A Structured Method for Zero Carbon Design Using Dynamic Simulation

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Birmingham Zero Carbon House – evidence base for experimental research

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Birmingham Zero Carbon House

- Designed by Architect John Christophers and his team
- Originally built 170 years ago
- Achieved Code for Sustainable Homes Level 6 through retrofit
- Winner of the RIBA Architecture Award 2010
- Featured extensively in the media
  - The Times "I have seen the future – and it's in Birmingham"
  - New York Times: "An English House That Generates as Much as It Consumes"

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Zero Carbon Retrofit Research at BCU

The scope of work

- Thermal imaging studies
- Occupant studies
- Continuous instrumental monitoring
- Dynamic simulation experiments
- Analysis of Influence of climate change
- Recommendations for retrofit of different types of properties

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Monitoring system

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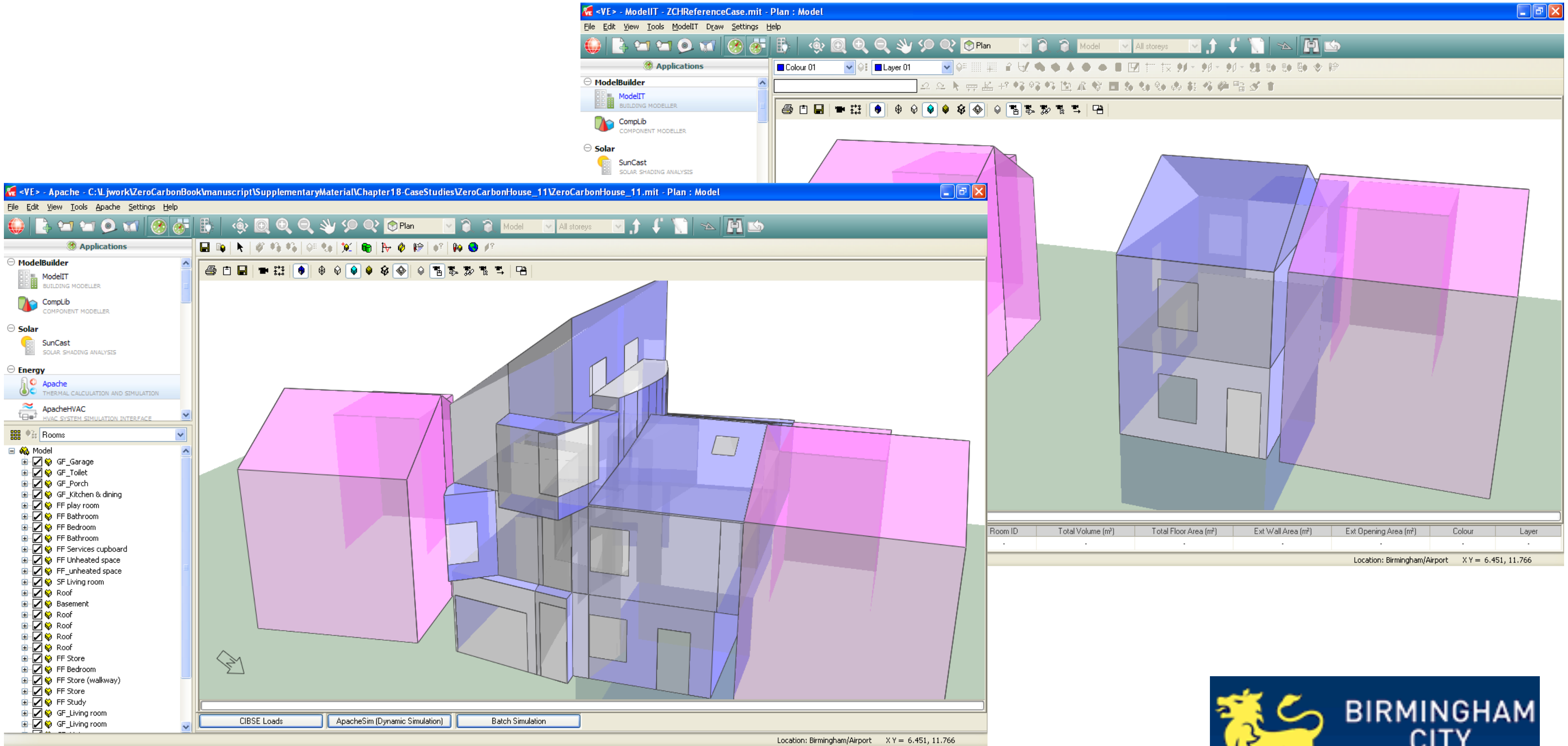
Dynamic simulation experiments

Models of the original house and retrofit house were created, calibrated, and annual performance evaluated



