Conception optimisée du bâtiment par la SIMUlation et le Retour d'EXpérience, 00006 (2012)
DOI:10.1051/iesc/2012simurex00006

Sustainable energy systems: addressing the myriad uncertainties

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SIMUREX 2012 : Impact de la fiabilité des modèles et des incertitudes

Sustainable energy systems: addressing the myriad uncertainties

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cnrs advancing the frontiers

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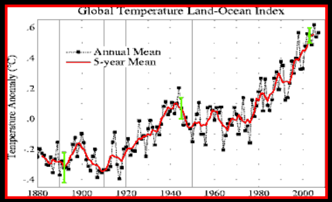
Sustainable energy systems



Different perspectives:

- ❑ human well-being (moral obligation)
- ❑ climate change mitigation (save the planet)
- ❑ environment protection (healthy habitats)
- ❑ fossil fuel replacement (economic growth)
- ❑ security of supply (political autonomy)

The challenge is to accommodate disparate views while taking effective action.

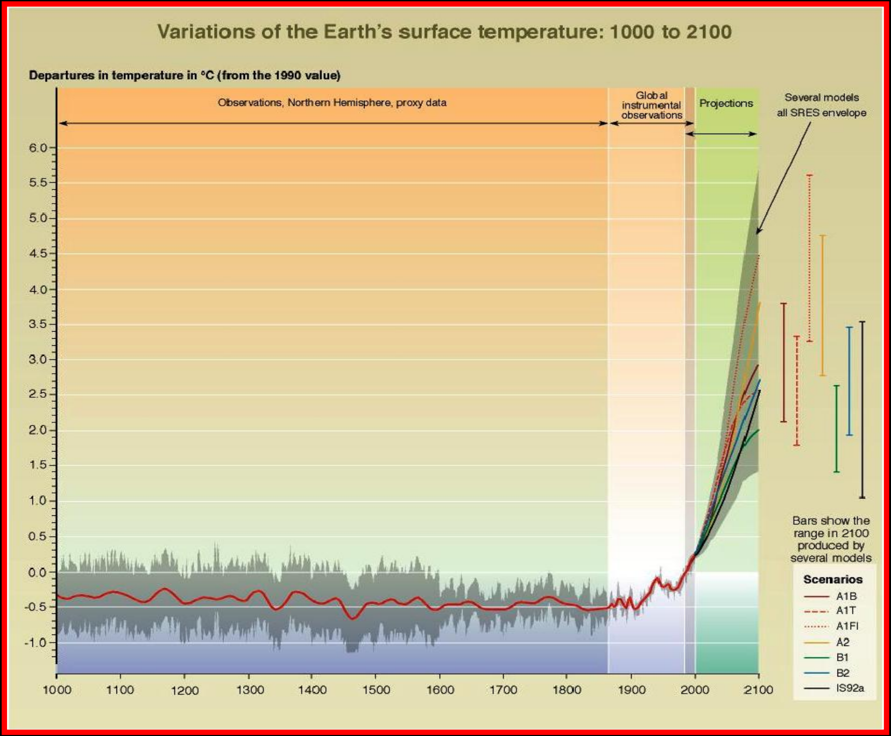
Reduce/reshape energy demand:

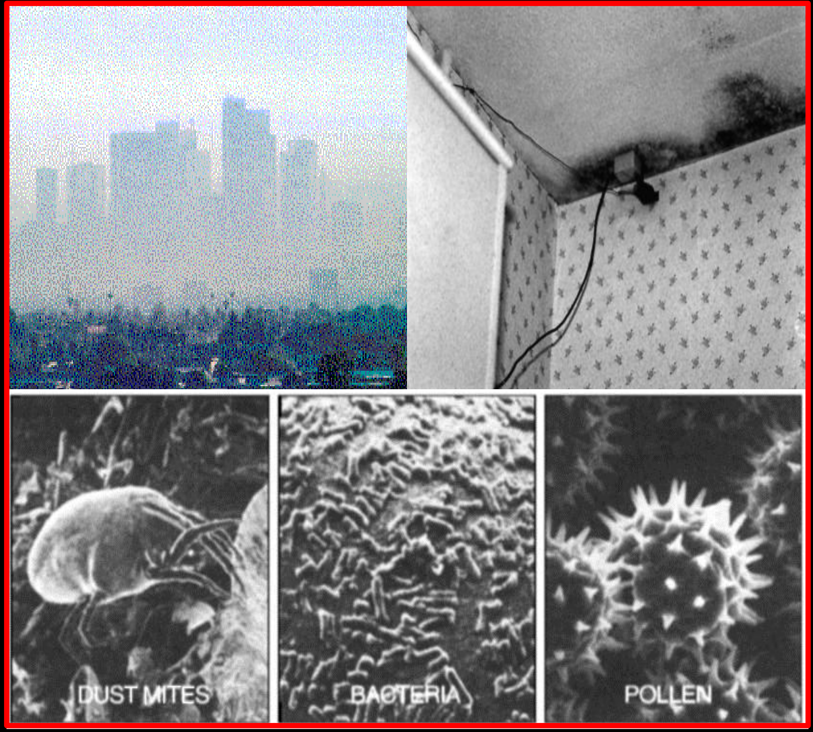
- ❑ population control (not an option)
- ❑ lifestyle change (do a little, save a little)
- ❑ apt technologies (plethora of options)

Deploy clean energy sources:

- ❑ clean fossil fuels
- ❑ nuclear fission (fusion)
- ❑ new & renewable energy

Conflicting viewpoints

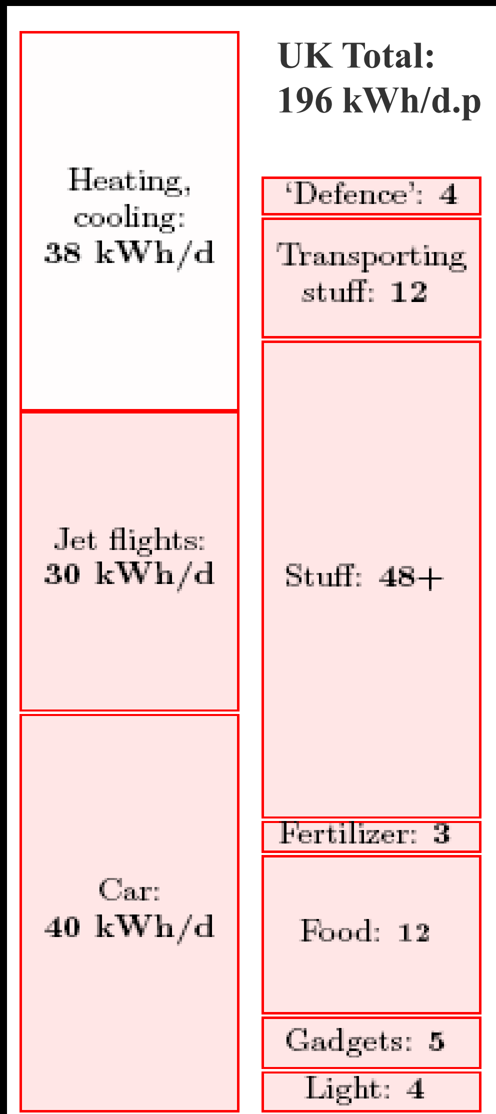




Caution!:

- ❑ energy efficiency measures may exacerbate indoor air quality;
- ❑ decentralised power production reduces global emissions but moves them to the breathing zone;
- ❑ increased system complexity may increase capital, operating and maintenance costs.

Lifestyle change



Source: MacKay, www.withouthotair.com

'Simple' actions	**Possible saving (kWh/d.p)**
Frugal heating system use	20
Switch off appliances at home/work	4
Stop flying	35
Efficient transport	20
Do not replace gadgets	4
Use CFL or LED	4
Avoid clutter	20
Become vegetarian	10
Sub-total	117
'Difficult' actions	
Eliminate draughts	5
Double glazing	10
Improve insulation	10
Solar hot water panels	8
Photovoltaic panels	5
Replace old building with new	35
Electric heat pump for heating	10
Sub-total	83

Lifestyle change is unlikely to result in substantial energy demand reduction.

Apt technologies

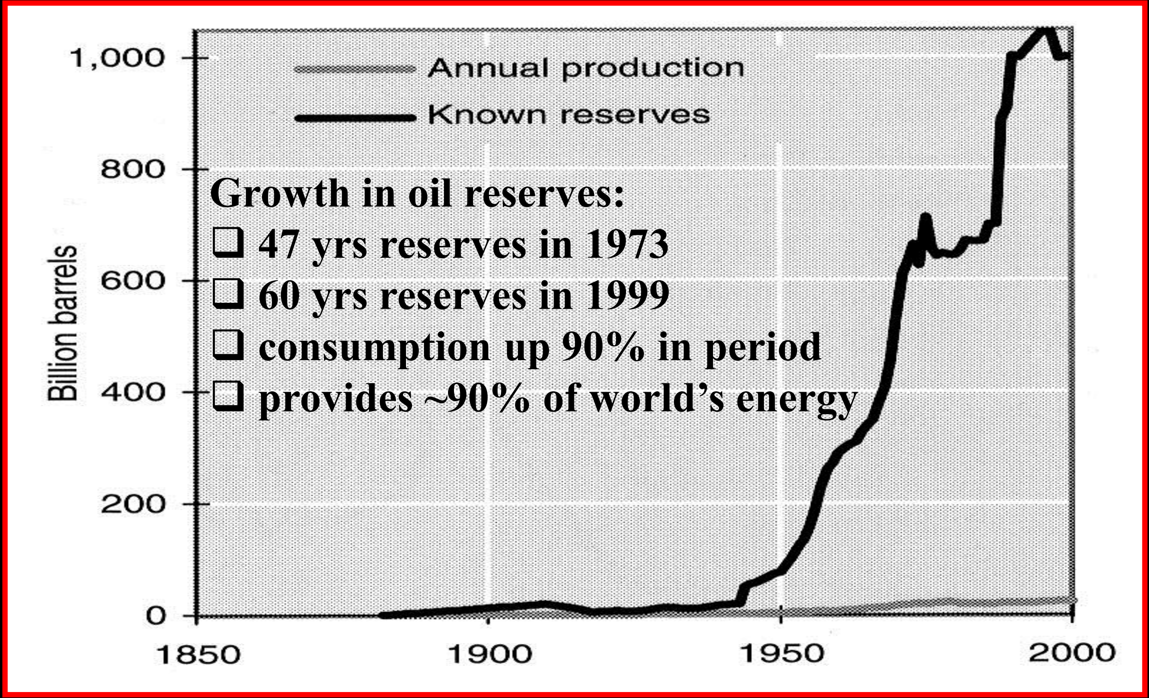
With so many options, how do we identify the optimum deployment combinations?

Transport (25-65%):
- ❑ ~~journey curbing~~
- ❑ efficient engines
- ❑ alternate fuels
- ❑ fuel cells
- ❑ hybrid engines

Buildings (30-85%):
- ❑ ~~frugal living~~
- ❑ fabric & ventilation
- ❑ efficient systems
- ❑ passive solar
- ❑ embed renewables

Industry (15-75%):
- ❑ ~~produce less~~
- ❑ efficient plant
- ❑ heat recovery
- ❑ smart control
- ❑ new materials

Fossil fuels



Reserves:

- ❑ Coal 230-1500 yrs;
- ❑ Oil 40-250 yrs;
- ❑ Gas 60 yrs.

Outlook:

- ❑ global energy spend <2% of GDP;
- ❑ UK spend 6% of GDP (£75b/y; c.f. £10b/y spent on discarded food);
- ❑ will dominate the world economy for 30 years or more.

Challenges:

- ❑ refine exploration techniques;
- ❑ make less 'polluting' (e.g. decarbonise);
- ❑ enhanced extraction (e.g. sequestrate C);
- ❑ new resources (e.g. coal bed methane, oil shale, tar sand)
- ❑ new uses (e.g. methanol production)

Nuclear

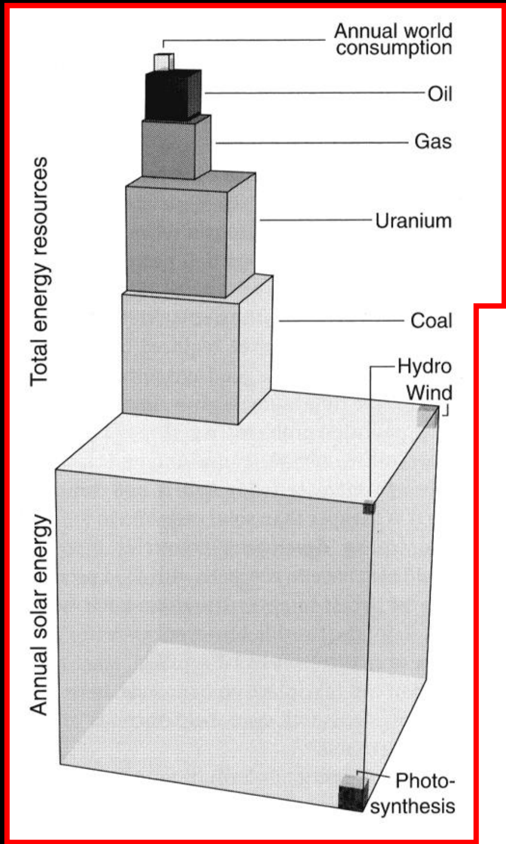
"We made the mistake of lumping energy in with nuclear weapons, as if all things nuclear were evil. I think that's a big mistake, as if you lumped nuclear medicine in with nuclear weapons."

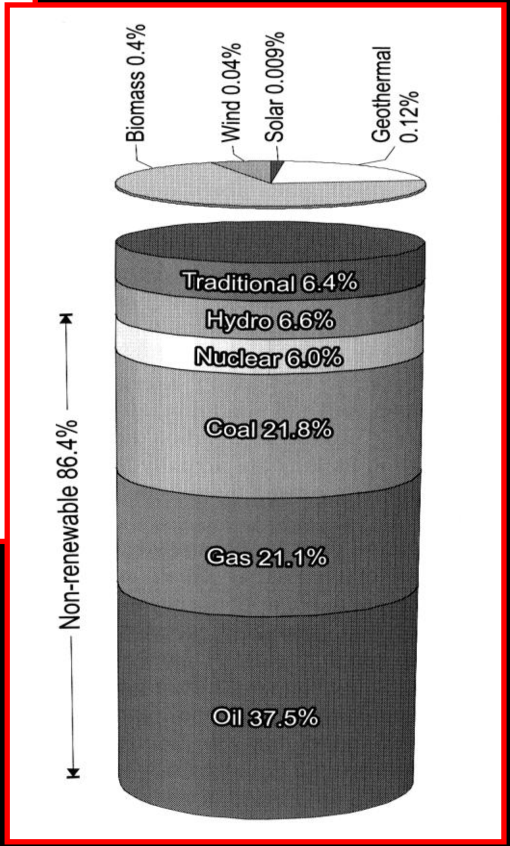
Patrick Moore, Greenpeace Co-founder

Fission:
- ❑ ~6% of global energy production;
- ❑ more expensive than fossil-based power generation but less expensive than most renewables;
- ❑ radioactive waste is a problem (transmutation initiatives);
- ❑ 100 years of $U_{235;}$
- ❑ 14,000 years of U_{238} but security problematic.

Fusion:
- ❑ abundant fuel supply (sea water);
- ❑ 1g equivalent to 45 barrels of oil;
- ❑ little radioactive waste;
- ❑ astronomical temperatures required;
- ❑ commercial by 22nd century?

Strategic renewable energy





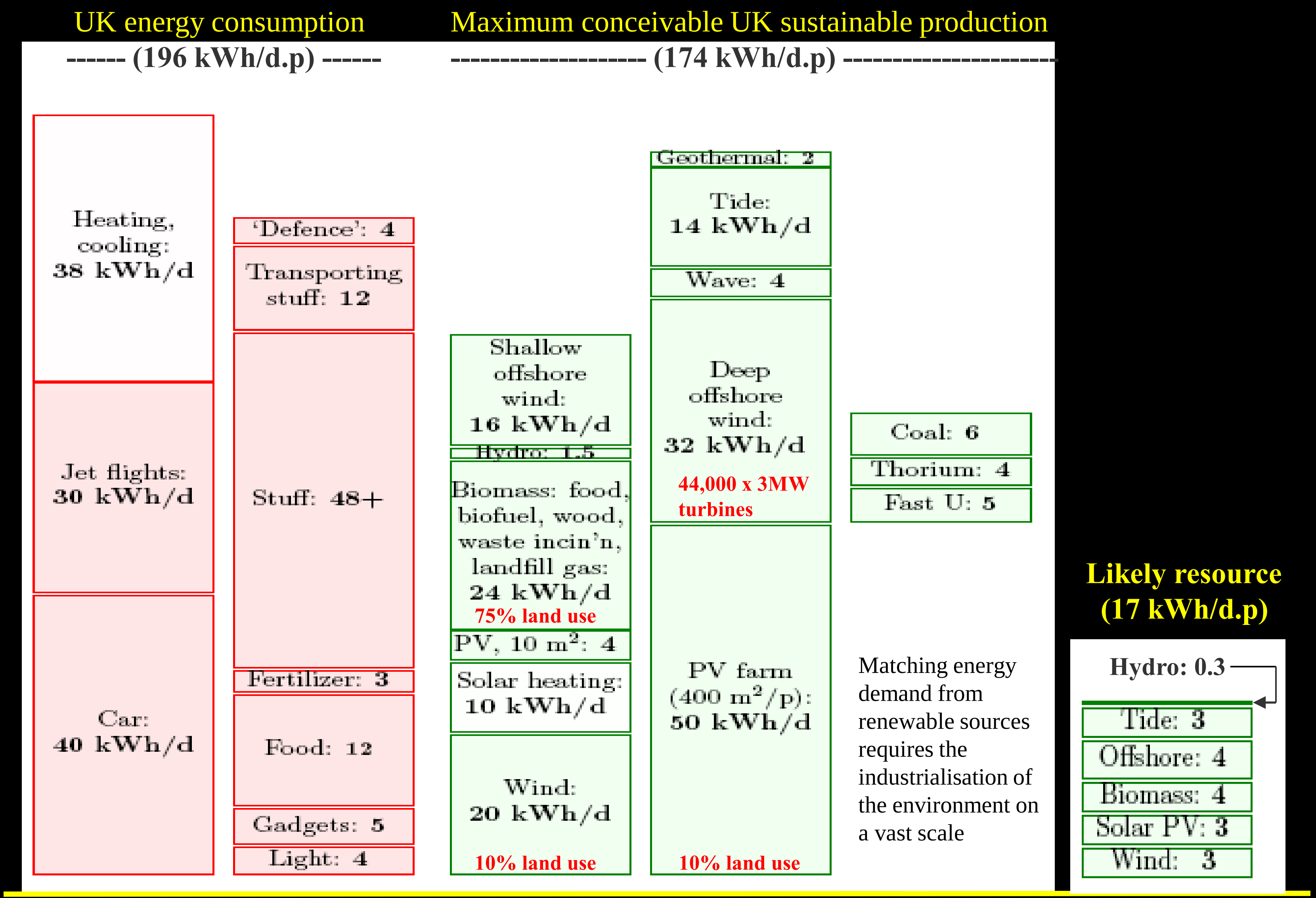
Source: Lomborg, The Skeptical Environmentalist

To avoid problems with fault clearance, network balancing and power quality, distributed RE systems with limited control possibility should be restricted to ~25% of network capacity.

