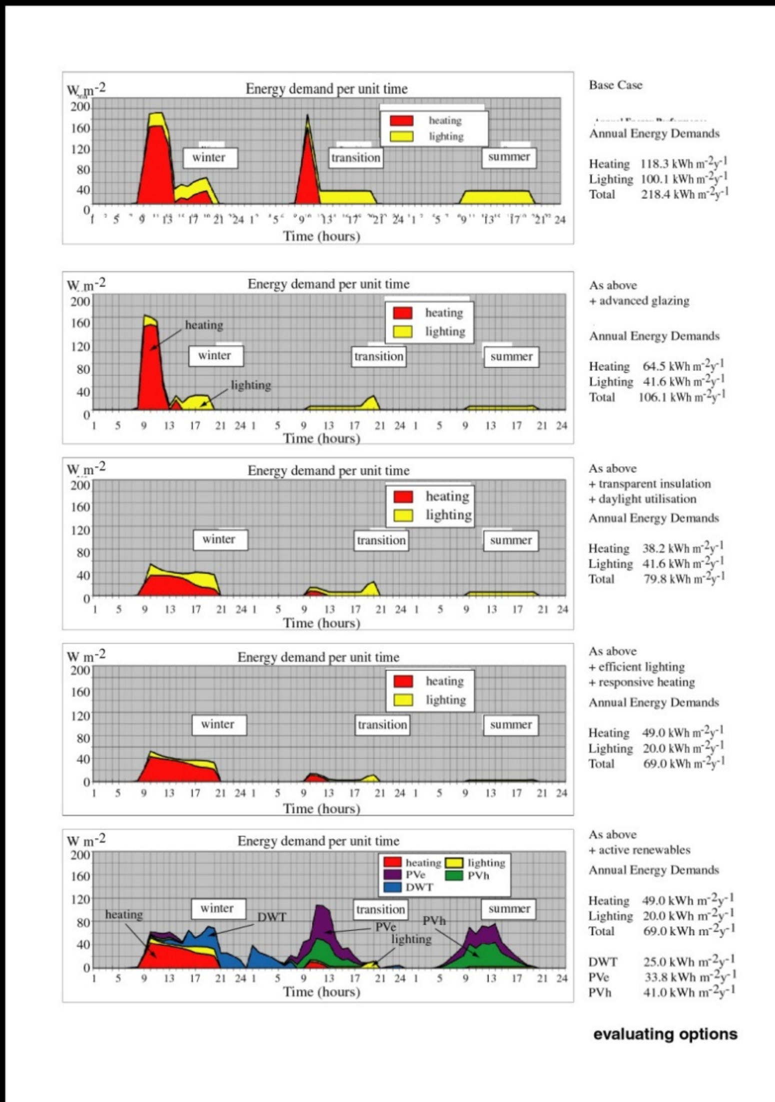
total demand:
68 kWh/m^2.yr

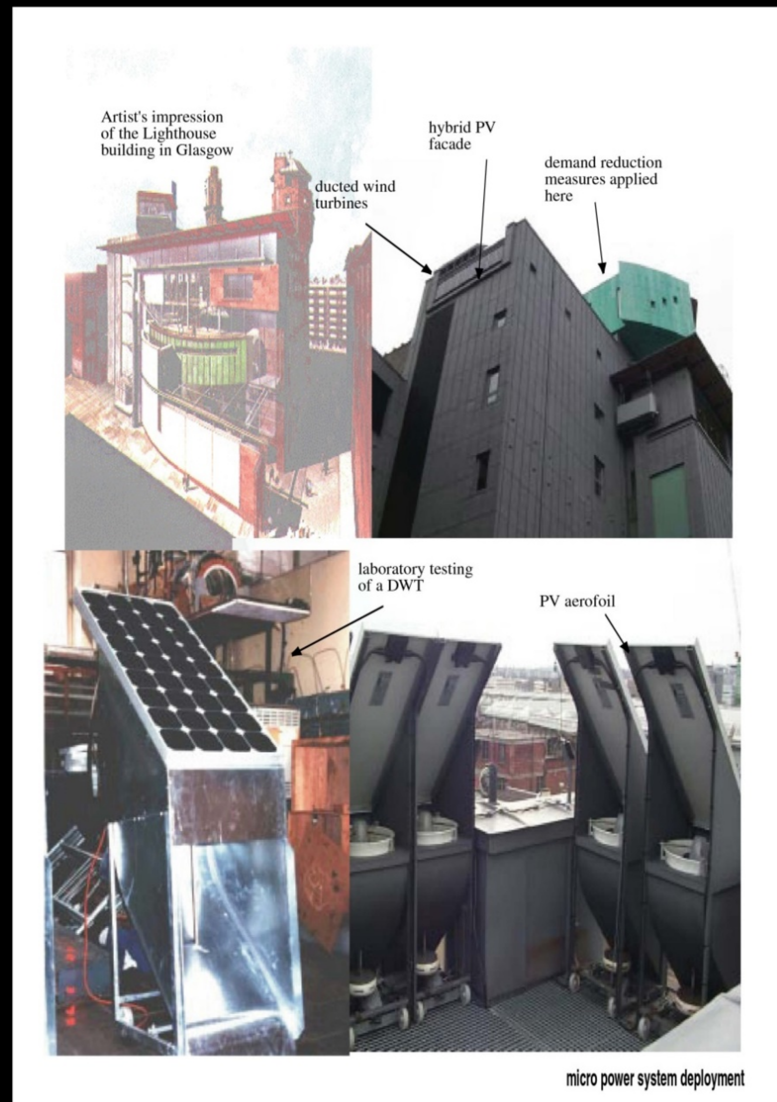
total RE supply:
98 kWh/m^2.yr

Issues:

- accommodating the grade, variability and unpredictability of energy sources/demands;
- hybrid systems design and maintenance;
- strategies for co-operative control of stochastic demand and supply;
- active network control for network balancing, fault handling and power quality maintenance.

Simulation application: integrating renewables



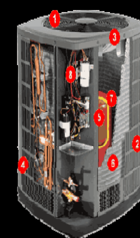


Simulation application: hybrid micro-generation

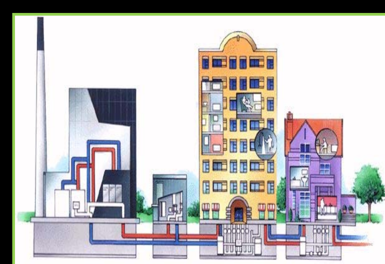
Electricity generation

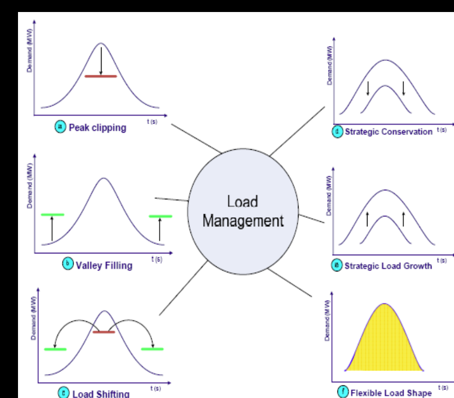
Energy storage

Heat generation



public
energy supply
connection





Simulation tools can be used to generate representative demand and supply profiles.

Active network management

- ANM controls power station units and switches wind generators in response to demand.