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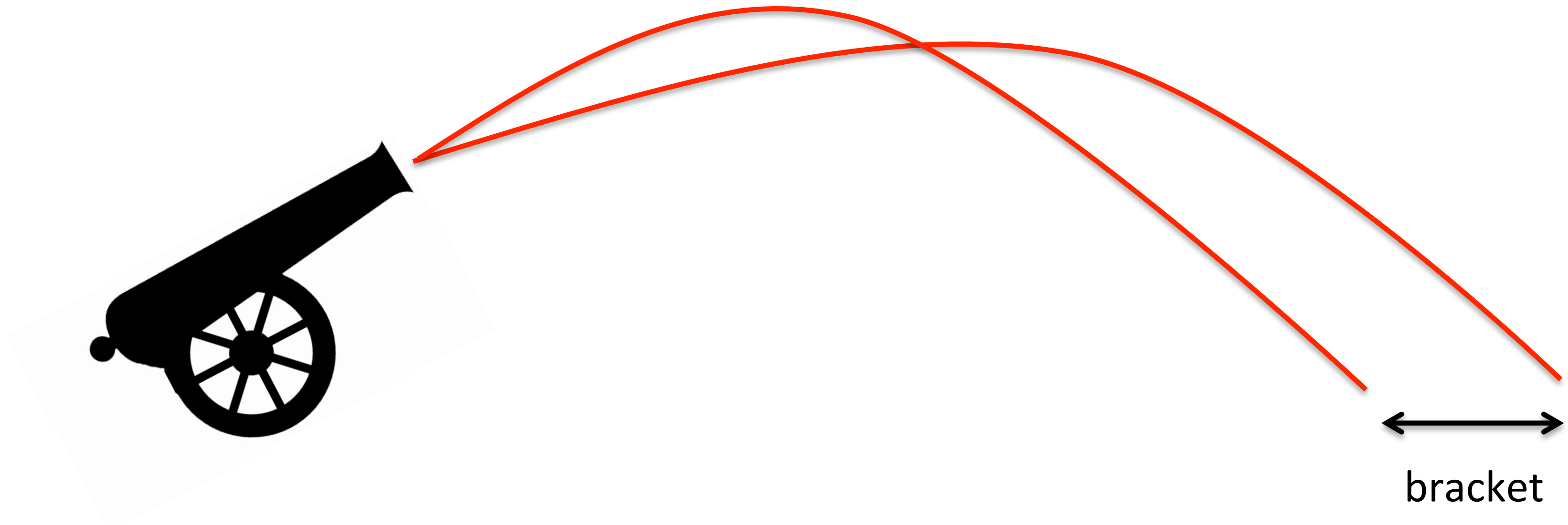
Calibration

- Analogous to bracketing in artillery fire
- The error ‘bracket’ is reduced by changing the parameters of the model until desired accuracy is achieved
- Energy calibration: relative error: 0.06%
- Temperature calibration: root mean squared error < 0.95 ^{o}C



Energy and Carbon Performance

	Thermal energy (MWh/annum)	CO2 emissions (kgCO2/annum)
Space heating energy	1.78	23
DHW heating energy	7.86	102
Solar thermal energy	-4.08	-53
Sub-total thermal energy	5.56	72
	Electrical energy (MWh/annum)	CO2 emissions (kgCO2/annum)
Electrical energy used	2.73	1411
Total electricity generated	-4.06	-2145
Sub-total electricity energy (exported)	-1.33	-734
Grand total thermal and electrical	4.23	-662

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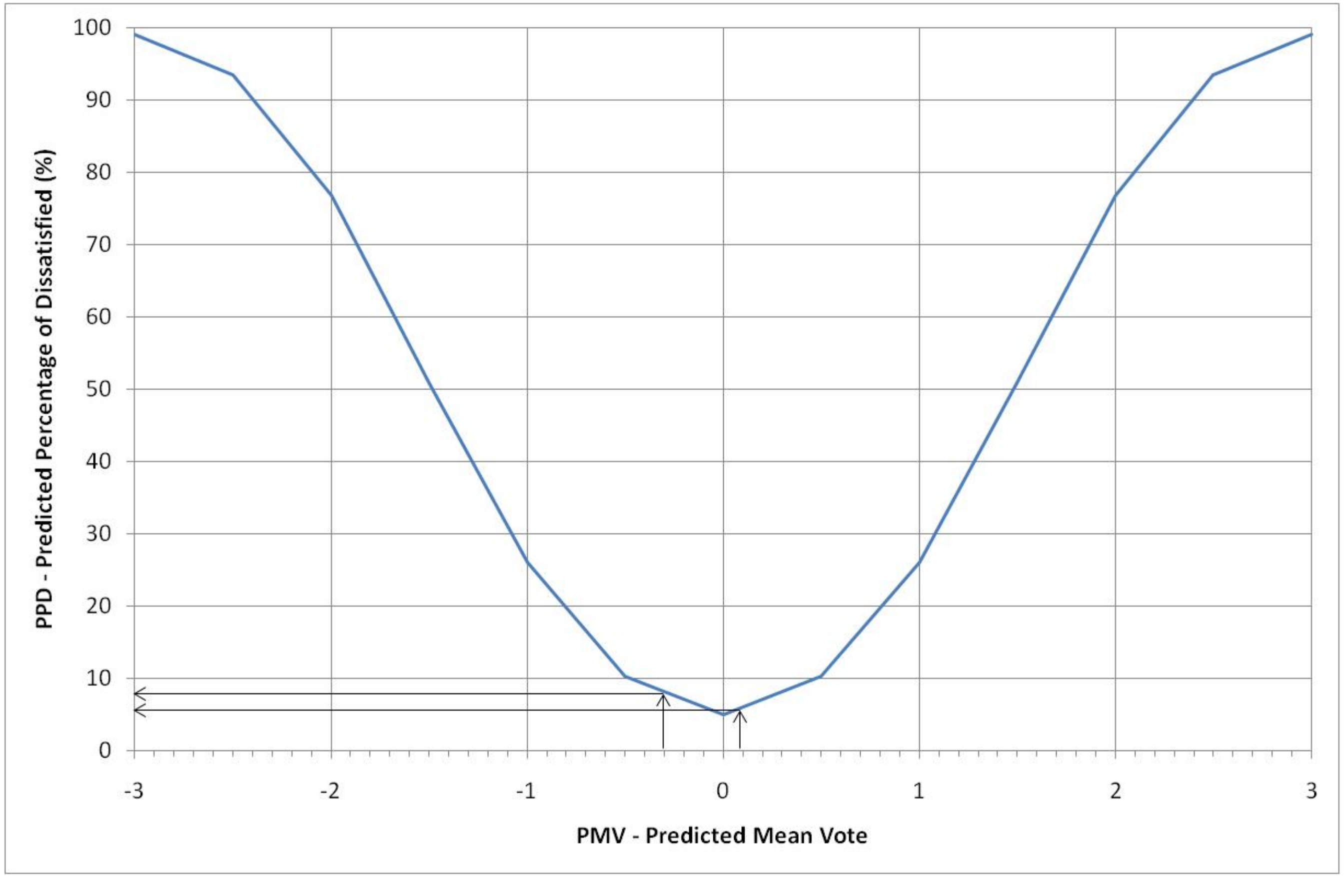
Thermal Comfort