❑ High capture levels require:
- increased transmission network capacity;
- active distribution network management;
- energy storage and/or standby capacity.

❑ Practical resource not vast relative to total demand.

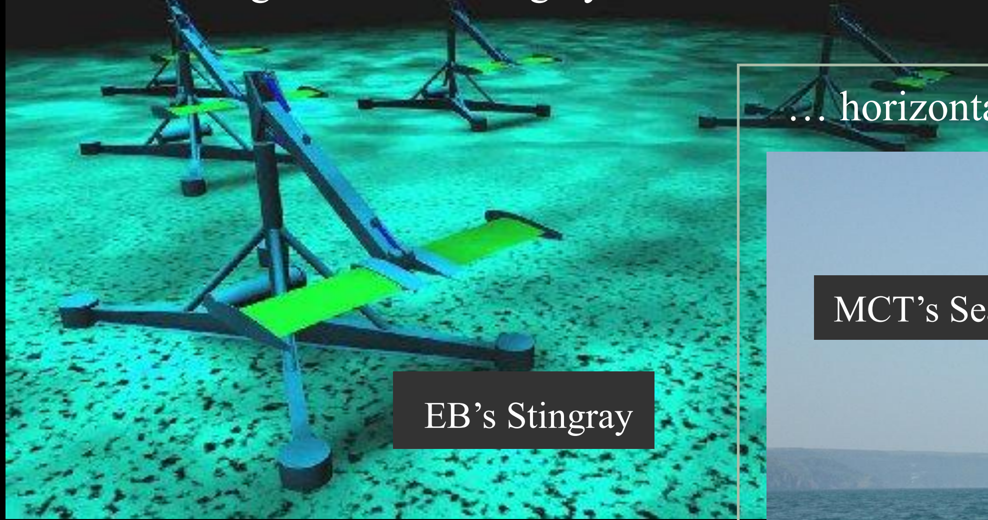
Strategic renewable energy



Source: MacKay, www.withouthotair.com

Marine tidal current

… oscillating aerofoil driving hydraulic accumulators



… horizontal axis turbine evolved from wind technology

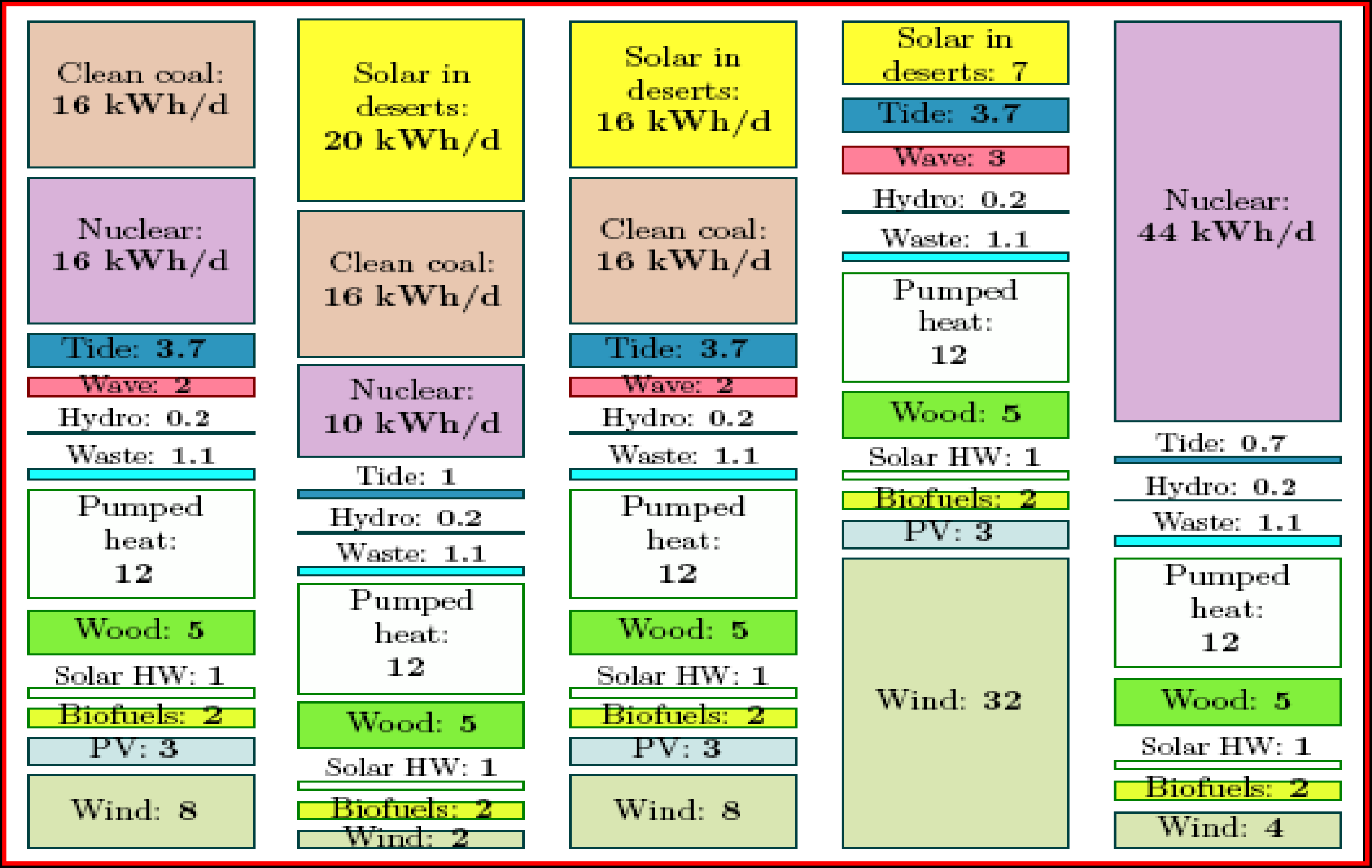
… contra-rotation

Challenges:

- ❑ reduce capital cost;
- ❑ limit corrosion and abrasion;
- ❑ maintenance and safety issues;
- ❑ power take-off at low rotation speed;
- ❑ gearing reduction/elimination;
- ❑ power transmission/grid access;
- ❑ land access and use;
- ❑ phased operation of different sites;
- ❑ maritime & aquaculture impact;
- ❑ overcome vested interest.

Energy supply scenarios

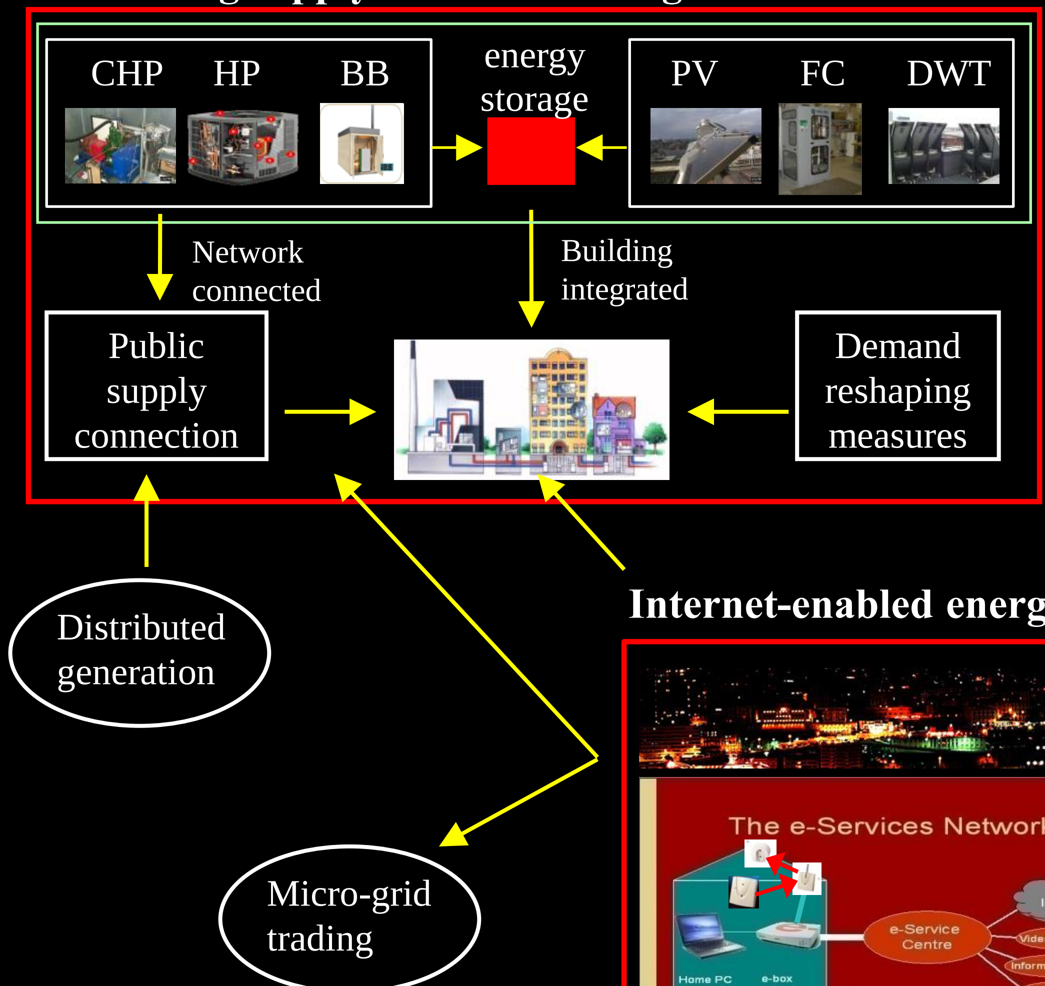
Source: MacKay, www.withouthotair.com



Diversity NIMBY LibDem Green Economist

Emerging concepts

Embedding supply within a micro-grid



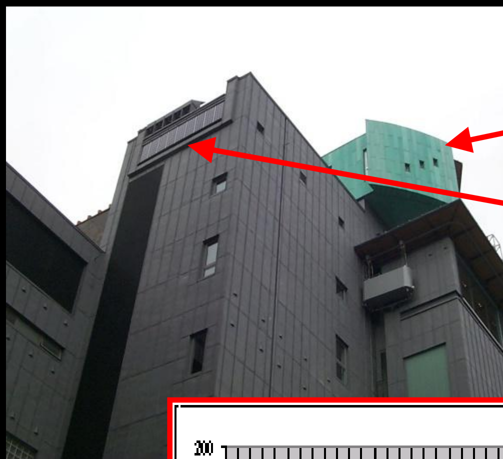
Power station .... 1 @ 2000 MW
Wind .... 100 @ 20 MW
Marine .... 4,000 @ 0.5 MW
CHP .... 40,000 @ 0.05 MW
Urban RE .... 200,000 @ 0.01 MW

Renewable energy systems 3-5 times larger if the requirement is to match energy production.

Internet-enabled energy services

New energy-related services:
- ❑ environmental monitoring;
- ❑ smart metering;
- ❑ local & aggregate control;
- ❑ demand-side management;
- ❑ information for citizens.

<u>**The Lighthouse Building, Glasgow**</u>

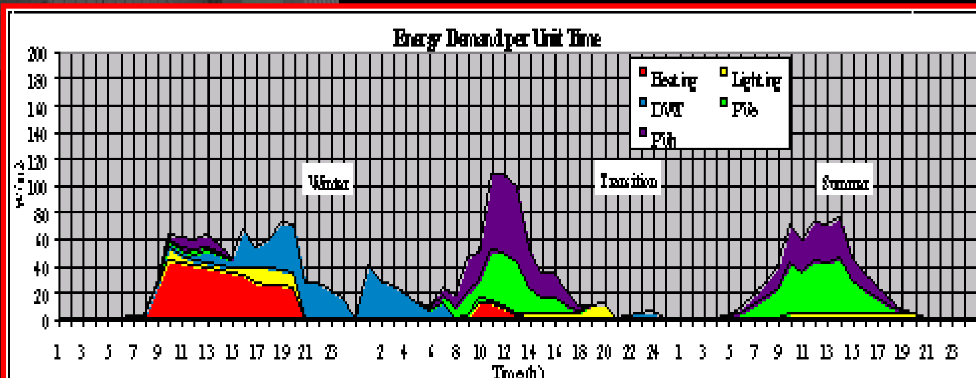


Demand reduction through transparent insulation, advanced glazing and smart control.

PV: 0.7 kW_e

DWT: 0.6 kW_e

PV hybrid: 0.8 kW_e / 1.5 kW_h

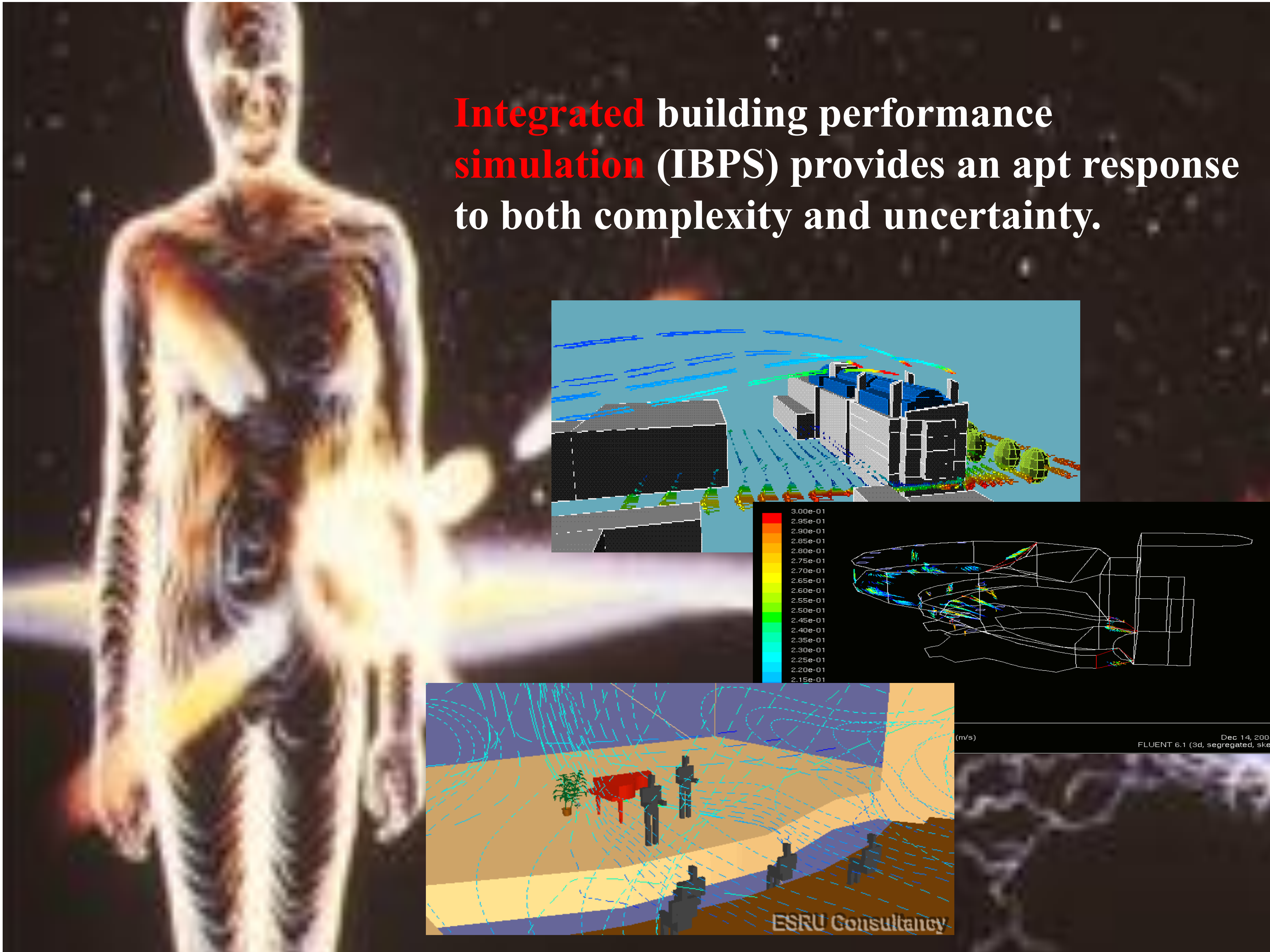


total demand:
68 $kWh/m^2.yr$

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

Challenges:

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


Integrated building performance simulation (IBPS) provides an apt response to both complexity and uncertainty.
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2.95e-01
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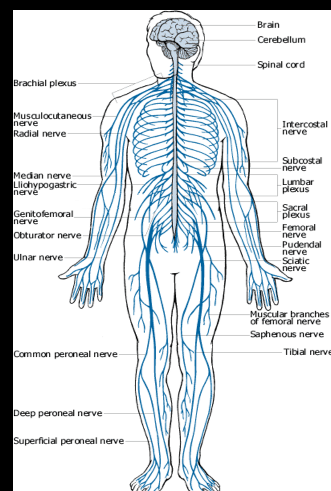
2.25e-01
2.20e-01
2.15e-01
(m/s)
Dec 14, 2004
FLUENT 6.1 (3d, segregated, ske)
ESRU Consultancy

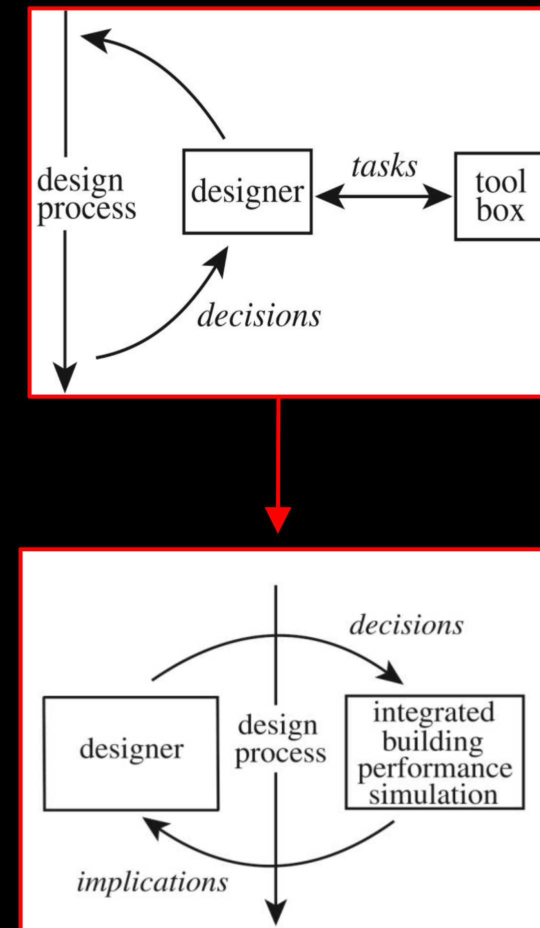
Decision-support

Most design decisions are ill-informed.

Energy systems are dynamic, non-linear and systemic.

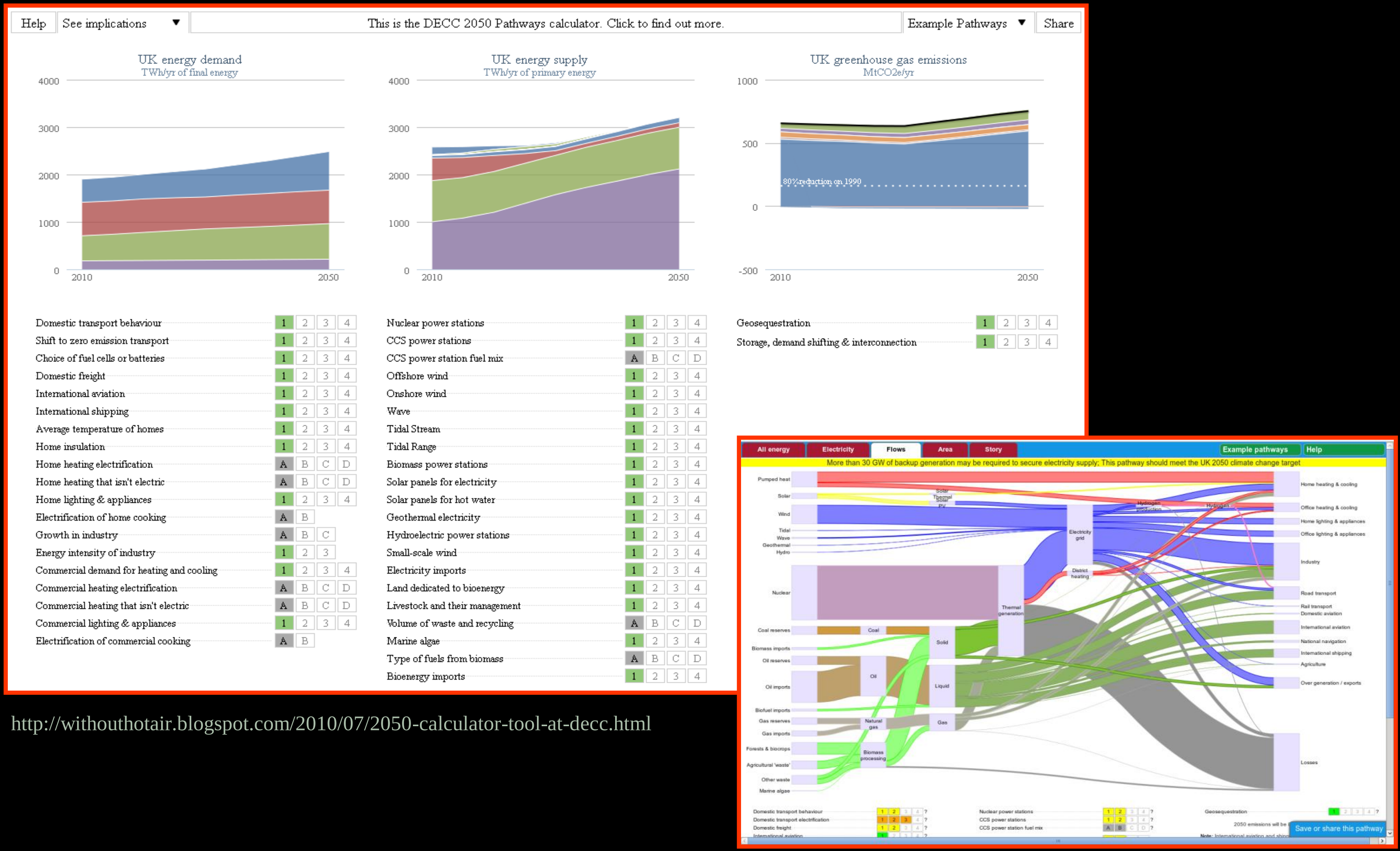


A computational approach to design provides a solution



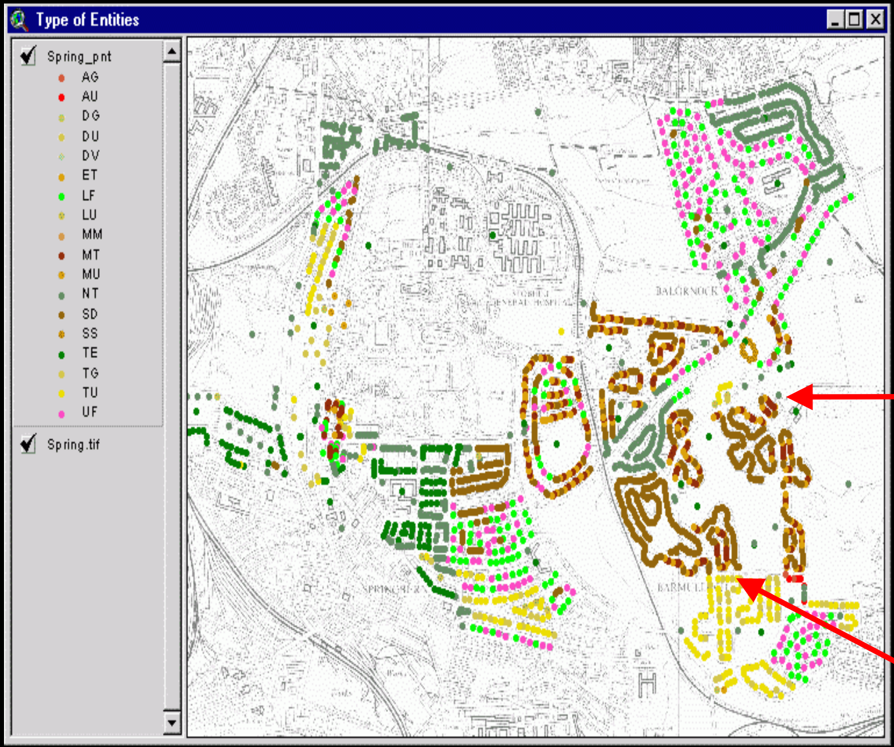
The aim is to embed advanced design tools in businesses.

DECC: 2050 calculator



http://withouthotair.blogspot.com/2010/07/2050-calculator-tool-at-decc.html

EnTrak: energy management and action planning



metered energy use

database of actual & future consumption

interrogations

scenario simulations

e-services

consumption & emissions monitoring;
city profiling & property classification;
trend analysis & action planning

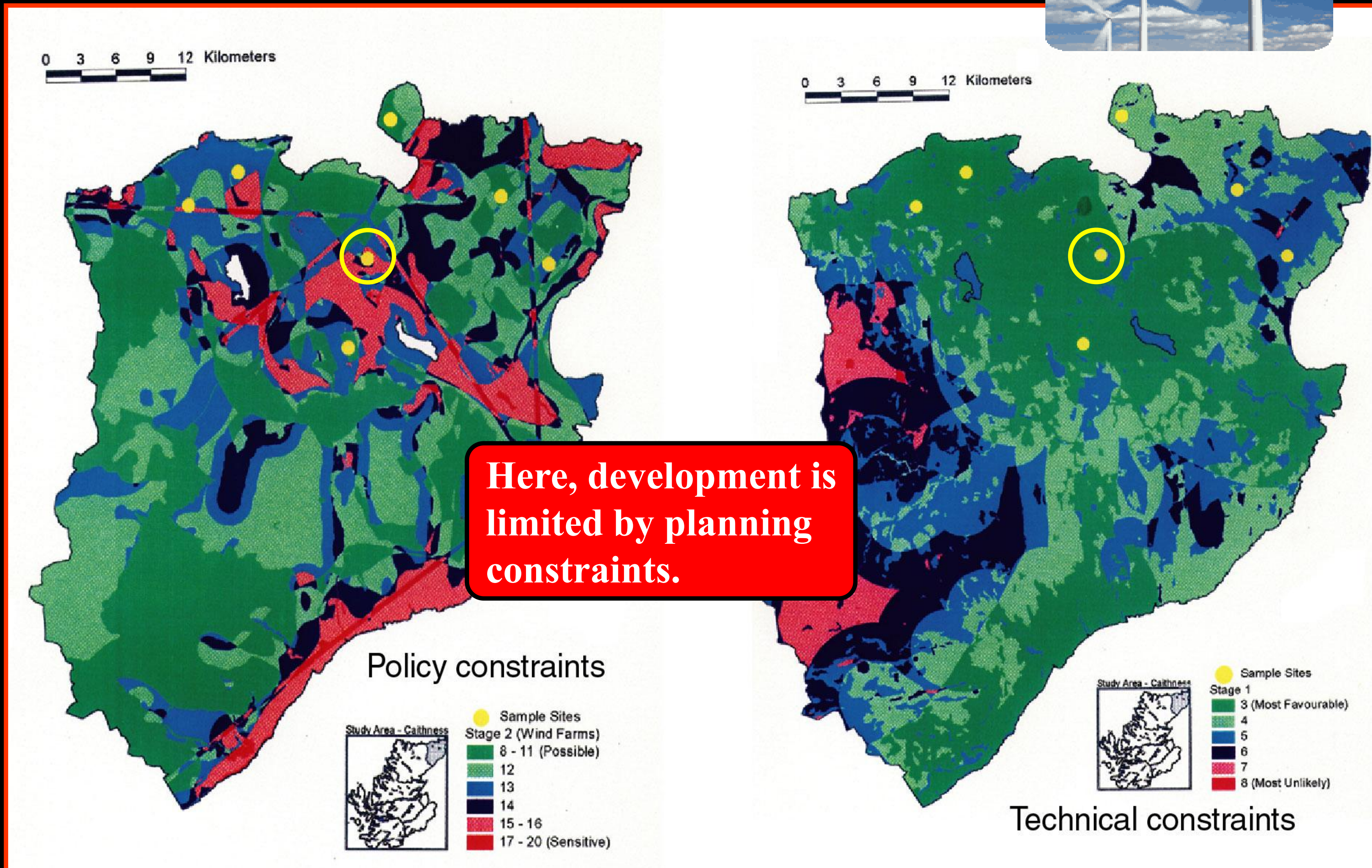
information for government, local authorities, institutions, industry, utilities, designers, planners, citizens and others

Urban planning study

Interrogation examples:

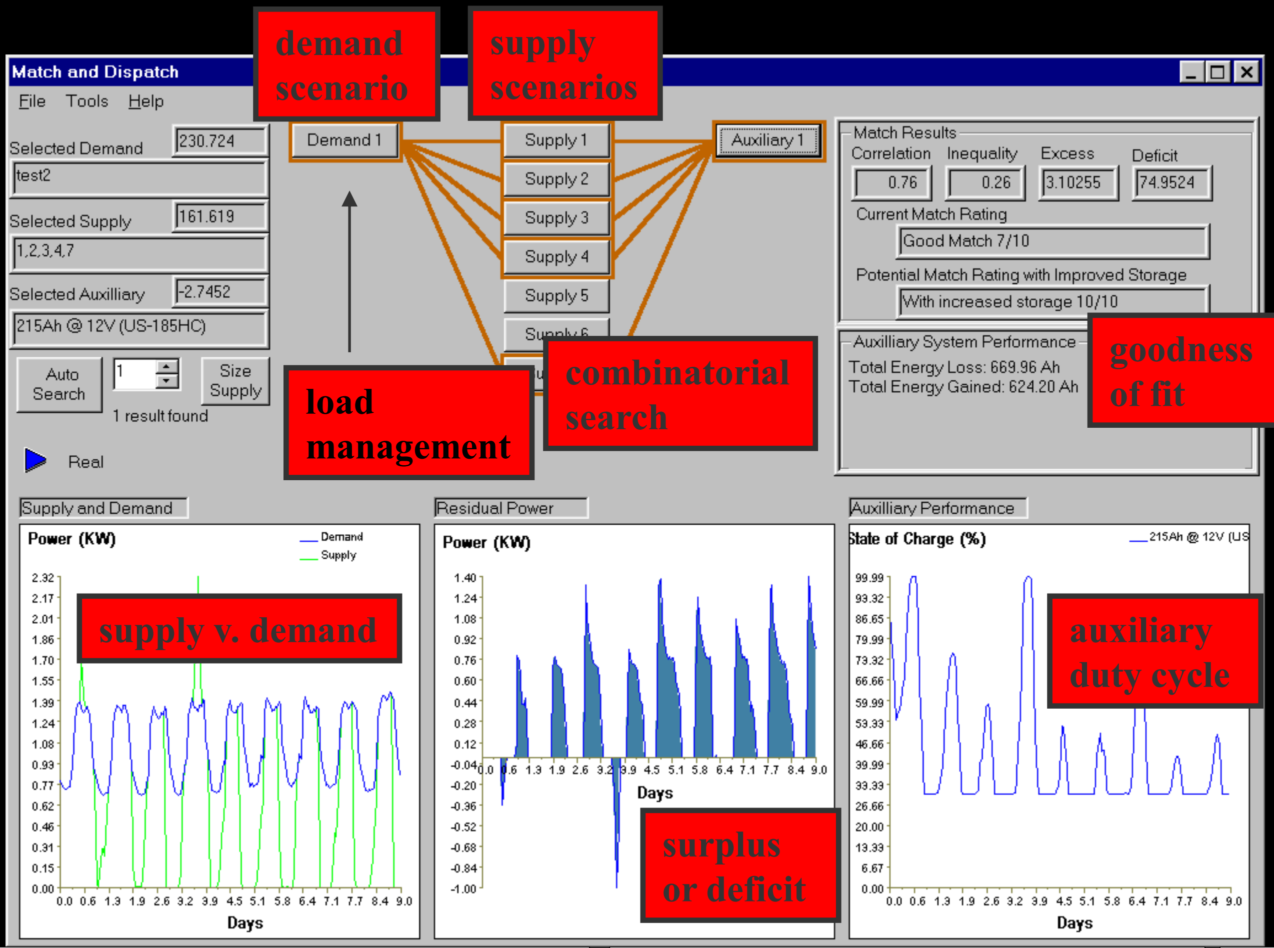
- ❑ energy use;
- ❑ heat-to-power ratio;
- ❑ district heating;
- ❑ daylight/solar/wind access;
- ❑ biomass scheme planning.