- Energy storage devices are controlled centrally: 1 MW battery, 4 MW district heating store, and domestic energy storage with total capacity of 2.1 MW distributed across 235 dwellings.
- Basic instruction is a power input schedule by ¼ hour for the upcoming 24 hour period based on anticipated supply, demand and network status.

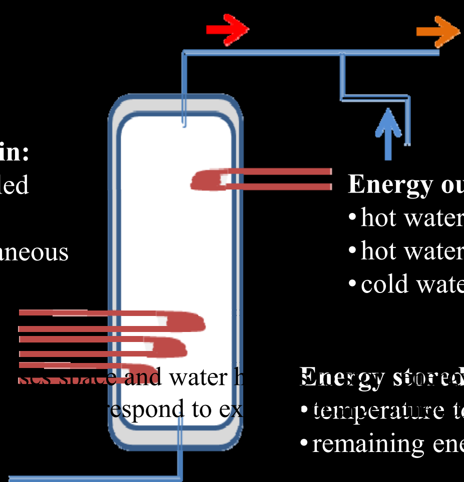
Active Network Manager → Local Interface Controller

Charge schedule

Hot water storage

Space heater storage

Amenity :
- hot water volume
- hot water temperature
- cold mixer volume



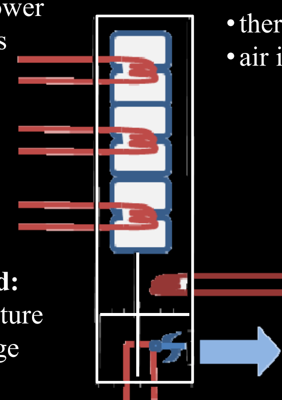
Energy in:
- scheduled power
- instantaneous power

Energy out:
- hot water volume
- hot water temperature
- cold water temperature

Energy stored:
- temperature top & bottom of tank
- remaining energy storage capacity

Amenity:
- outside air temperature
- room temperature
- thermostat setting
- air intake temperature