	PMV (-3 to +3)	*PPD (%)*	*Discrepancy from neutrality (%)*
Summer	0.09	5.17	0.17
Winter	-0.30	6.87	1.87

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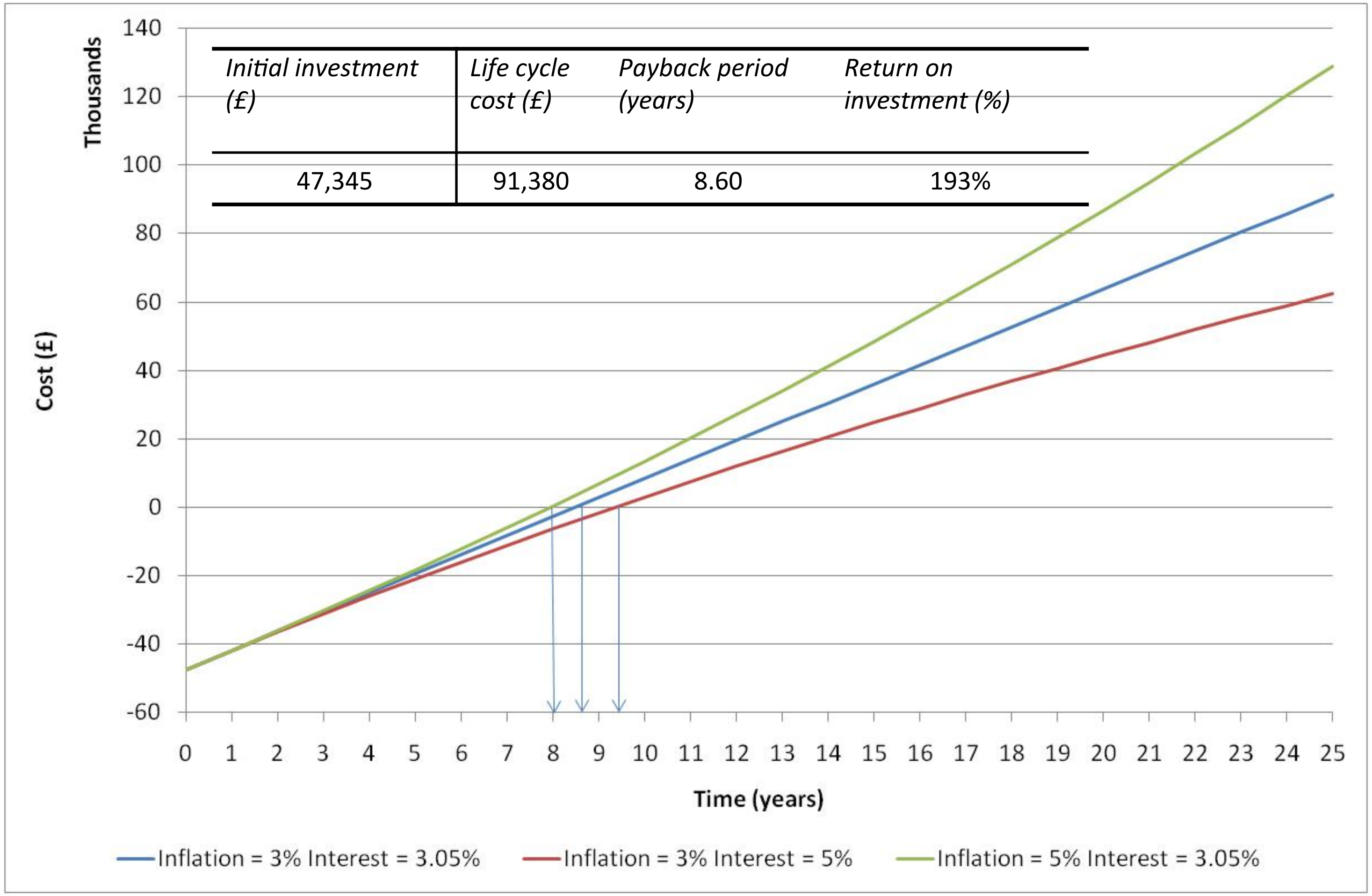
Economic analysis



Initial investment (£)	*Life cycle cost (£)*	*Payback period (years)*	*Return on investment (%)*
47,345	91,380	8.60	193%