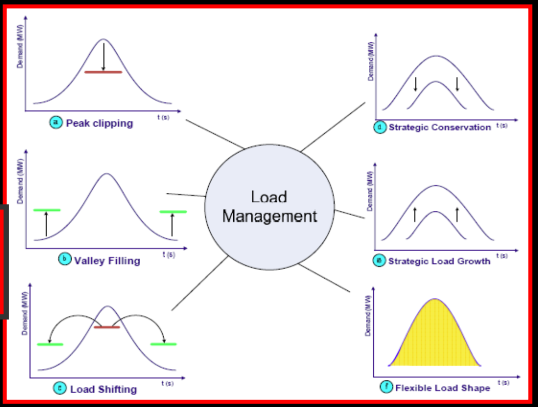
Regional planning: SRO wind farm consent



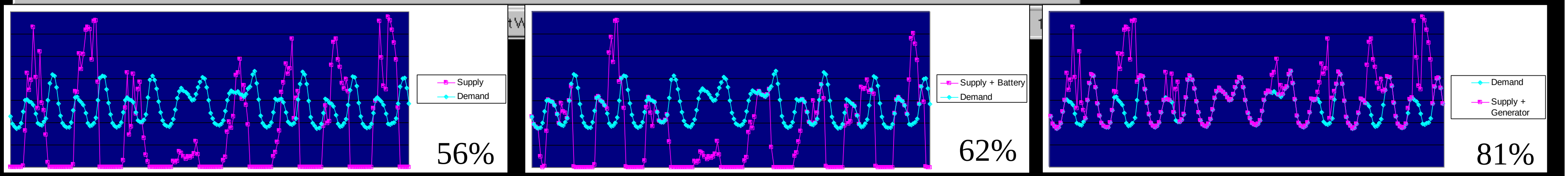
Here, development is limited by planning constraints.

Merit: matching supply to demand

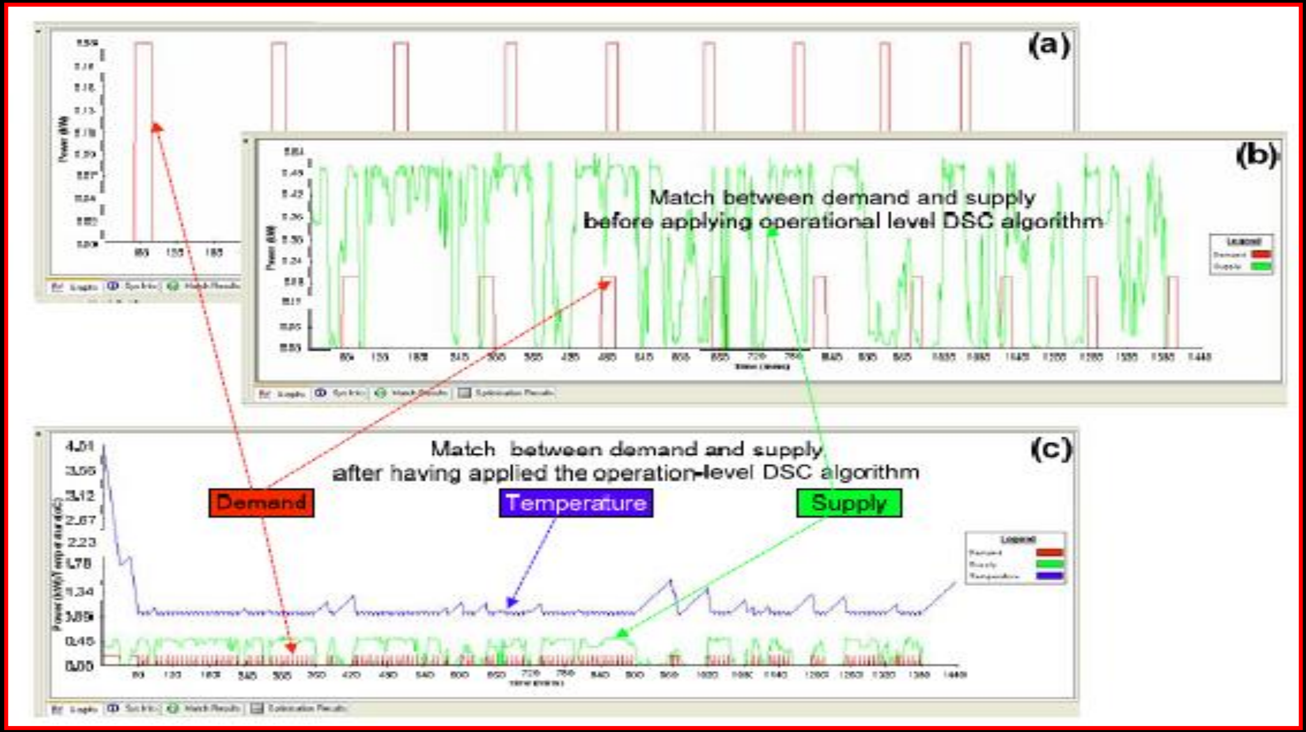




load management approaches



Micro-grid options to improve demand/supply match

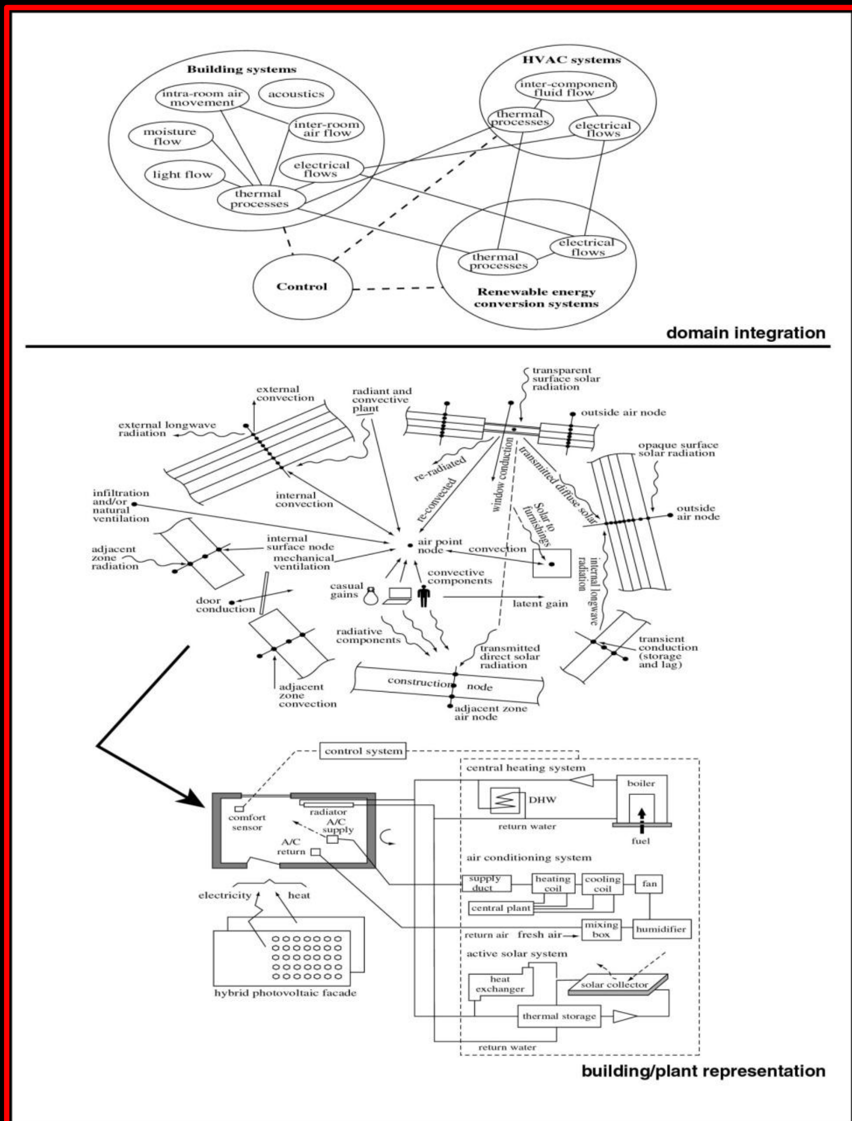


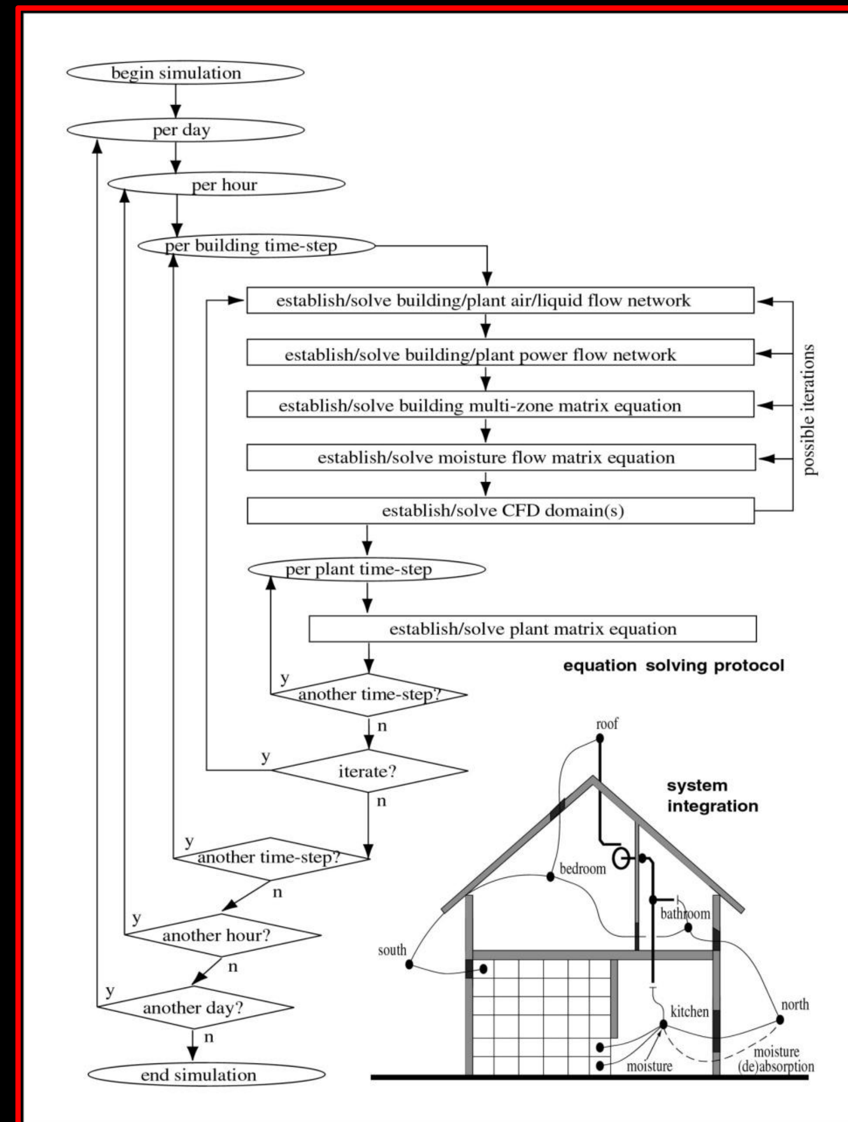
❑ In absence of local storage, not possible to maintain a demand/supply match over time.

❑ Options: use national grid and/or inter-connect MGs to allow trading of energy surpluses/deficits.

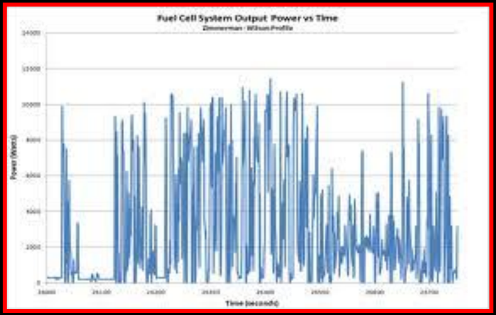
❑ *MGT-s* program developed to examine the impact of governing parameters on criteria relating to MG trading performance.

Energy systems simulation



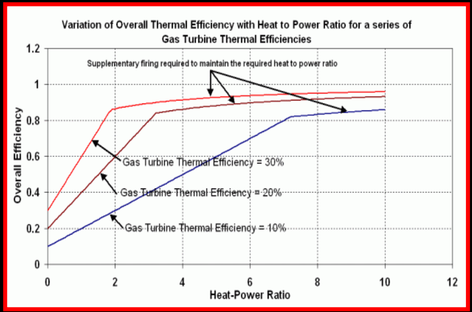


Systems characterisation

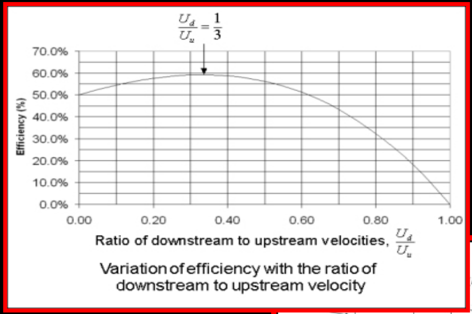


fuel cell

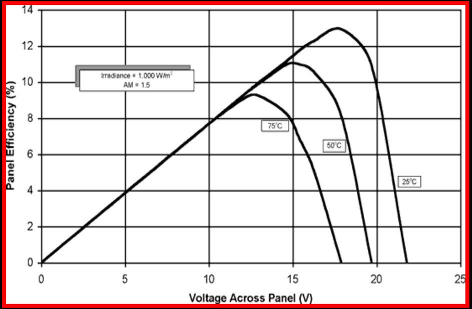
gas turbine

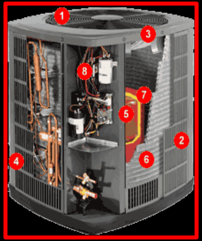


wind turbine

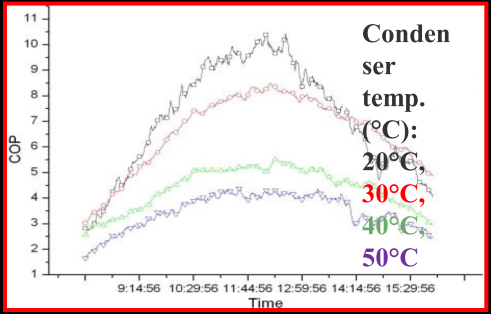


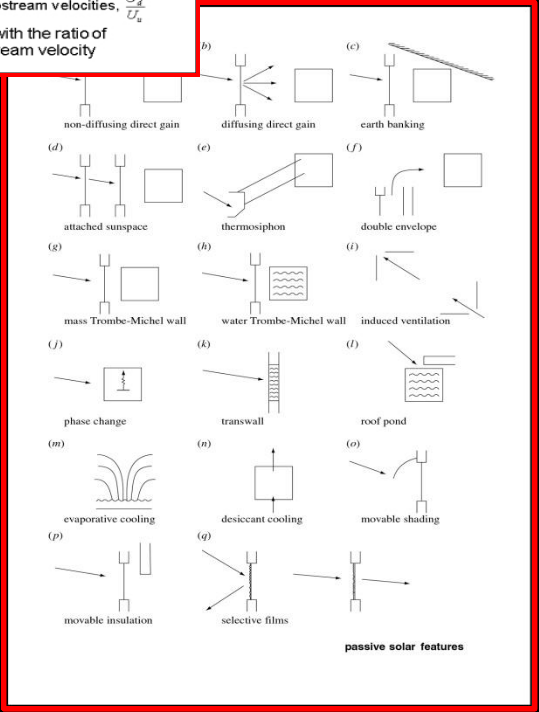
photovoltaics





heat pump





IBPS development goals and progress

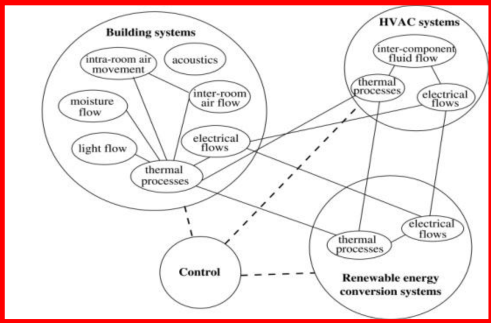
High integrity representation of the dynamic, connected and non-linear physical processes that govern the different performance domains that impact each other and the overall acceptability of buildings, new or existing.

- ❑ Good progress with fundamental process representation.
- ❑ Need for formal research into acceptable levels of abstraction.

Developments: air movement, light distribution, moisture flow, occupant behaviour, fuzzy logic, exergy, uncertainty, new supply systems, smart control, micro-grids, adaptive materials, fast solvers, enhanced geometry *etc*.

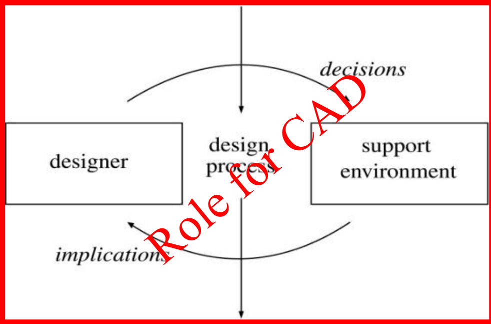
Performance domain conflation to represent the interactions and conflicts that occur between problem parts and thereby give rise to the need to make performance trade-offs and accept non-optimum solutions overall.

- ❑ Good progress with coupling of principal domains.
- ❑ Need for formal research into domain interactions.



Design process integration to embed high fidelity tools within work practices in a manner that adds value and, in the long term, supports virtual design through the interactive manipulation of a design hypothesis with performance feedback in real time.

- ❑ Good progress with data and process representation mechanisms.
- ❑ Need for formal research into design process adaptation.



IBPS: cheaper, quicker and better

Helps practitioners to:

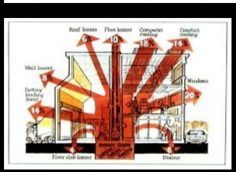
- ❑ ensure requisite levels of thermal, visual & acoustic comfort;
- ❑ attain indoor air quality, health & productivity goals;
- ❑ reduce operational and embodied energy;
- ❑ lessen environmental emissions and impacts.
- ❑ ensure systems controllability and in-built digital intelligence;
- ❑ incorporate innovative EE & DSM solutions;
- ❑ embody high levels of new and RE technologies;
- ❑ conform to legislative requirements;
- ❑ facilitate participation in future ‘smart’ grids.