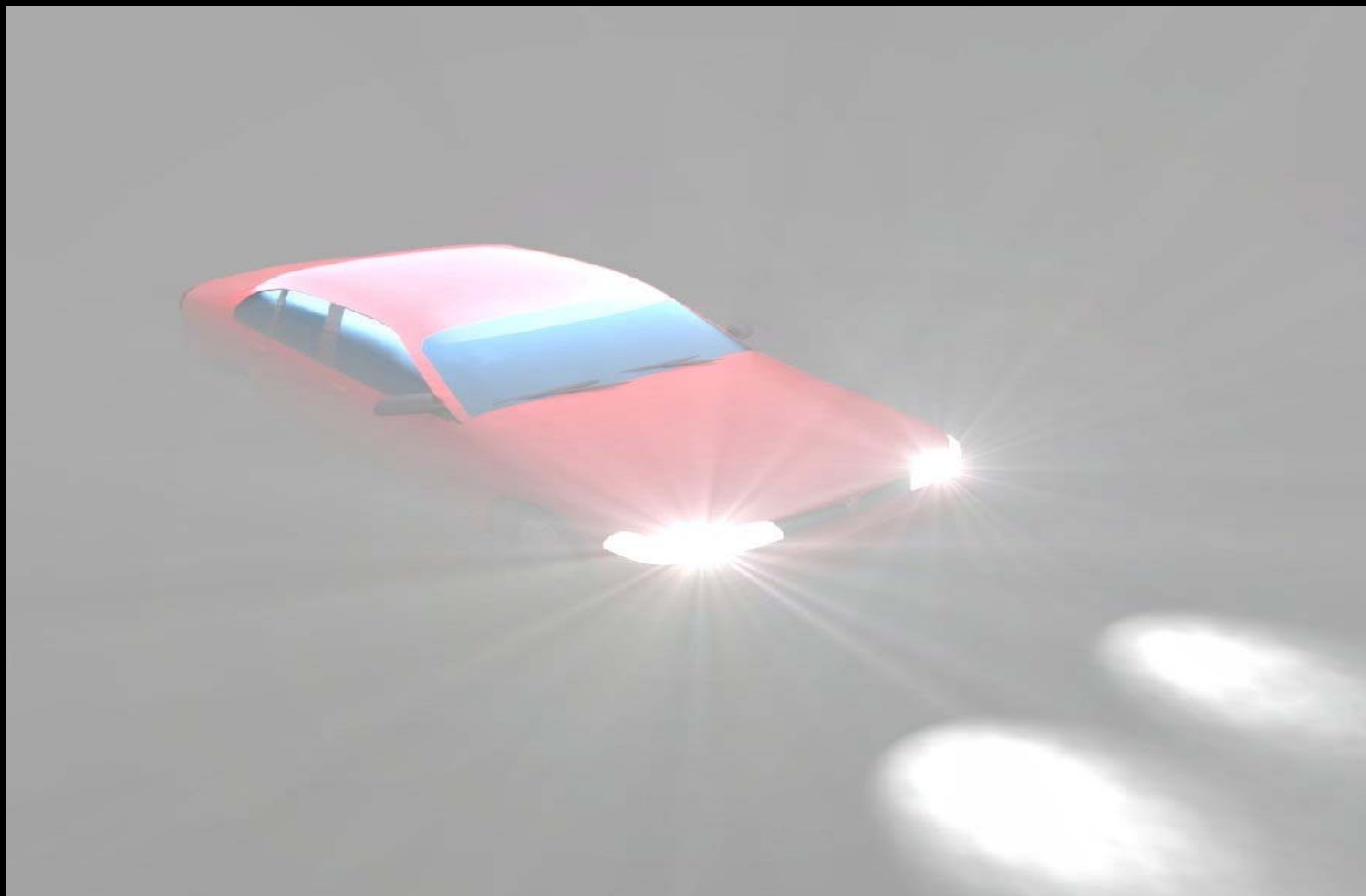
Energy in:
- scheduled power
- instantaneous power



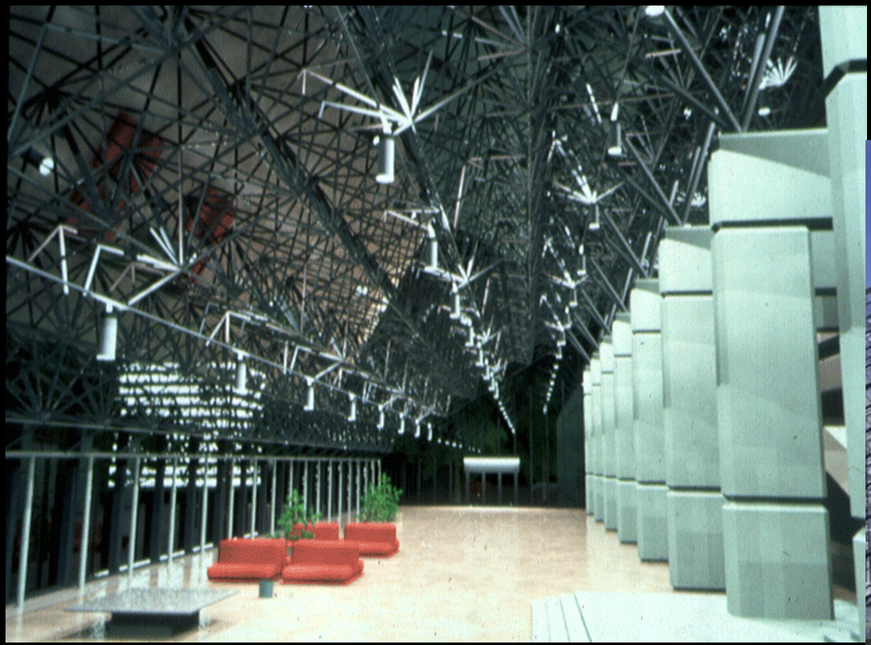
Energy stored:
- core temperature
- energy storage capacity