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Design method

- Create a base model
  - Either of of the existing building (retrofit)
  - Or applying initial design principles for maximising building energy efficiency (newbuild)
- Run simulation
- Check summary results
- Use annual CO_2 emissions as performance criterion
- Apply design principles for passive design and for maximising building energy efficiency, making one improvement at a time
- Save every improvement as a new model to be able to go back to previous versions for comparison
- When passive measures and energy efficiency improvements have been exhausted, apply renewable energy options one at a time
- Evaluate thermal comfort
- Calculate life cycle costs
- Repeat the above process until satisfactory outcomes are achieved in terms for CO_2 emissions, thermal comfort and economic viability

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Example – Greenpower Centre

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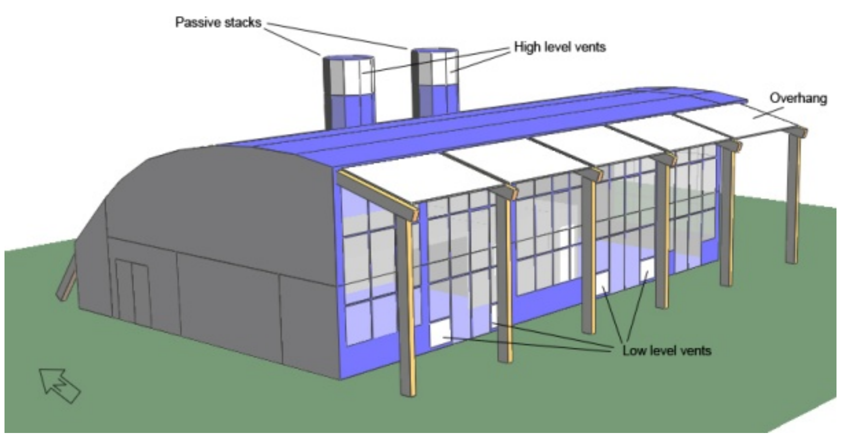

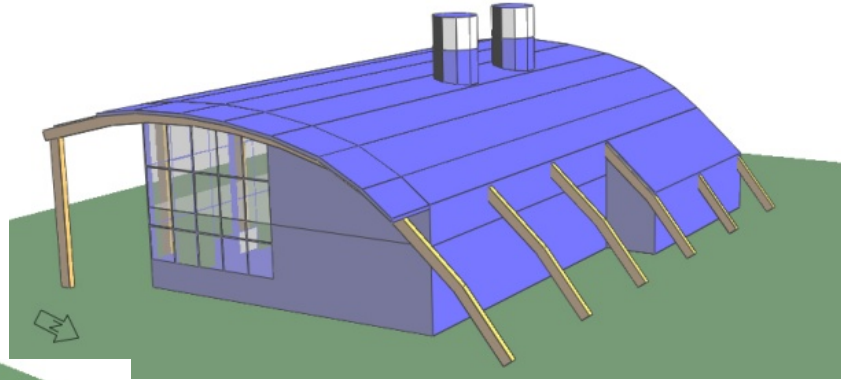

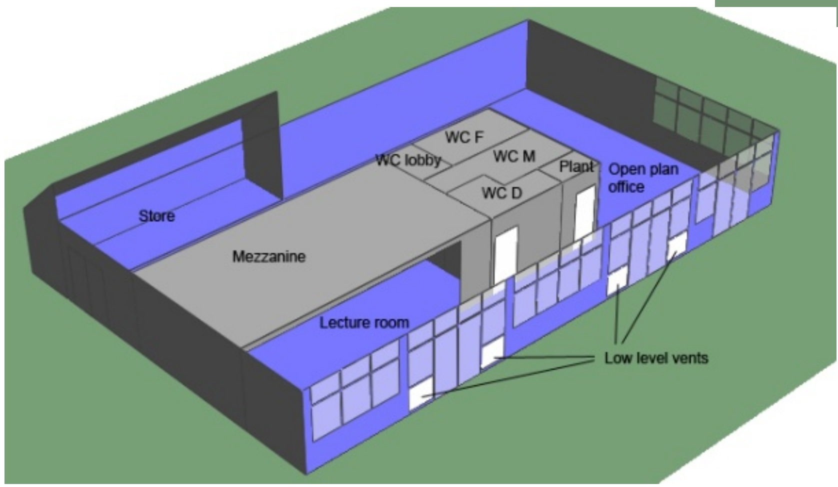

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Example – Greenpower Centre

- Several principles for maximising building energy efficiency have been put in place in the initial model:
  - Response to site context
  - Building geometry
  - Thermal insulation
  - Air tightness
  - Thermal mass
  - Natural ventilation
  - Natural daylight
  - Condensing gas boiler