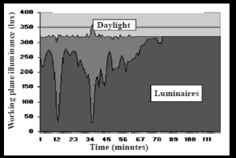
Defines a new best practice:

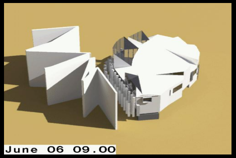
- ❑ respects temporal aspects and interactions;
- ❑ integrates all technical domains;
- ❑ supports co-operative working;
- ❑ enables realistic life cycle assessments;
- ❑ links building design to local and global issues.

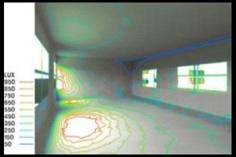
The approach is rational:

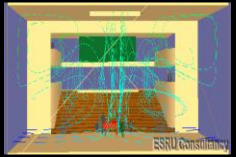
- ❑ gradual evolution of the problem description;
- ❑ action taken against performance outputs at discrete stages.

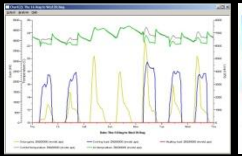


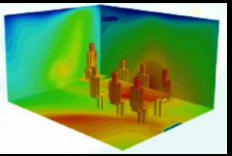


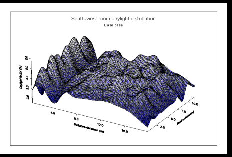


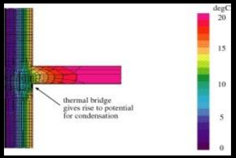












Behaviour follows description (i.e. reward follows effort)

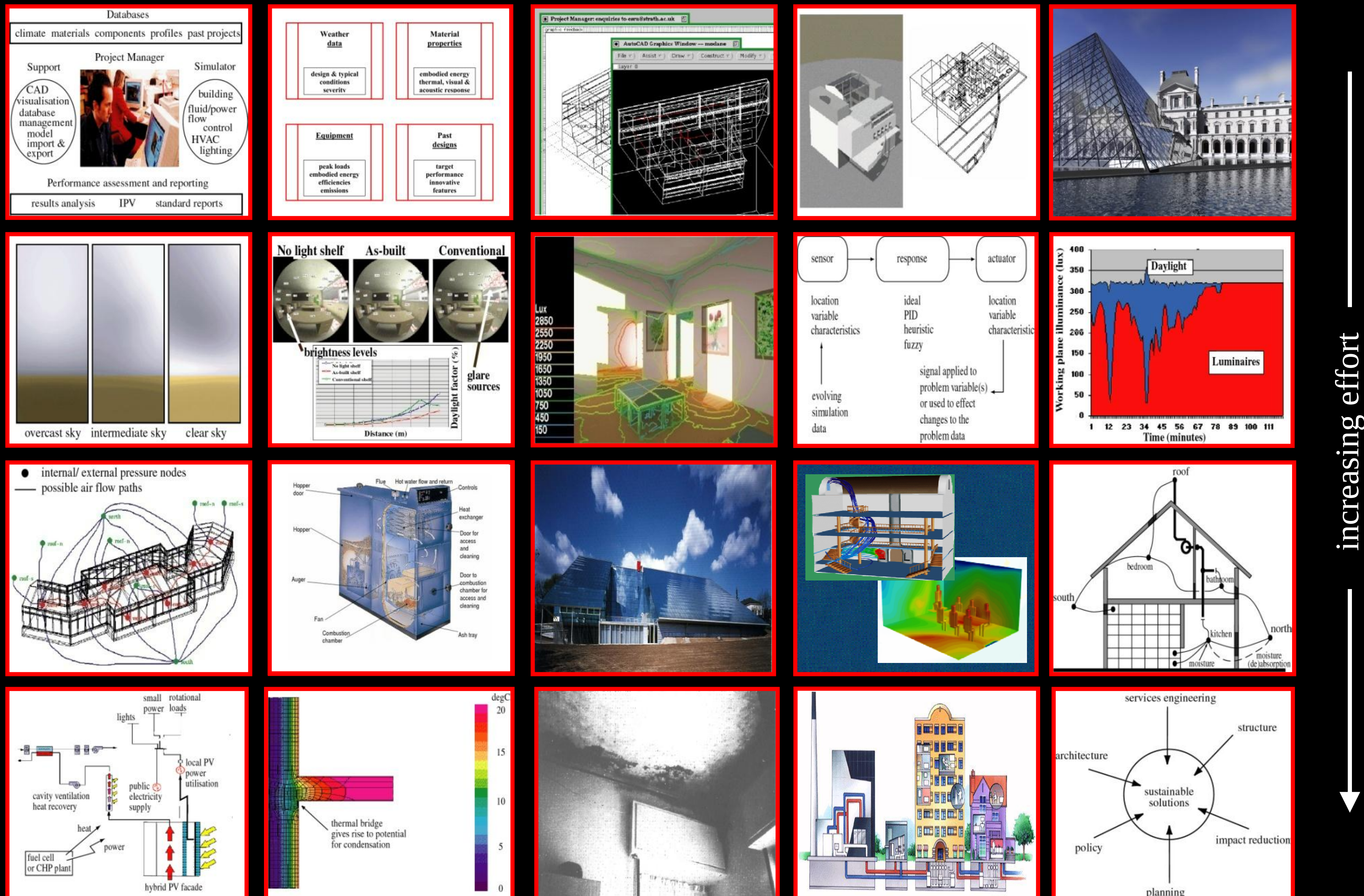
pre-constructed dbs	performance indicators
+ geometry spec.	visualisations, shading *etc*
+ constructional	embodied energy *etc*
+ operational data	energy demand profiles *etc*
+ boundary conditions	‘no-system’ comfort *etc*
+ special materials	PV, switchable glazings *etc*
+ control systems	energy use, system response *etc*
+ flow network	ventilation, heat recovery *etc*
+ HVAC network	component sizing, systems design *etc*
+ CFD domain	IAQ, comfort, ventilation η *etc*
+ power network	DSM, RE integration *etc*
+ enhanced resolution	thermal bridging *etc*
+ moisture network	condensation, mould & health

Quantifying the effects of uncertainty

- External approach
  - alters only the input data
  - requires multiple simulations and analysis of differences in predictions
  - differential method alters one parameter at a time and requires 2P +1 simulations for P uncertain parameters
  - factorial method alters groups of parameters to quantify interactions between and requires 2P simulations
  - Monte Carlo method alters all parameters simultaneously to quantify the overall effect (number of simulations is independent of P and is typically ~80)
  - to quantify individual contributions, interactions between contributions and the overall effect requires all three methods.

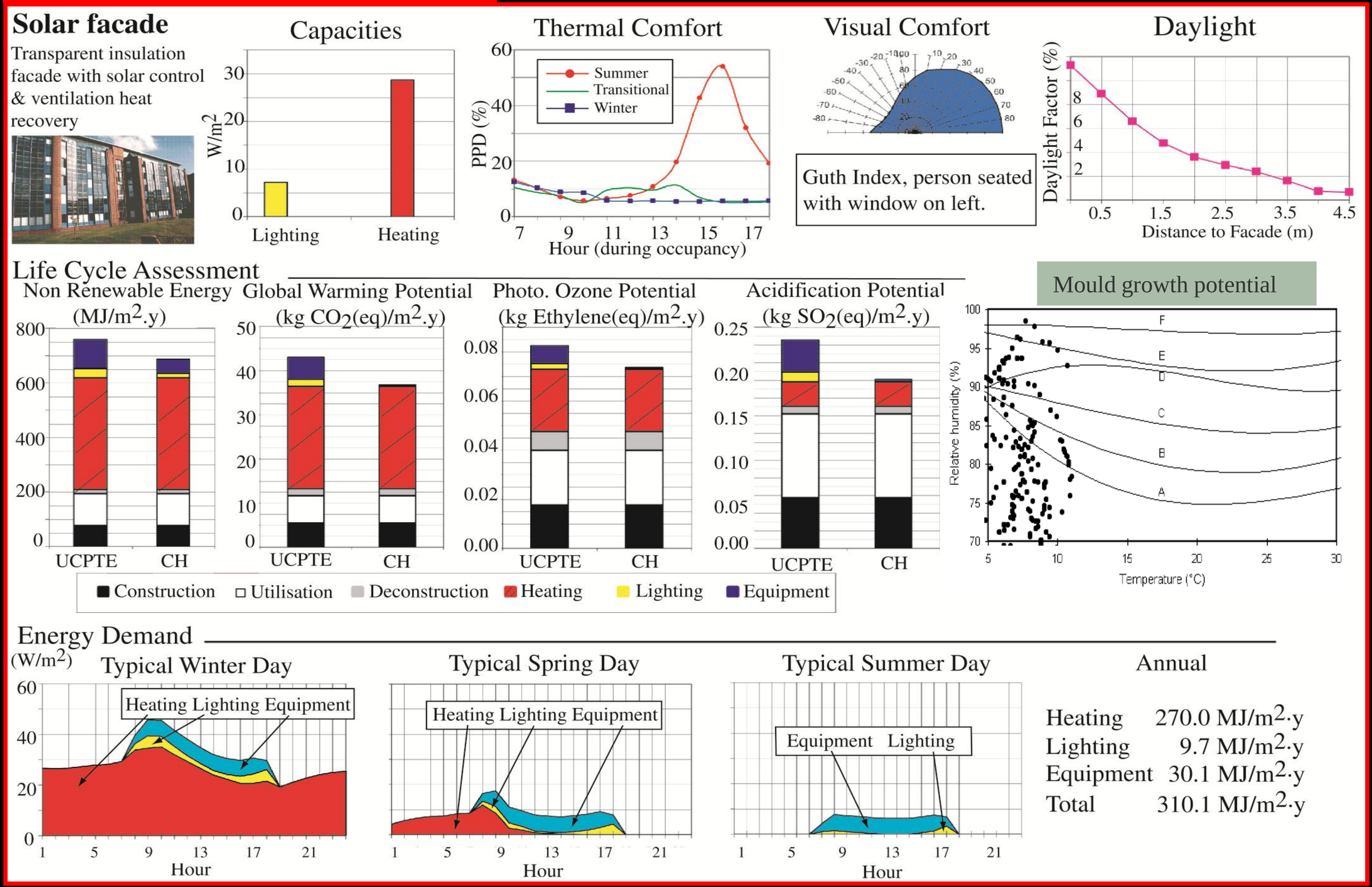
- Internal approach
  - Includes uncertainty within the simulation
  - represents model parameters as a function of uncertainty (interval, fuzzy and affine arithmetic methods)
  - requires only a single simulation to quantify individual and overall effects
  - Uncertain parameters are represented by a polynomial comprising a mean value and individual uncertainty terms represented as interval numbers
  - Specific performance instances are created in a post-simulation analysis by specifying value for each of the uncertainty terms.

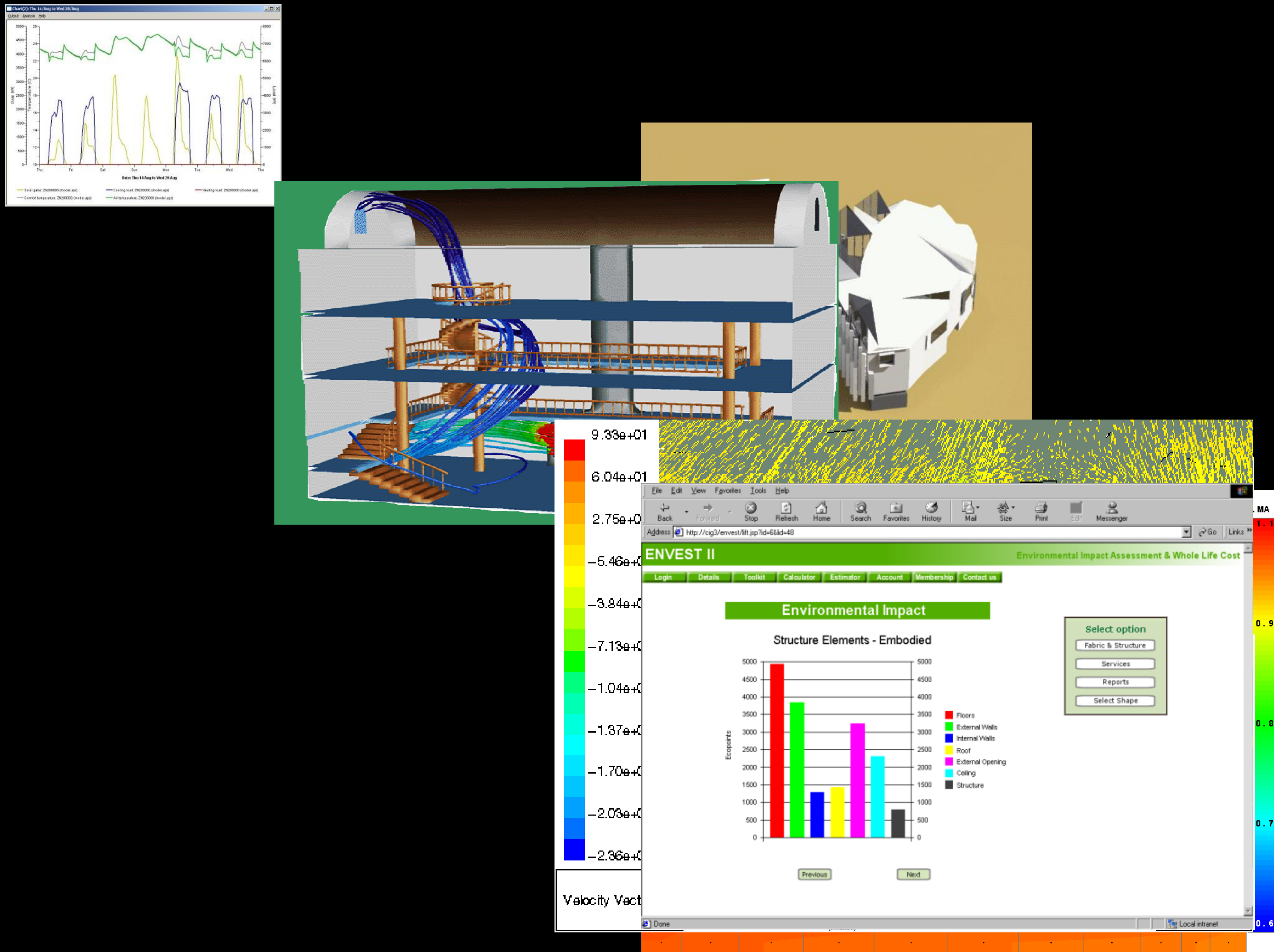
ESP-r: integrated performance simulation