Energy out:
- boost status
- fan status
- fan duct temperature

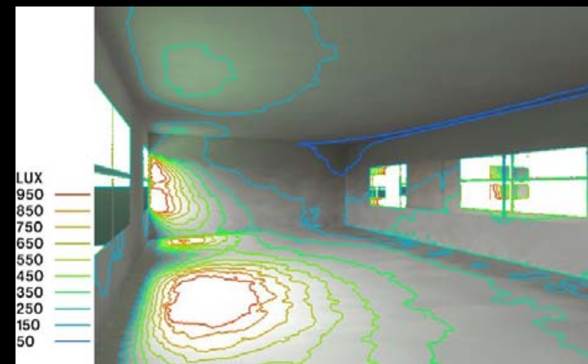
Simulation application: car safety testing

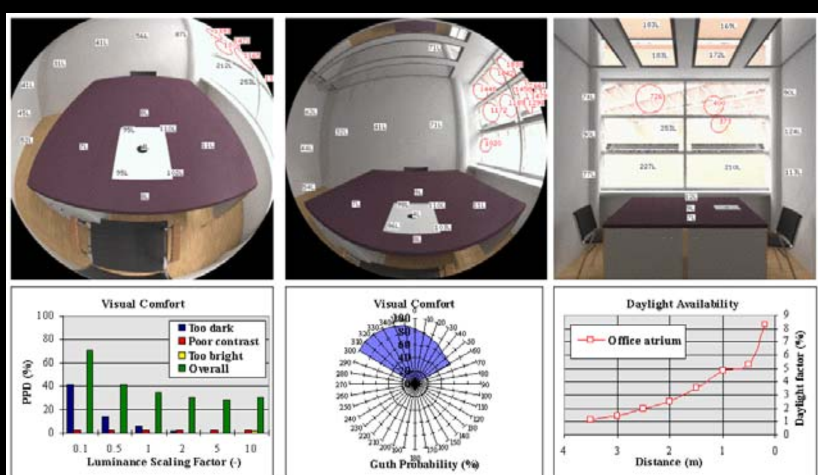


Visualisations



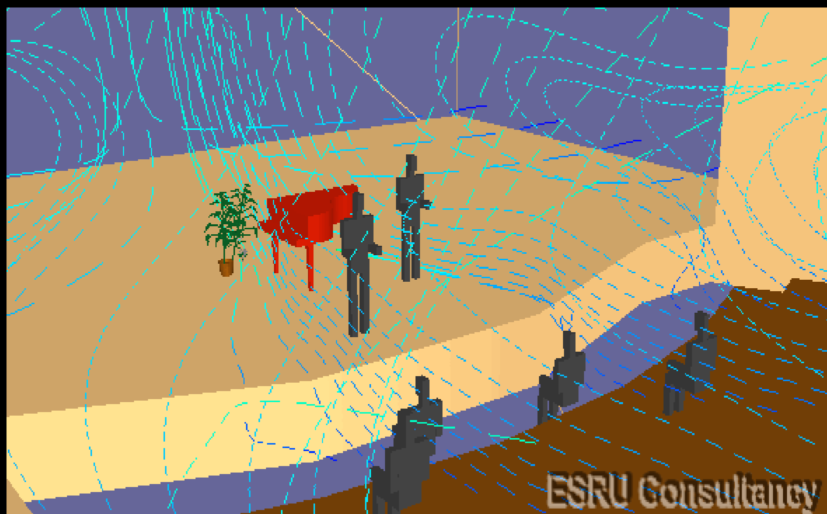
Internal lighting