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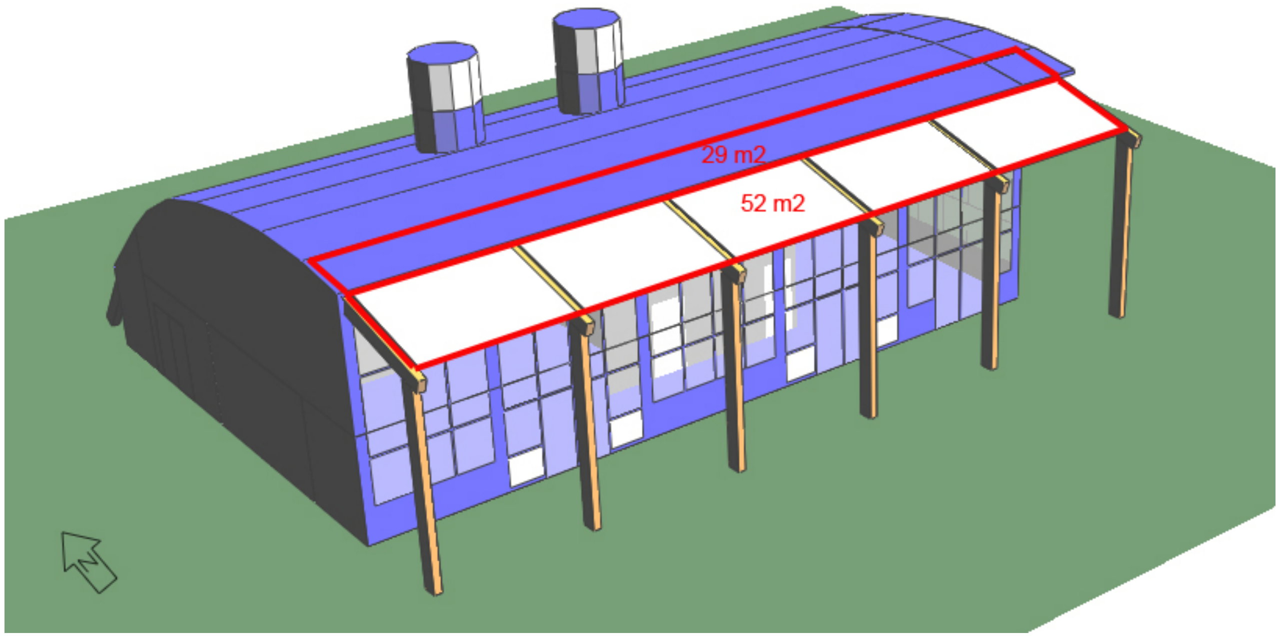
Example – Greenpower Centre

- 15 different variations of the simulation model were created and evaluated



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Simulation analysis

Step	Model version	Description	Total Yearly Energy Consumption (MWh)	Yearly Total Heating (MWh)	Yearly Total Electricity (MWh)	Electricity generated (MWh)	Electricity exported (MWh)	Total carbon dioxide emissions (kg CO2)	Absolute improvement (kg CO2)	Relative improvement (%)
1	a	gas heating, standard insulation	30.3	12.6	17.7			11653.3		
2	b	= a+ increased insulation	27.4	9.7	17.7			11089.9	563.4	4.8%
3	c	= b + increased lighting efficiency	23	12.8	10.2			7834.2	3255.7	27.9%
4	d	= c + daylight sensitive controls	22.2	13.3	8.9			7200.8	633.4	5.4%
5	e	air source heat pump	12.4	3.6	8.8			6418.2	782.6	6.7%
6	f	= e + 52 m2 monocrystalline PV system 15% efficiency, 13.8 deg inclination from horizontal	6.1	3.6	2.5	6.4		3057.0	3361.2	28.8%
7	g	= f + wind generator qr5 with maximum rating of 7.4 kW	5.8	3.6	2.2	6.6		2934.3	122.7	1.1%
8	h	= g + 3 more wind turbines, with combined total rating of 29.6 kW	5.1	3.6	1.5	7.3		2565.8	368.5	3.2%
9	e2	biomass heating, boiler efficiency 93%	22.2	13.3	8.9			4931.8	1486.4	12.8%
10	f2	= e2 + 52 m2 monocrystalline PV system: 15% efficiency, 13.8 deg inclination from horizontal	15.8	13.3	2.5	6.4		1570.7	3361.1	28.8%
11	g2	= f2 + wind generator qr5 with maximum rating of 7.4 kW	15.6	13.3	2.3	6.6		1447.9	122.8	1.1%
12	h2	= g2 + 3 more wind turbines, with combined total rating of 29.6 kW	14.9	13.3	1.6	7.3		1079.5	368.4	3.2%
13	i2	= h2 + super insulation	11.6	10.1	1.5	7.3		984.7	94.8	0.8%
14	j2	= i2 + additional 29 m2 monocrystalline PV system of 15% efficiency at 7.8 deg inclination	8.2	10.1	-1.9	10.7	1.9	-830.3	1815.0	15.6%
15	f3	= f2 + additional 29 m2 monocrystalline PV system of 15% efficiency at 7.8 deg inclination	12.4	13.3	-0.9	9.8	0.9	-244.2	1814.9	15.6%

Economic analysis

Step	Model version	Description	Life cycle cost (£)	Payback period (years)
1	a	gas heating, standard insulation		
2	b	= a+ increased insulation	10,791	4
3	c	= b + increased lighting efficiency	10,091	5
4	d	= c + daylight sensitive controls	9,951	5
5	e	air source heat pump	5,551	11
6	f	= e + 52 m2 monocrystalline PV system 15% efficiency, 13.8 deg inclination from horizontal	32,555	6
7	g	= f + wind generator qr5 with maximum rating of 7.4 kW	3,996	21
8	h	= g + 3 more wind turbines, with combined total rating of 29.6 kW	-75,999	-
9	e2	biomass heating, boiler efficiency 93%	6,488	10
10	f2	= e2 + 52 m2 monocrystalline PV system: 15% efficiency, 13.8 deg inclination from horizontal	33,650	5
11	g2	= f2 + wind generator qr5 with maximum rating of 7.4 kW	4,933	20
12	h2	= g2 + 3 more wind turbines, with combined total rating of 29.6 kW	-75,062	-
13	i2	= h2 + super insulation	-86,799	-
14	j2	= i2 + additional 29 m2 monocrystalline PV system of 15% efficiency at 7.8 deg inclination	-72,107	-
15	f3	= f2 + additional 29 m2 monocrystalline PV system of 15% efficiency at 7.8 deg inclination	47,976	5