Integrated views of performance

Version 1 | Version 2 | Version 3

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–1.70e+0
–2.03e+0
–2.36e+0
Velocity Vect
ENVEST II
Environmental Impact Assessment & Whole Life Cost
Login
Details
Toolkit
Calculator
Estimator
Account
Membership
Contact us
Environmental Impact
Structure Elements - Embodied
Ecopoints
Floors
External Walls
Internal Walls
Roof
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Select option
Fabric & Structure
Services
Reports
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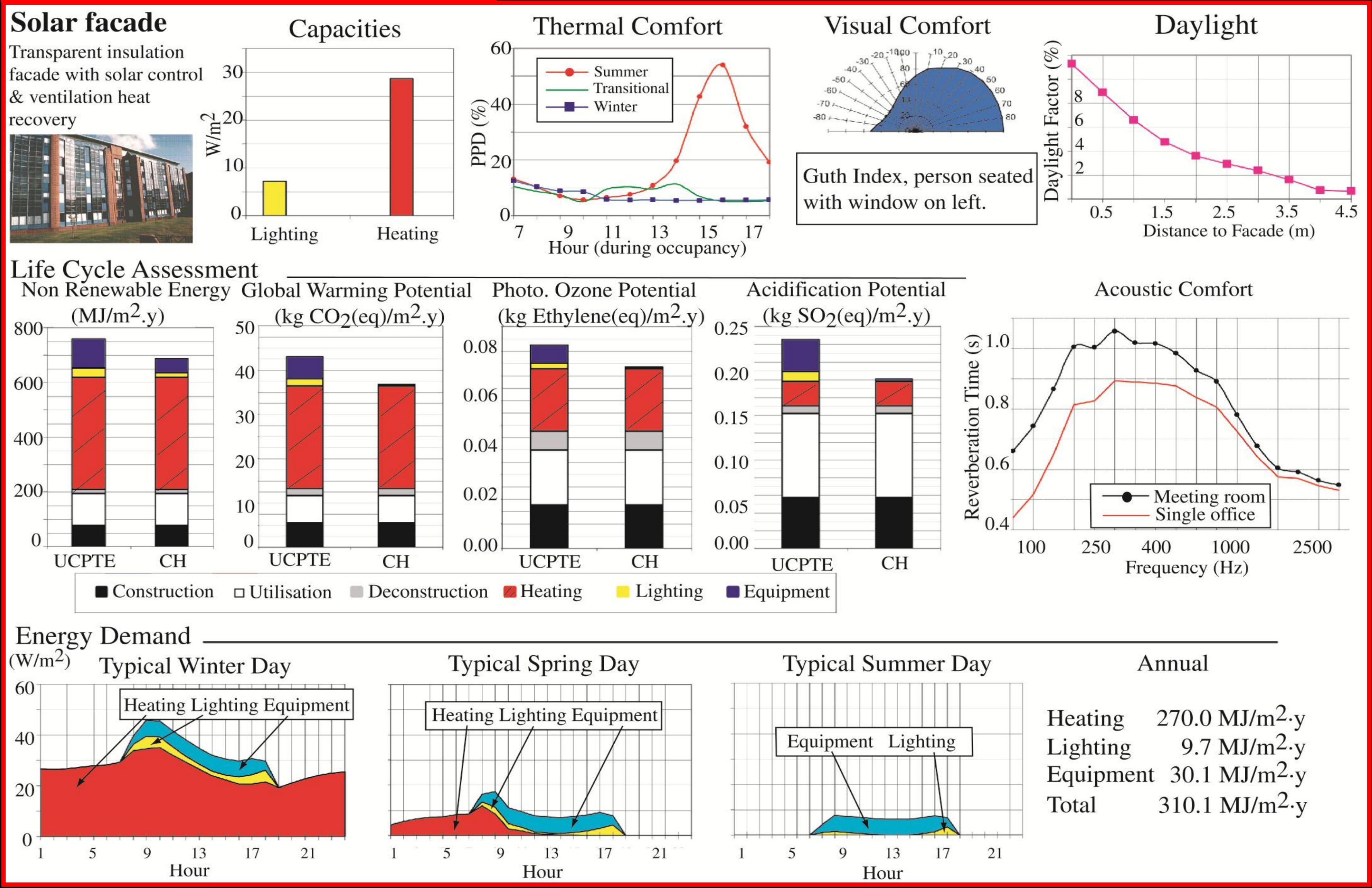
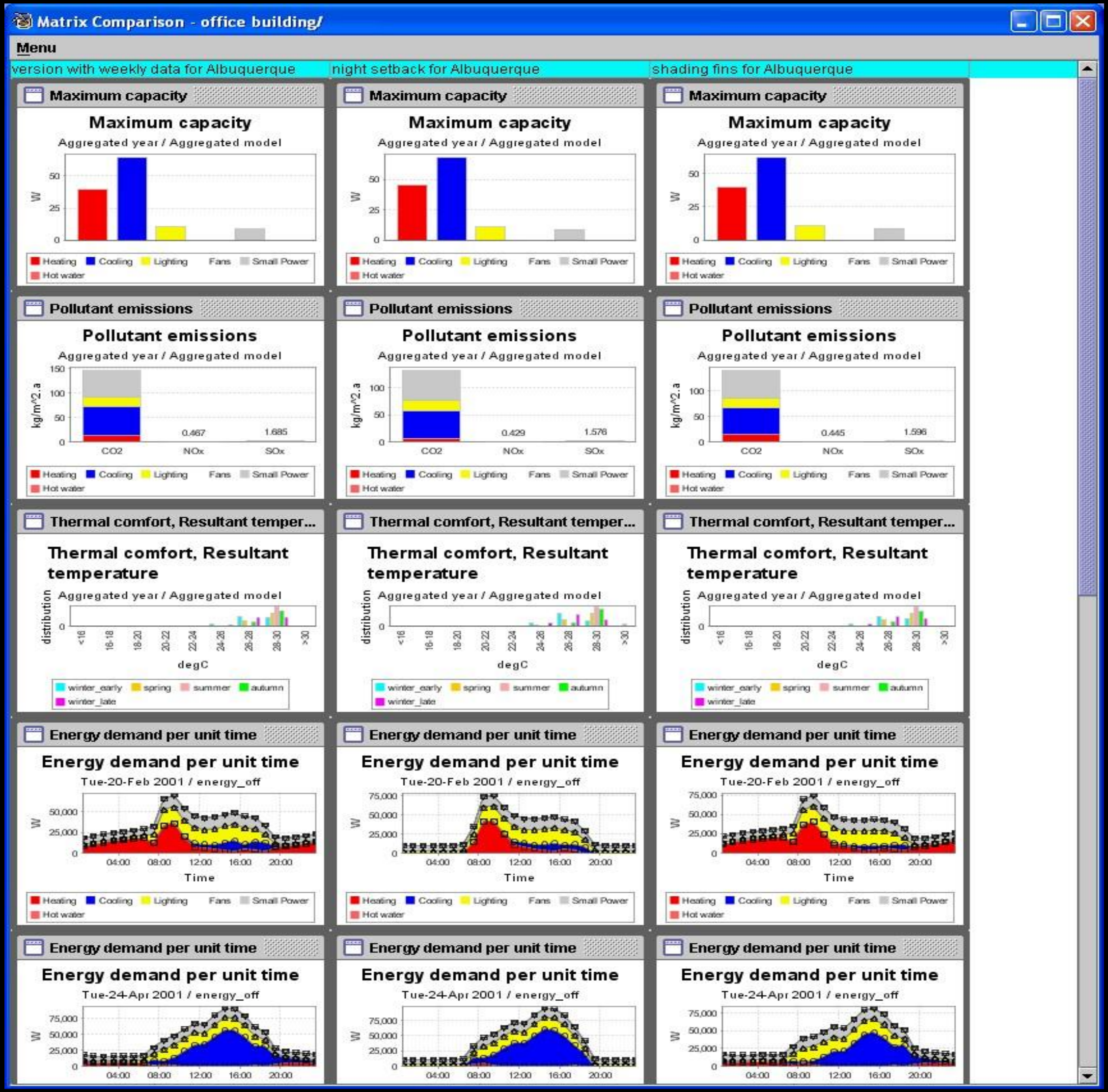
Previous
Next

An integrated views of performance

Version 1 | Version 2 | Version 3



Systematic investigation



Simulation-based design

Requires adherence to a formal performance assessment method:

1. **establish initial model** for an ***unconstrained base case design*****;**
2. **calibrate model** using ***reliable techniques*****;**
3. **assign boundary conditions** of ***appropriate severity*****;**
4. **undertake integrated simulations** using ***suitable applications*****;**
5. **express multi-domain performance** in terms of ***suitable criteria*****;**
6. **identify problem areas** as a function of ***criteria acceptability*****;**
7. **analyse results** to identify ***cause of problems*****;**
8. **postulate remedies** by ***relating parameters to problem causes*****;**
9. **establish reference model** to ***required resolution*** for each postulate**;**
10. **iterate from step 4** until overall ***performance is satisfactory*****;**
11. **repeat from step 3** to establish ***design replicability*****.**

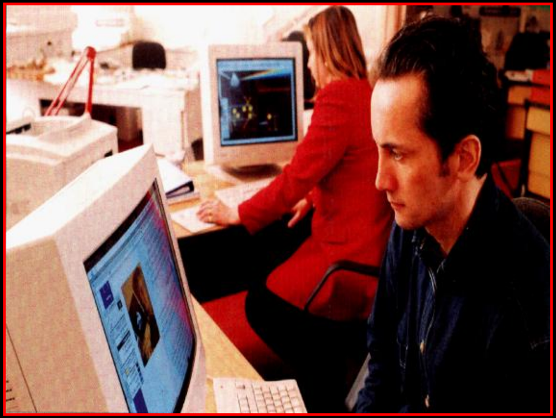
The time cycle of IBPS application is unacceptable in relation to the requirements of practice.

Attempts to address this by theoretical simplifications and/or reduced domain representation are ill-founded and unlikely to evolve the state-of-the-art in the direction required.

Simulation-based design evolution

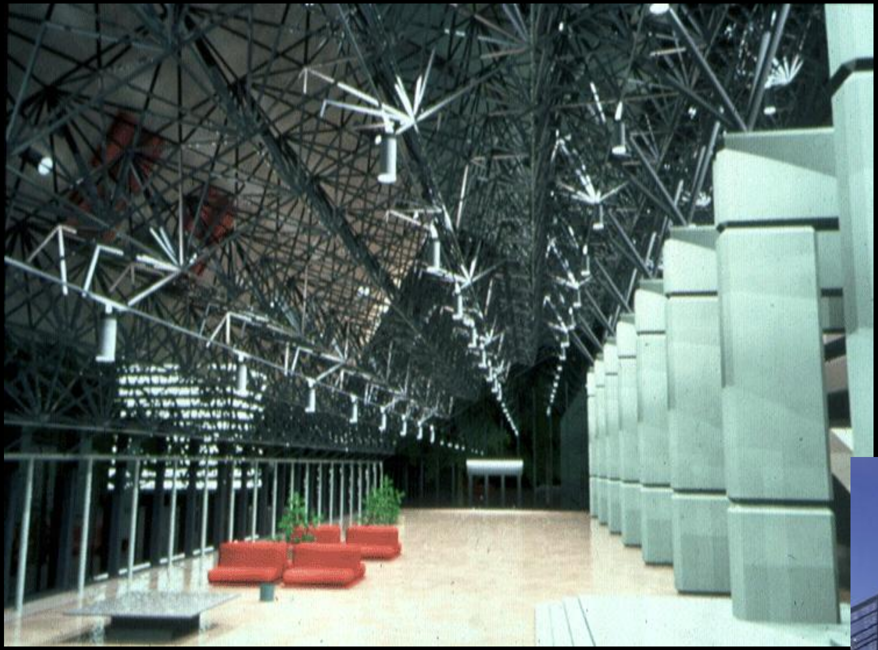
Requires changes to work practices and adherence to standard performance assessment methods (PAMs – action in **red**, knowledge in yellow):

1. establish initial model for an unconstrained base case design;
2. calibrate model using reliable techniques;
3. assign boundary conditions of appropriate severity;
4. undertake integrated simulations using suitable applications;
5. express multi-domain performance in terms of suitable criteria;
6. identify problem areas as a function of criteria acceptability;
7. analyse results to identify cause of problems;
8. postulate remedies by relating parameters to problem causes;
9. establish revised model to required resolution for each postulate;
10. iterate from step 4 until overall performance is satisfactory;
11. repeat from step 3 to establish design replicability.

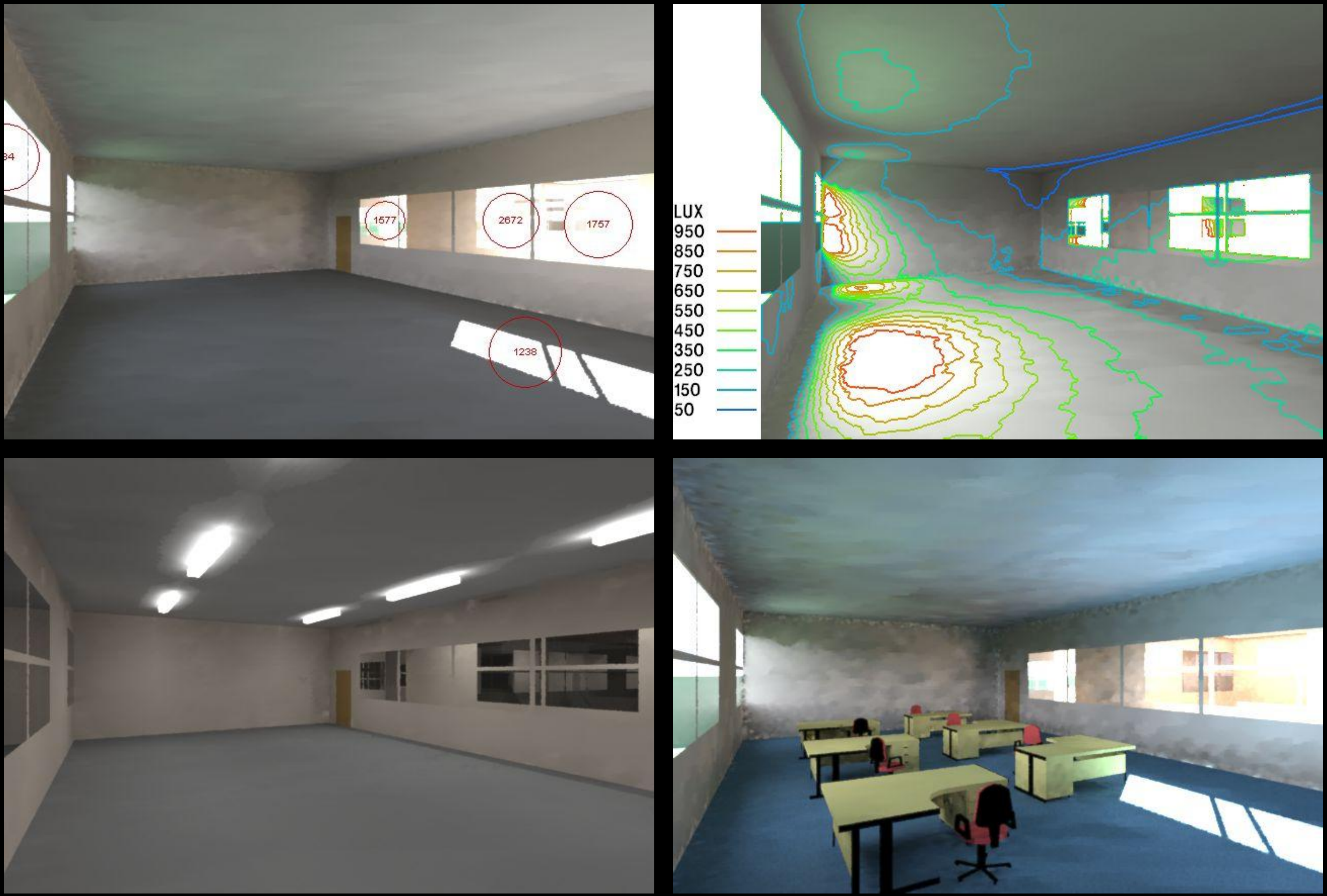


Standard PAMs required for all aspects of building life cycle performance: comfort, health & productivity; operational & embodied energy, emissions & environmental impact, technology options appraisal, demand management, embedded generation, regulations compliance, hybrid systems control, economics, *etc*. – all utilising agreed simulation contexts and performance metrics and activated by the evolving data model.