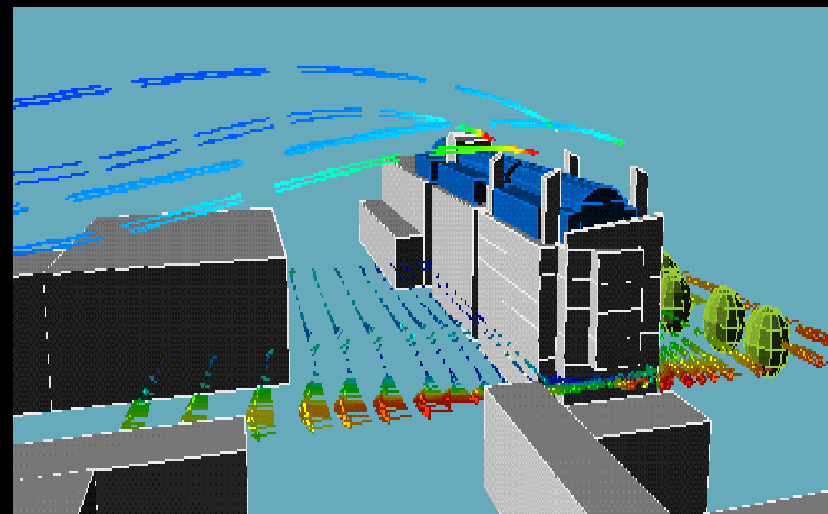


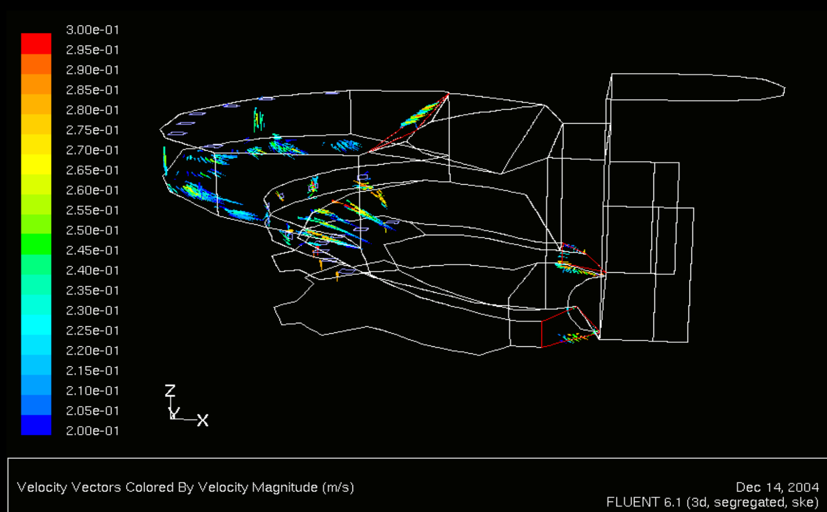


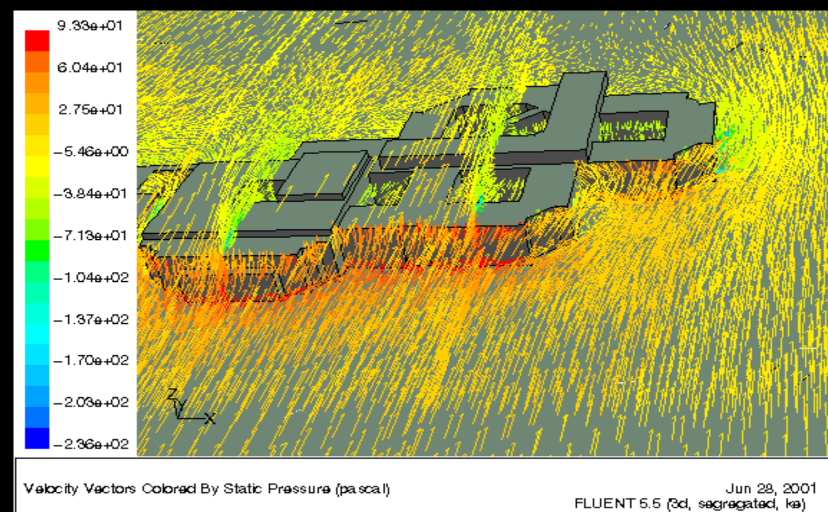
External lighting

Air flow and emissions

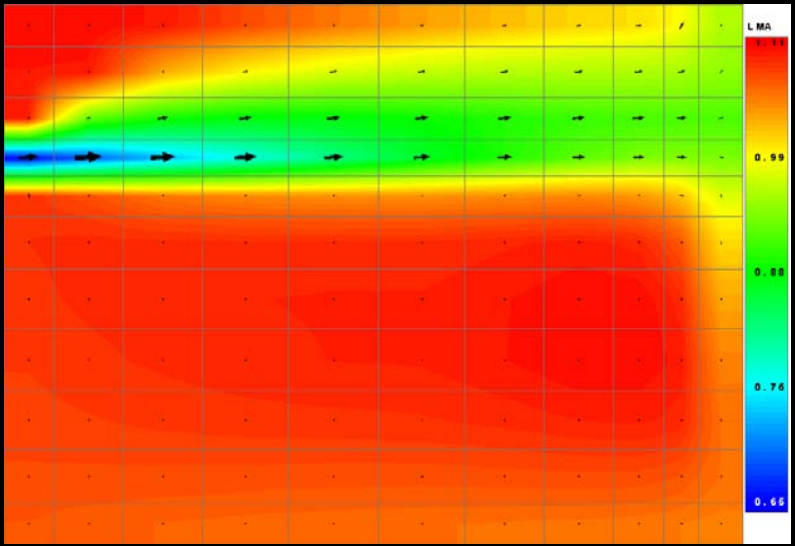


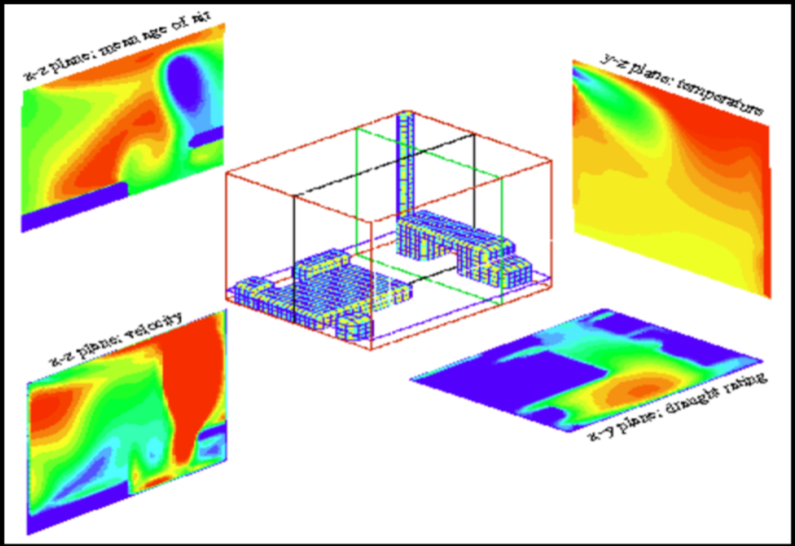