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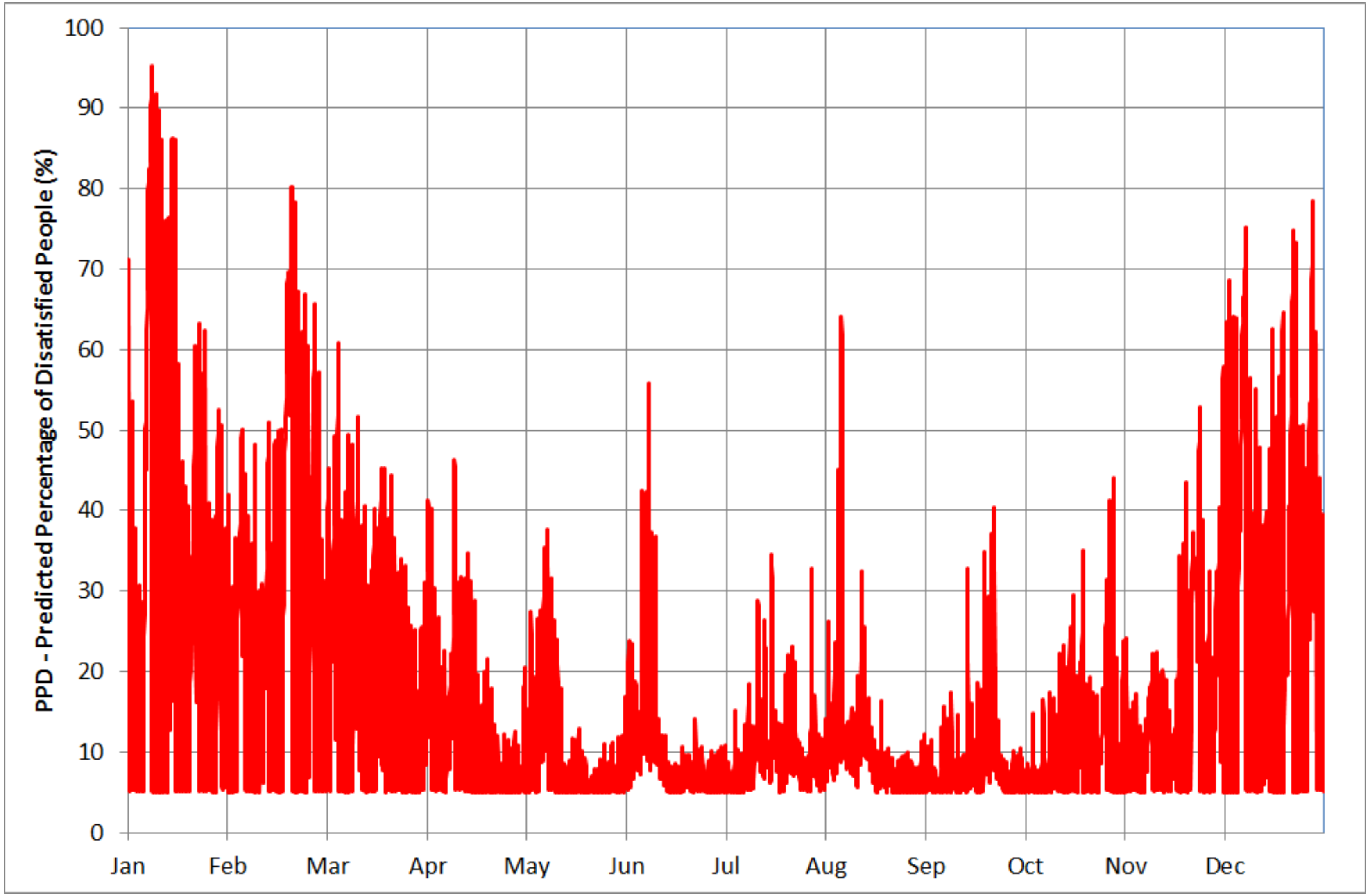
Model 'f': PPD obtained initially was very high – closer analysis revealed that it was calculated 24/7 but the building was occupied 9 – 5.