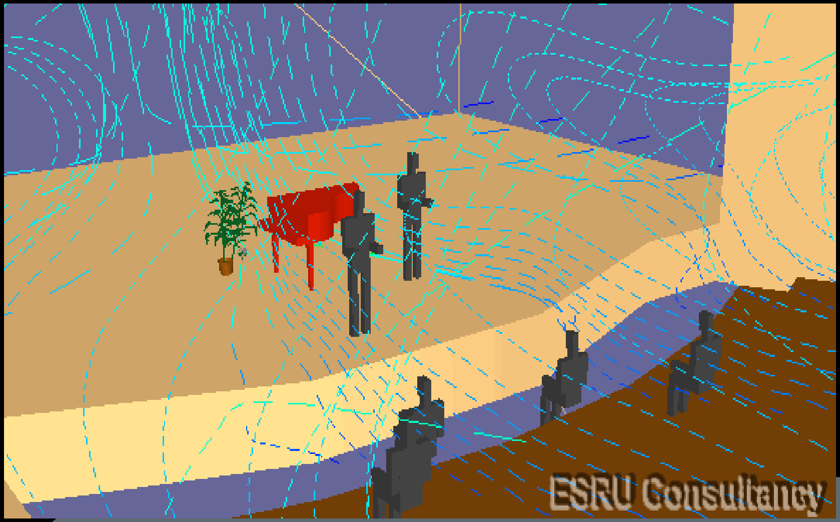
Visualisations

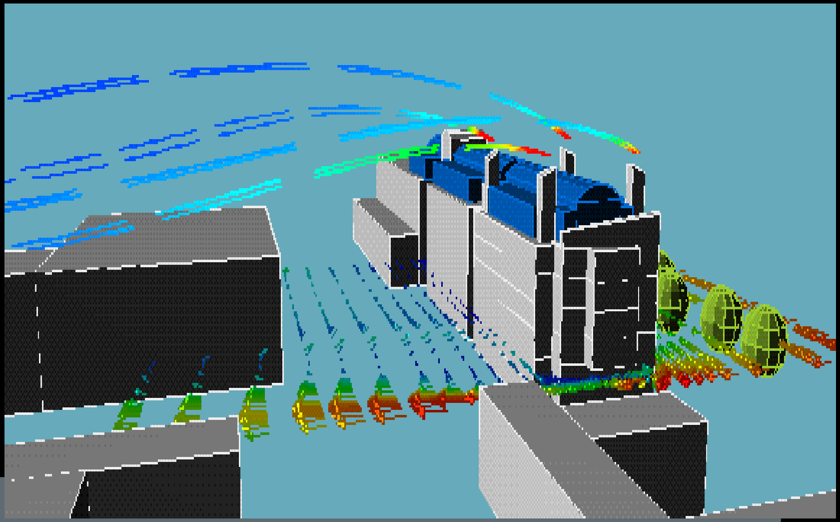


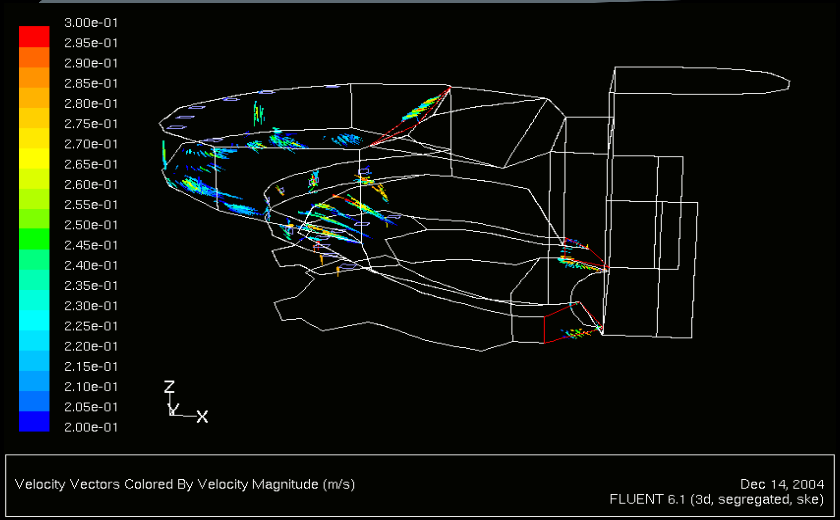
Internal lighting

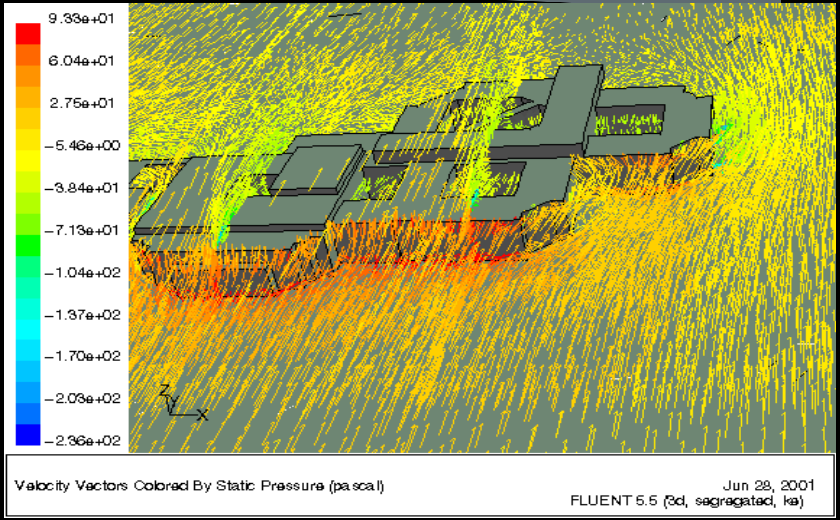


Air flow and emissions

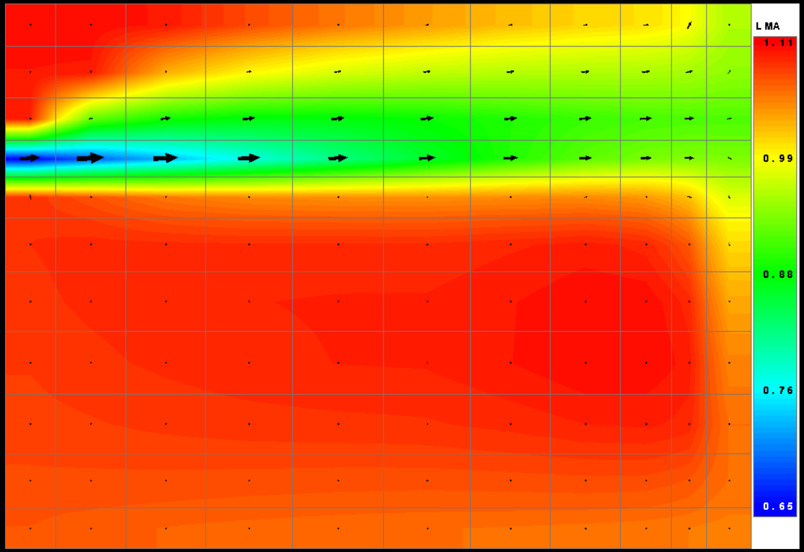


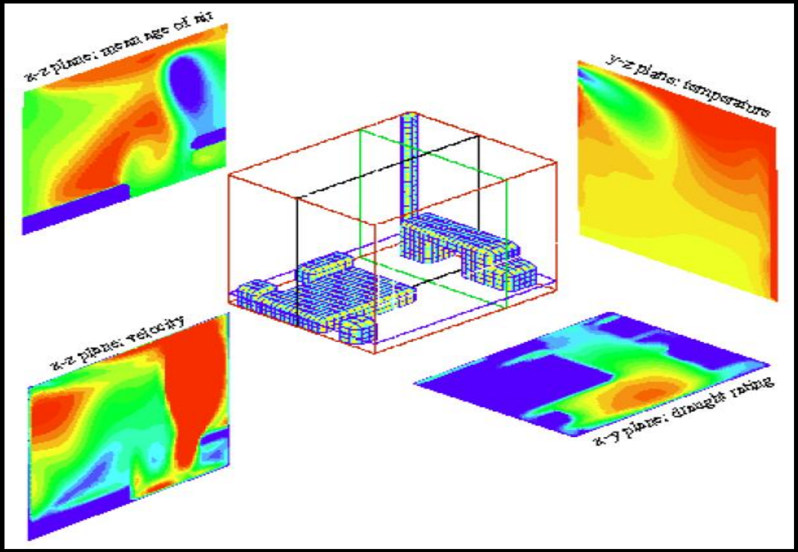


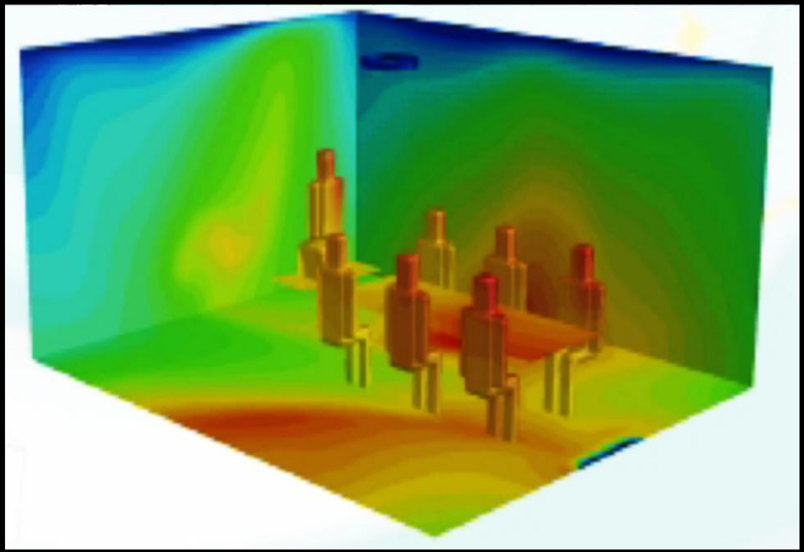


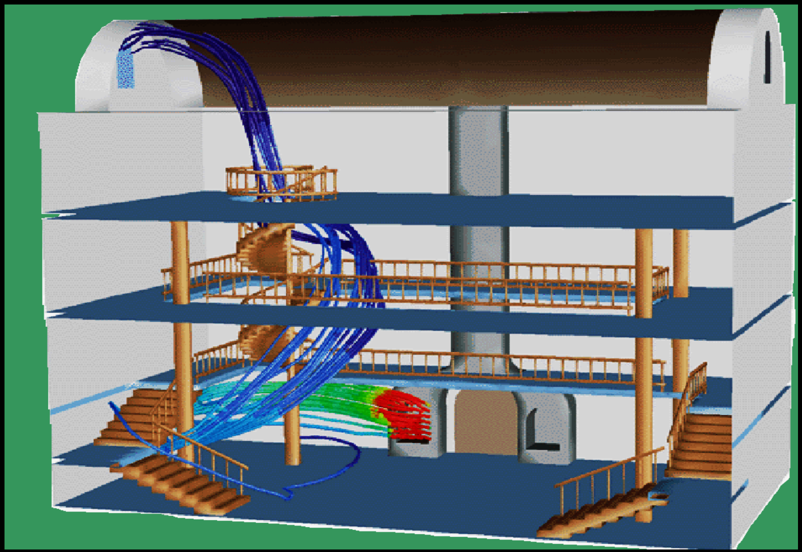


IAQ & comfort

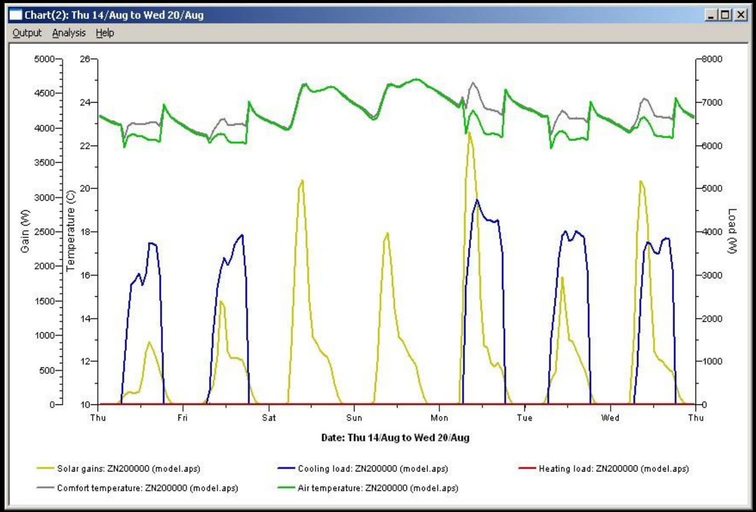

L MA
1.11
0.99
0.88
0.76
0.65

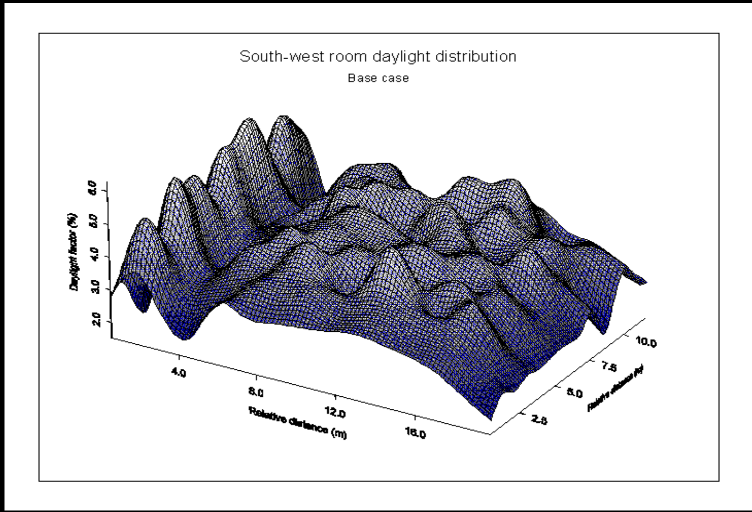

x-z plane: mean age of air
y-z plane: temperature
x-z plane: velocity
x-y plane: draught rating