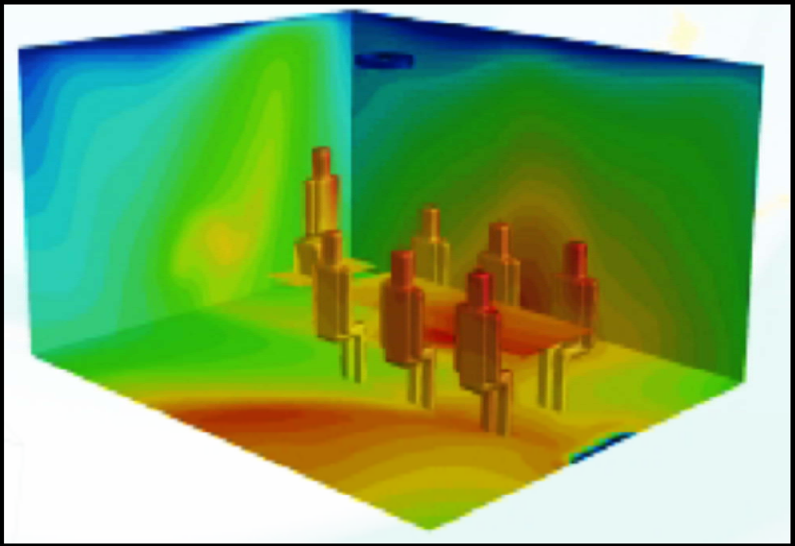


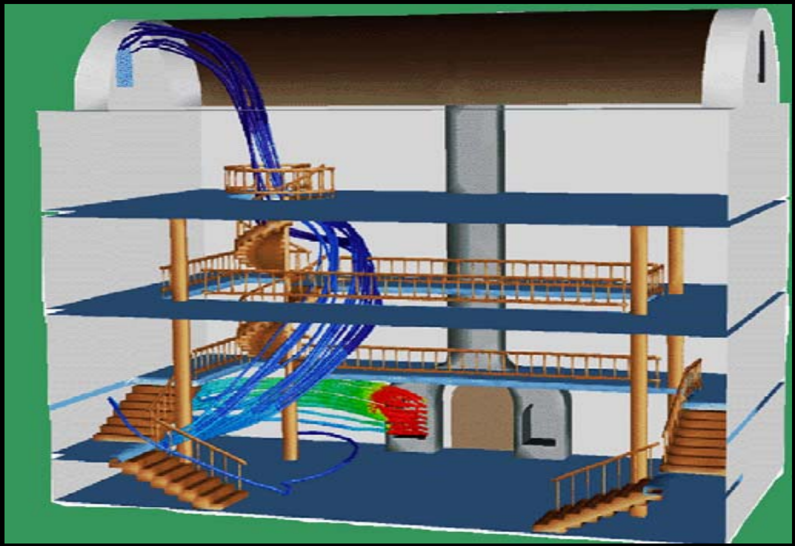


IAQ & comfort

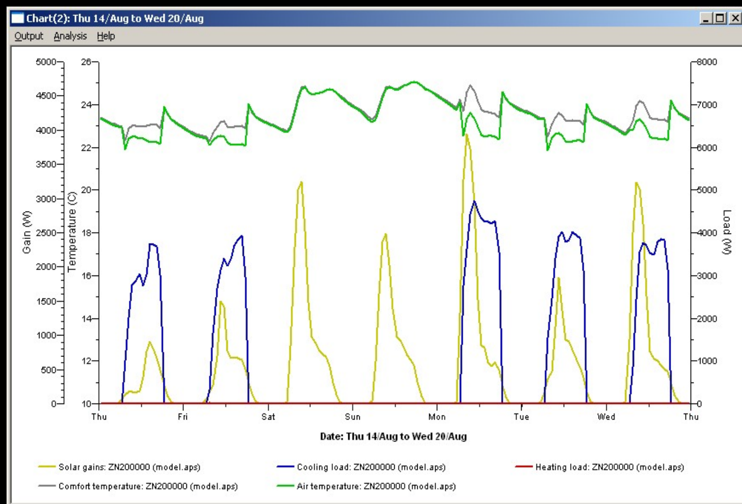


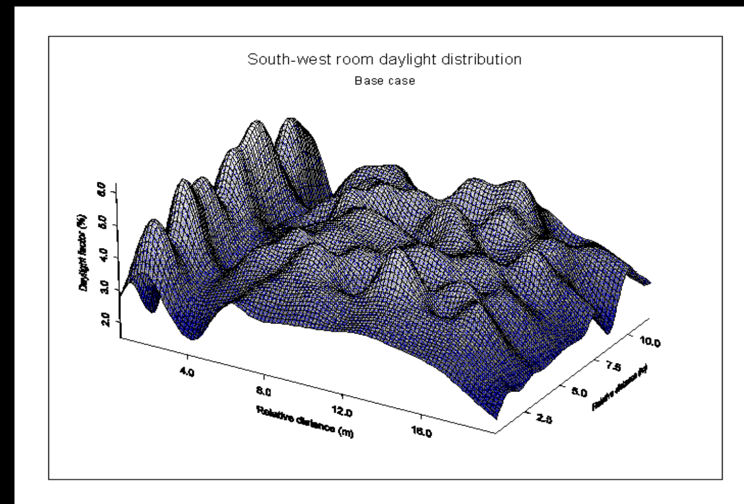

x-z plane: mean age of air
y-z plane: temperature
x-z plane: velocity
x-y plane: draught rating