Comfort analysis

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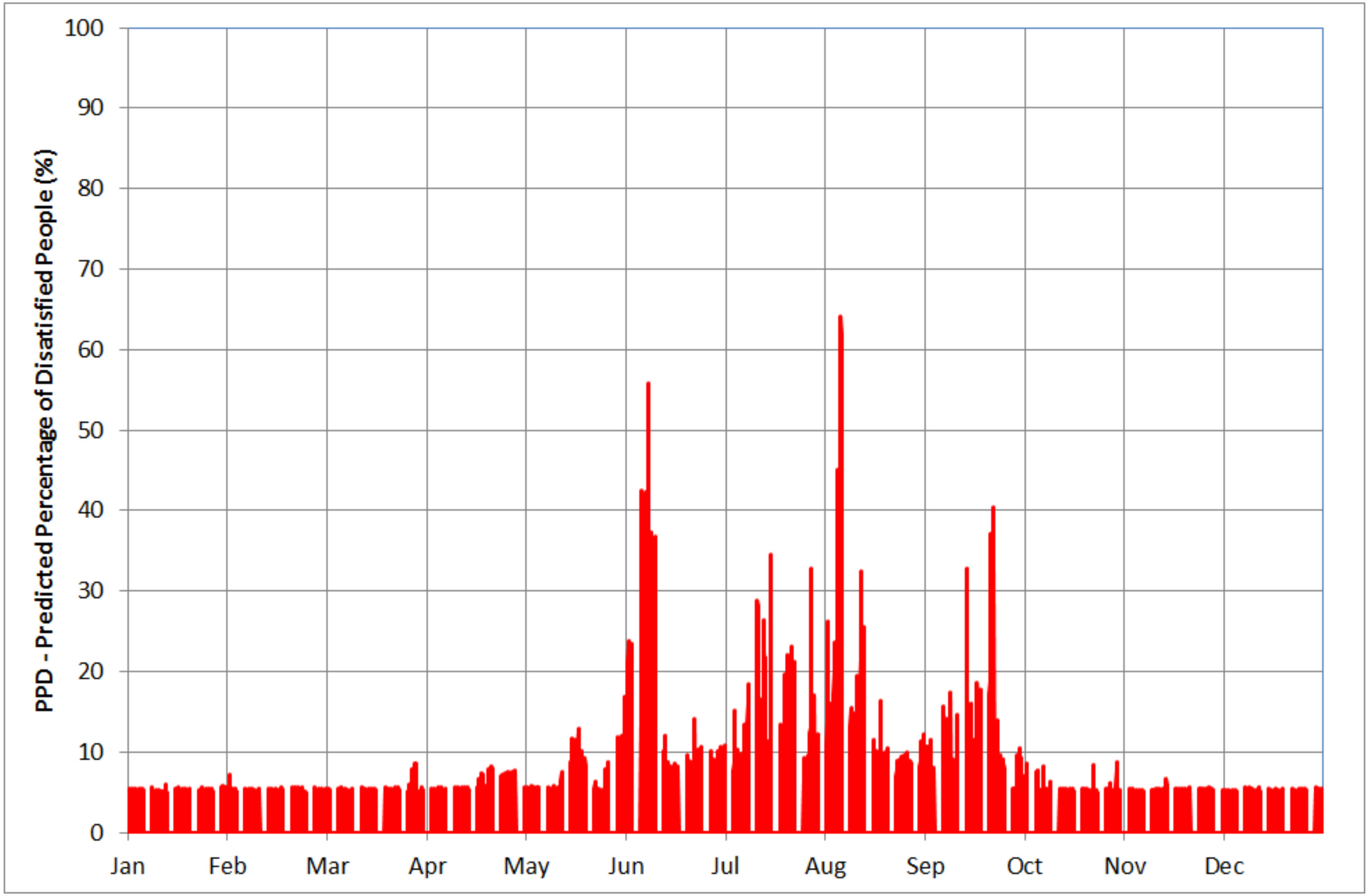
Model ‘f’ post-processed: PPD was recalculated for 9 – 5 occupancy.



Comfort analysis

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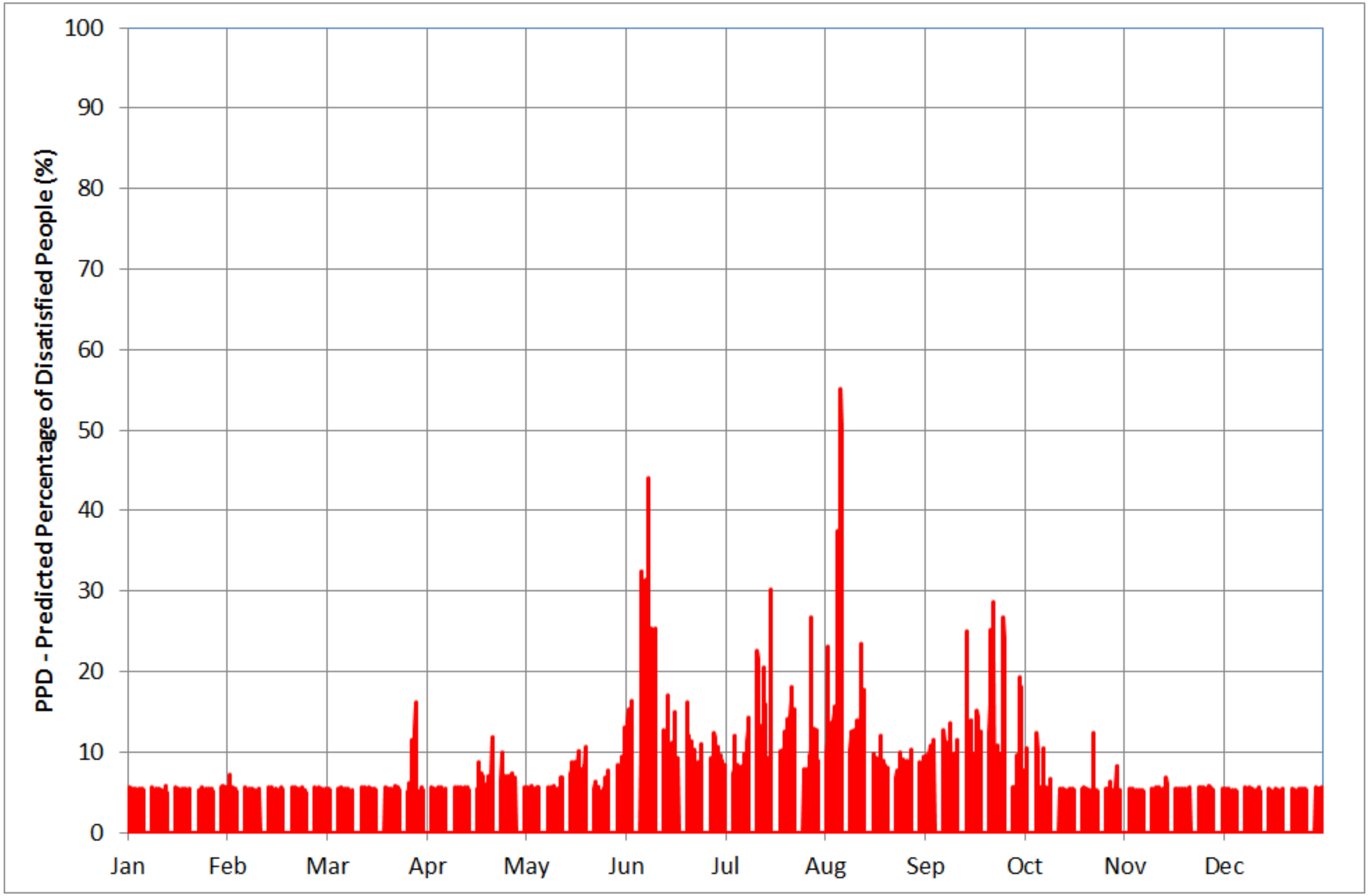
Model ‘f+’: PPD obtained from simulation with with all windows openable and post-processed for 9 – 5 occupancy.