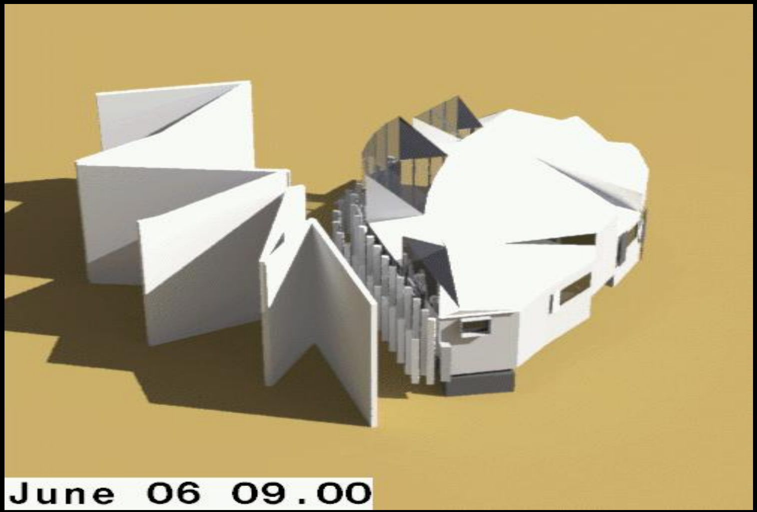


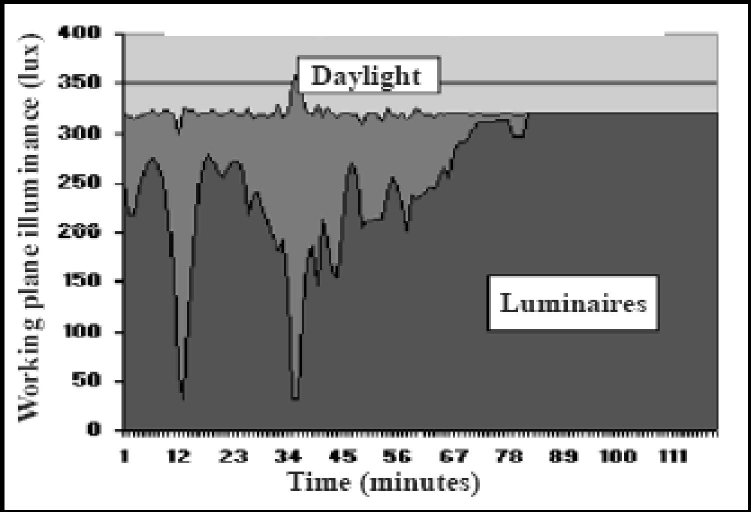


Appropriate data presentation

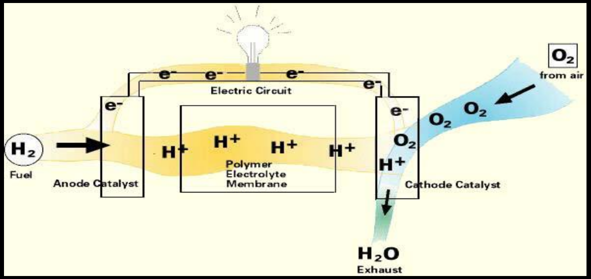


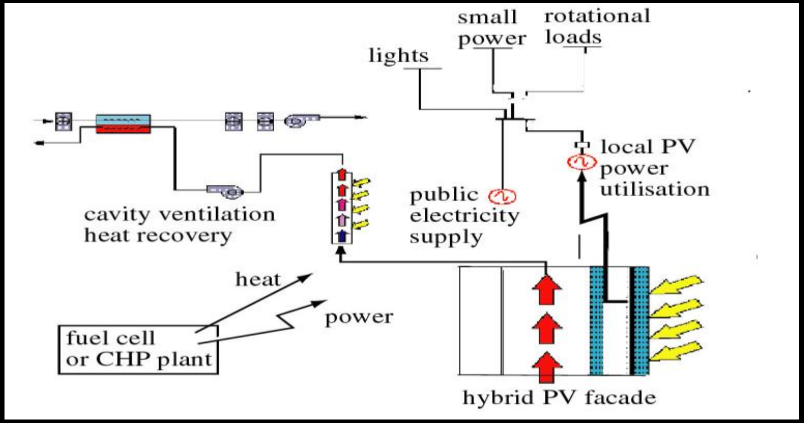




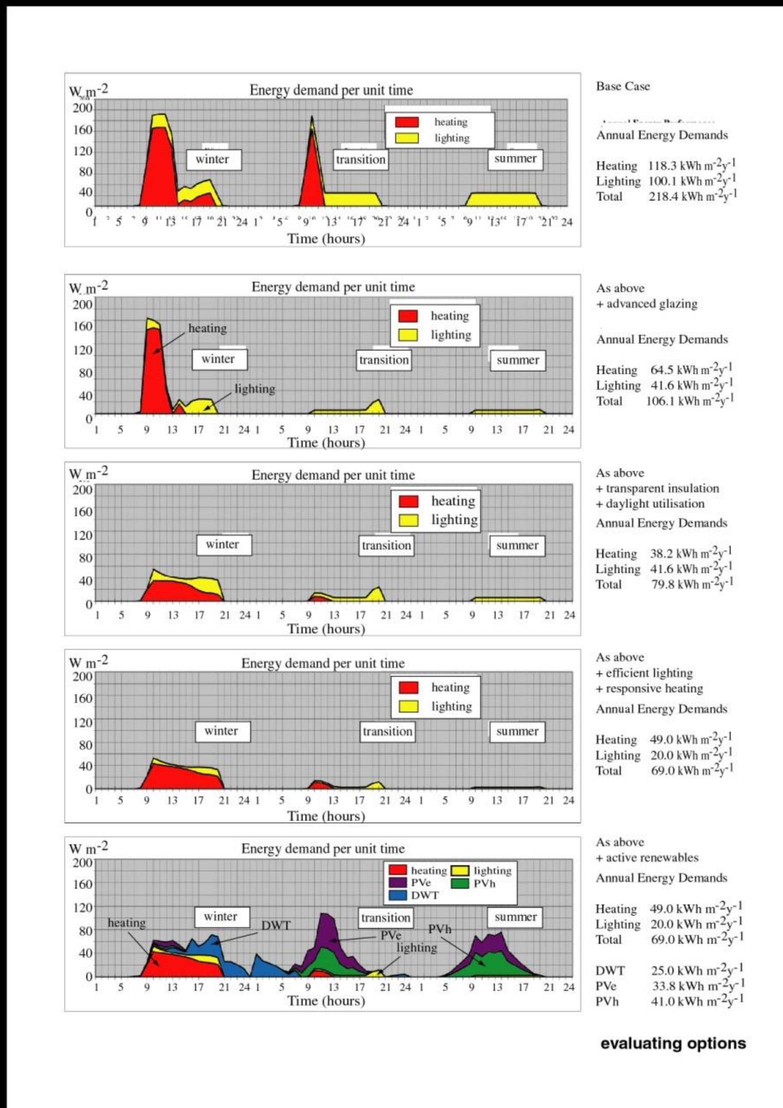


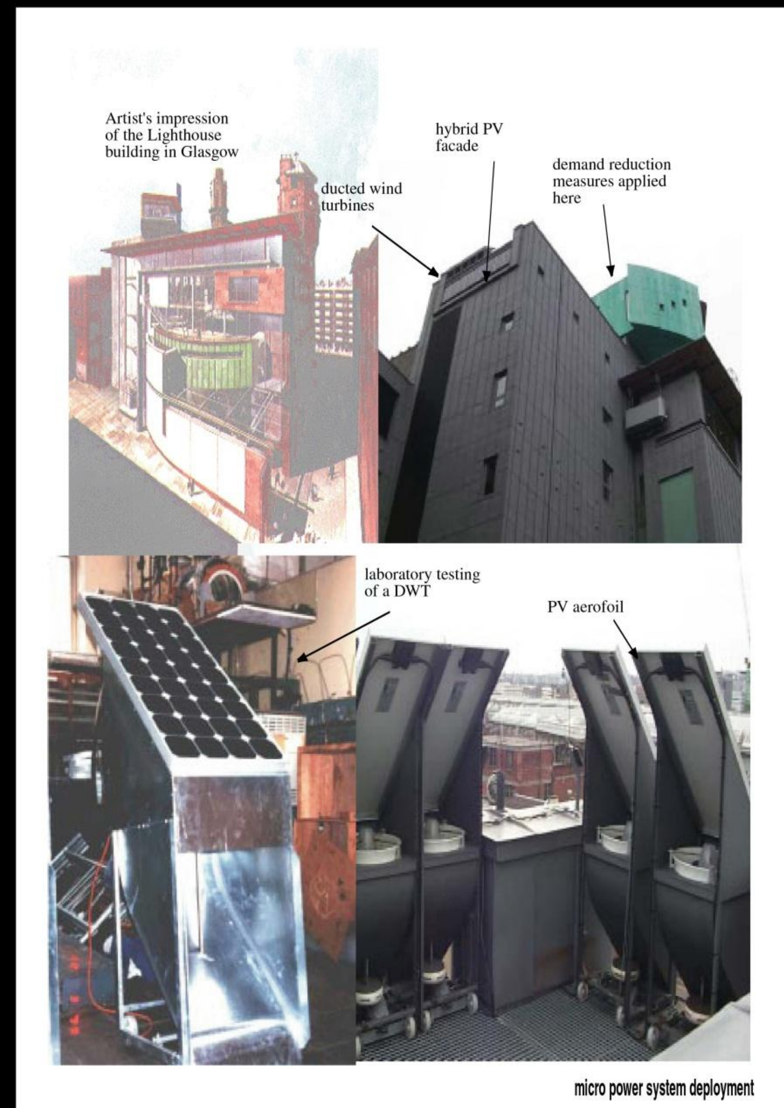
Integrating renewables

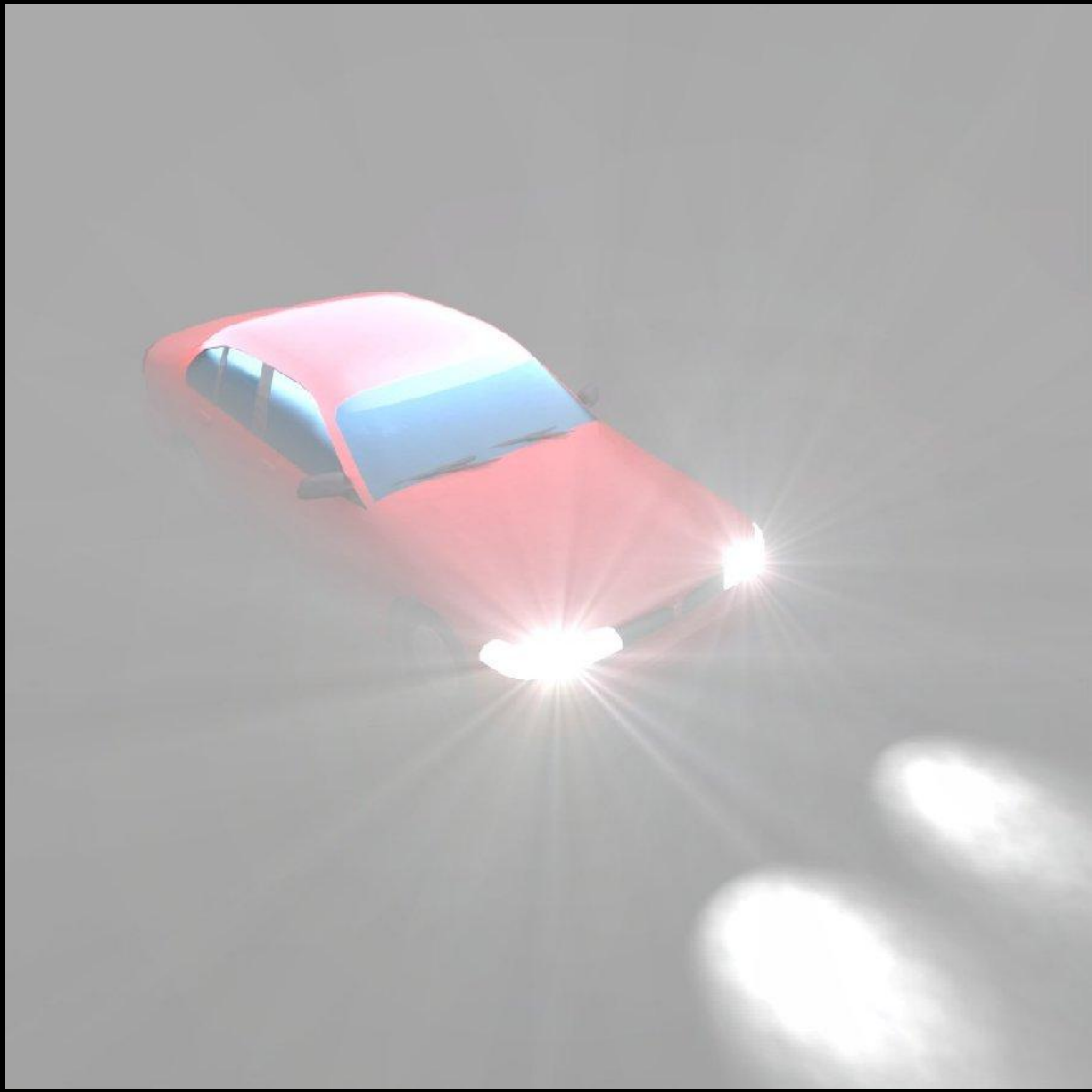




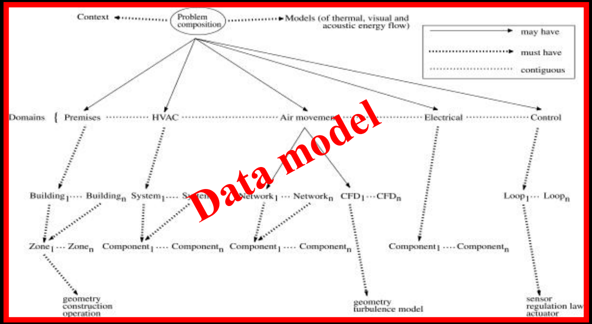
Integrating renewables: the Lighthouse Building



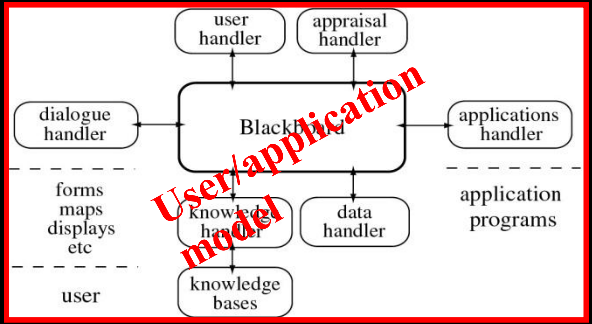




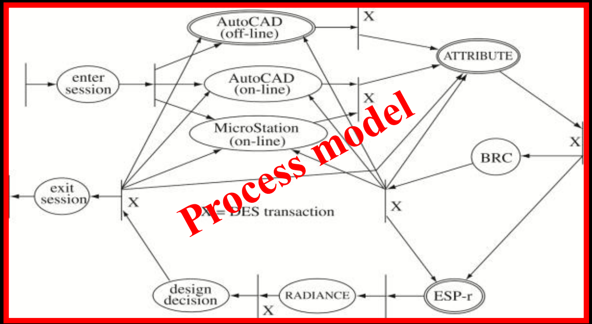
Simulation-embedded CAD



- ❑ IBPS defines the superset data model.
- ❑ CAD is the best agent for data model coordination.
- ❑ Data model representation technologies exist.
- ❑ Need to extend the data model to non-traditional areas (use reality as the guide, not past engineering abstractions).

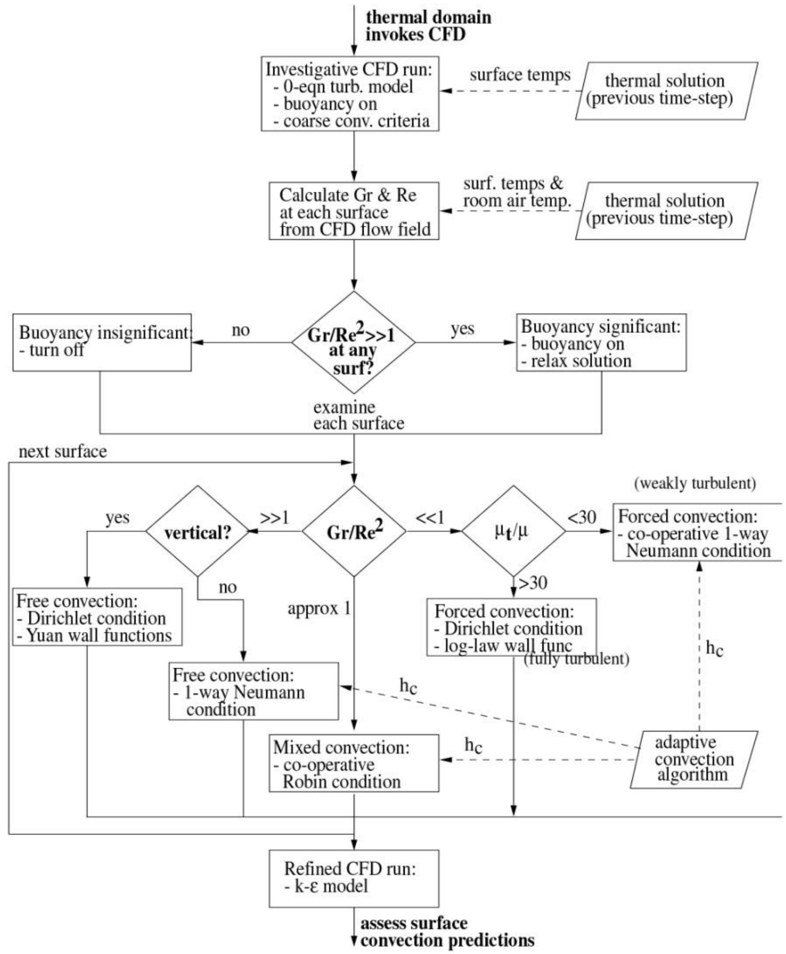


- ❑ Need to separate out the different aspects of the user interface: user dialogue, user/domain/application knowledge, data management and application control.
- ❑ CAD is the best agent for coordinating such aspects.
- ❑ HCI and user representation technologies exist and prototypes have been constructed and tested.



- ❑ Need to formally define work flow models and performance assessment approaches.
- ❑ CAD is the best agent for multi-variate performance assessment control.
- ❑ Process representation technologies exist and prototypes have been constructed and tested.

Solver uncertainty



Dirichlet BC: fixed surface temp. $\theta = \theta_S$

Neumann BC: fixed surface heat flux $k\frac{\delta\theta}{\delta n} = q$

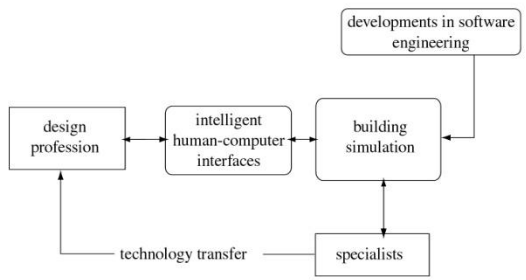
Robin BC: heat flux proportional to local heat transfer $k\frac{\delta\theta}{\delta n} = h_C(\theta - \theta_S)$

dynamic CFD model configuration

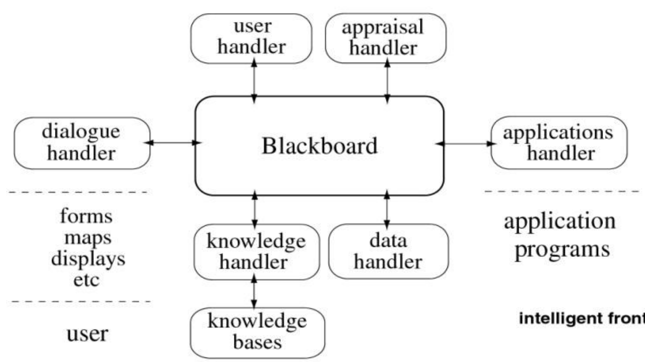
turbulence model	hand-shaking mechanism	CFD thermal boundary condition	applicability
$k-\varepsilon$ model and log-law wall functions (for momentum eqs)	one-way	+Dirichlet +CFD calculates q_{conv} with log-law wall function	+predicting flow &temp. field +not suitable for buoyancy-driven ow +not suitable for o ws strongly affected by q_{conv}
		+Neumann +thermal domain → T_{surf} +thermal domain → $T_{room-air}$ +ACA → h_c	+predicting flow and temp. field +suitable for flows strongly affected by q_{conv}
		+co-op Neumann +thermal domain → T_{surf} +CFD → $T_{room-air}(avg)$ +ACA → h_c	+predicting flow and temp.field +suitable for flows strongly affected by q_{conv} +useful when room stratfied
		+co-op Robin +thermal domain → T_{surf} +CFD → T_p (local) +ACA → h_c	+prediction flow and temp.field +suitable for flows strongly affected by q_{conv} +useful when room stratified
	conditional two-way	+Dirichlet +CFD calculates q_{conv} with log-law wall functions	+predicting flow and temp. field +enhancing surface conv. calcs +not suitable for buoyancy-driven flow +not suitable for flows strongly affected by q_{conv} +next-to-wall points must be properly placed
		+co-op Robin +thermal domain → T_{surf} +CFD → T_p (local) +ACA → h_c	+predicting flow and temp. field +enhancing surface conv. calcs +suitable for o ws strongly affected by q_{conv} +useful when room stratified
$k-\varepsilon$ model and Yuan wall functions	one-way	+Dirichlet +CFD calculated q_{conv} with Yuan wall function	+predicting flow and temp. field +only suitable for buoyancy-driven flow +only suitable for vertical surfaces
	conditional two-way	+Dirichlet +CFD calculated q_{conv} with Yuan wall function	+predicting flow and temp. field +enhancing surface conv. calcs +only suitable for buoyancy-driven flow +only suitable for vertical surfaces
Chen & Xu zero equation model	one-way	+Dirichlet +CFD calculates q_{conv}	+predicting flow and temp. field +suitable for quick indication of flow +less suitable for buoyancy-driven flow +less suitable for flows strongly affected by q_{conv}
	conditional two-way	+Dirichlet +CFD calculates q_{conv}	+predicting flow and temp. field +enhancing surface conv. calcs +less suitable for buoyancy-driven flow +less suitable for flows strongly affected by q_{conv} +next-to wall points must be properly placed

turbulence model applicability

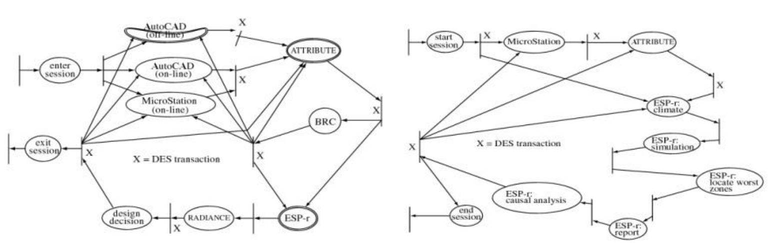
Modelling methods uncertainty



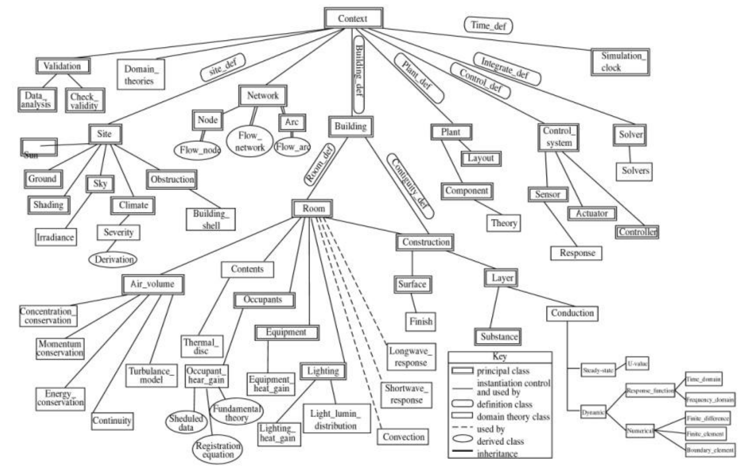
future options



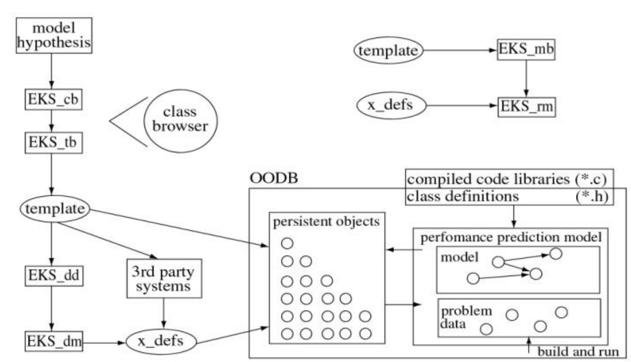
intelligent front-end



explicit process models



building class taxonomy



automated model building

"The real need is to leave future generations with knowledge and capital, such that they can obtain a quality of life at least as good as ours, all in all."

Nobel Laureate, Robert Shaw


The realisation of clean energy systems with low environmental impact presents a truly formidable engineering challenge.
Modelling and simulation is an apt tool to address this challenge.
The establishment of truly comprehensive design tools requires further, industry-led, effort.