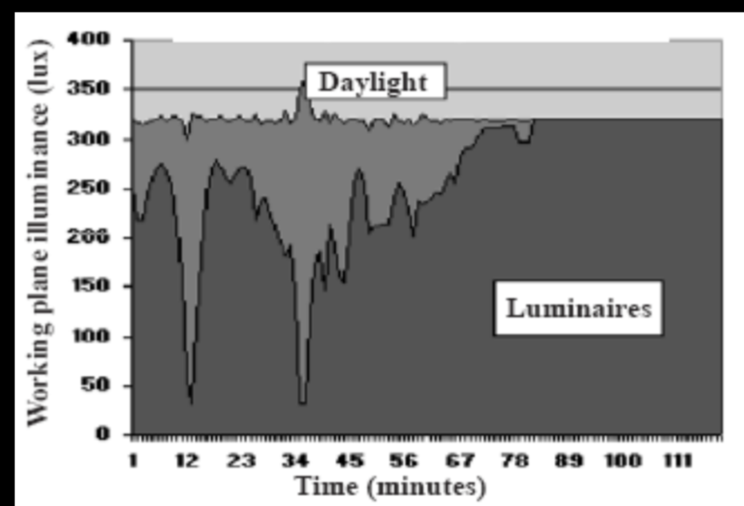




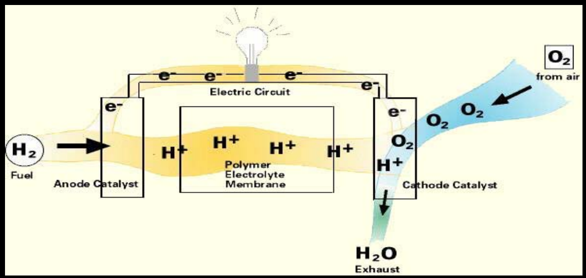
Appropriate data presentation

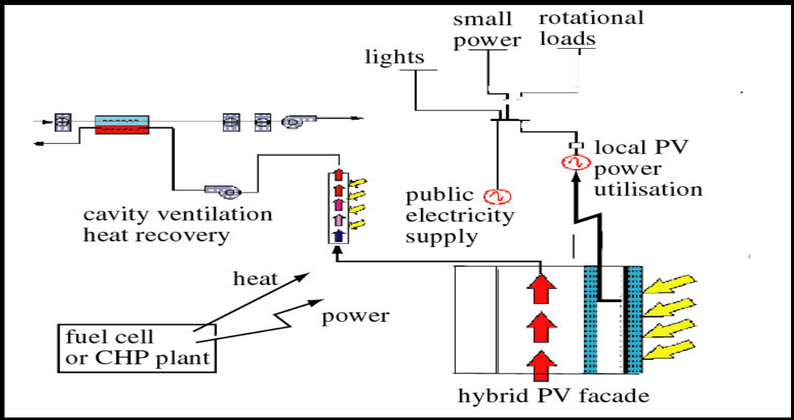






Local energy schemes

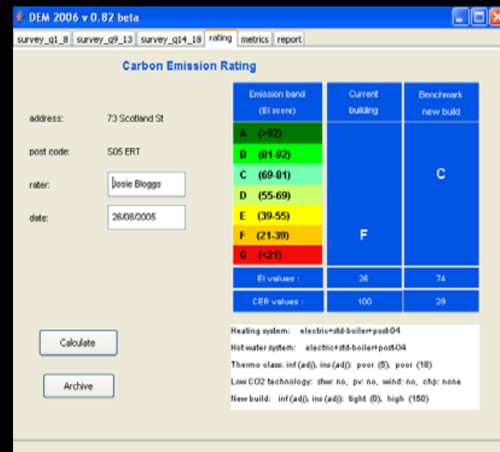


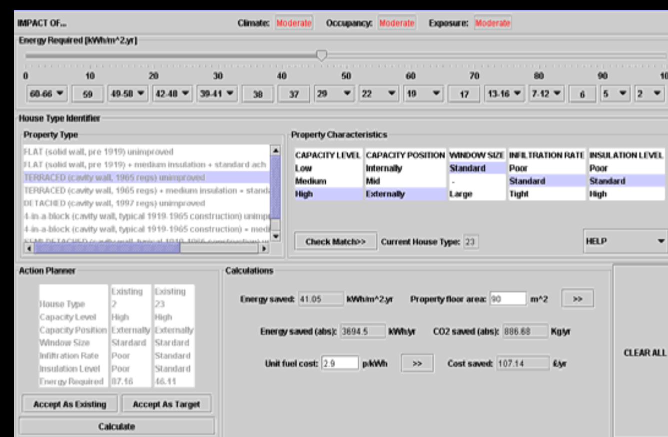


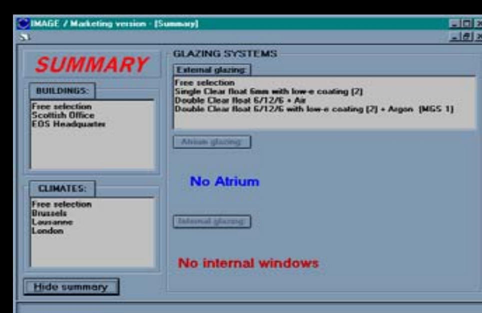
Embedded simulation

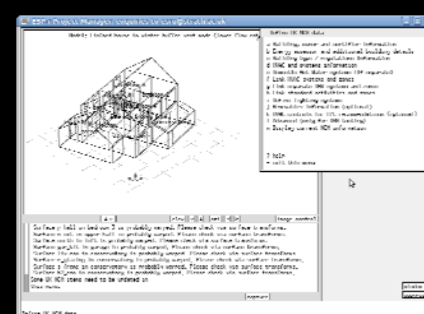
Production of focussed tools for:

- ❑ Advanced glazing selection
- ❑ Control systems design
- ❑ Legislation compliance
- ❑ Biomass boiler sizing
- ❑ Housing stock upgrade planning
- ❑ Policy formulation
- ❑ Intelligent EMS









IBPSA
International Building Performance Simulation Association

Argentina	Italy
Australasia	Japan
Brazil	Korea
Canada	Netherlands + Flanders
China	Nordic
Chile	Poland
Czech Republic	Scotland
Danube	Singapore
Egypt	Slovakia
England	Spain
France	Switzerland
Germany	Turkey
India	United Arab Emirates
Ireland	USA

Building Simulation 2009
University of Strathclyde, Glasgow
27th - 30th July

IBPSA Fellowships

Issues: buy-in to the computational approach to design; extension to all relevant domains; collaborative pursuit of a future vision.

Integrated systems thinking

Issues: computational approach to design; distinction between tools for compliance and prediction; applicability of the check-list approach.