Comfort analysis

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Comfort analysis

Frequency of occurrence analysis of temperatures

Temperature interval (°C)	Model f (hours) (only nat vents openable)	Model f+ (hours) (all windows openable)	Model f (%) (only nat vents openable)	Model f+ (%) (all windows openable)
20	4	5	0.2%	0.2%
22	1234	1225	59.1%	58.7%
24	593	714	28.4%	34.2%
26	209	125	10.0%	6.0%
28	42	16	2.0%	0.8%
30	6	3	0.3%	0.1%

Model ‘f+’: only 0.9% of temperatures are greater than 28 °C

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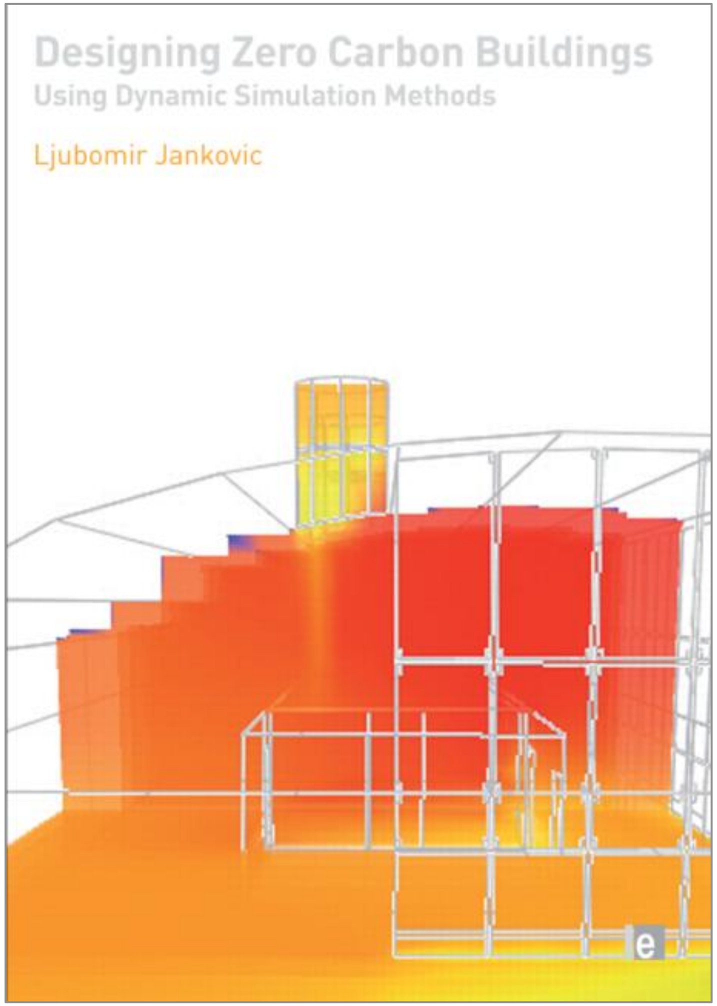
Designing Zero Carbon Buildings



- The first time a structured method for zero carbon design and retrofit has been published
- It integrates technical, economic, and social aspects of building performance
- It has been adopted as core text by a number of UK, US and European universities and used by consultancies such as ARUP

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Designing Zero Carbon Buildings

- Application of well known principles
- Dynamic simulation is a pre-requisite
- Improving energy efficiency first
- Implementing renewable energy systems
- Thermal comfort analysis is essential to ensure that carbon emission reduction is not at the expense of thermal comfort
- Economic analysis of life cycle costs is essential to confirm feasibility of a design
- Conducting the process recursively until design objectives are reached
- Post occupancy monitoring of buildings is essential to calibrate simulation models

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Conclusions

- We can do a lot on zero carbon design and retrofit before 2050
- We don't need to wait till 2016 when all new houses need to be zero carbon or till 2019 when all new buildings will need to be zero carbon
- Existing buildings represent the vast majority of the building stock: 80% of 2050 buildings have already been built
- Zero carbon design is easily possible today with existing knowledge and technology
- Advanced simulation methods are a pre-requisite
- Simulations need to be validated by instrumental monitoring
- In the future the recursive simulation analysis of technical, social and economic criteria will be replaced by optimisation algorithms

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