

Architecture, Design and Conservation

Danish Portal for Artistic and Scientific Research

Aarhus School of Architecture // Design School Kolding // Royal Danish Academy

A methodological study of environmental simulation in architecture and engineering

Sattrup, Peter Andreas; Strømann-Andersen, Jakob

Published in:

SimAUD 2011 Symposium on Simulation in Architecture and Urban Design, conference proceedings

Publication date:

2011

Document Version:

Publisher's PDF, also known as Version of record

[Link to publication](#)

Citation for published version (APA):

Sattrup, P. A., & Strømann-Andersen, J. (2011). A methodological study of environmental simulation in architecture and engineering: Integrating daylight and thermal performance across the urban and building scales. *SimAUD 2011 Symposium on Simulation in Architecture and Urban Design, conference proceedings*, 115-123. <http://www.simaud.org/proceedings/index.php>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



SIM AUD

2011

Boston MA USA

2011 Proceedings of the
**Symposium on Simulation for
Architecture and Urban Design**

Edited by
Ramtin Attar



2011 Proceedings of the
**Symposium on Simulation for
Architecture and Urban Design**

Edited by
Ramtin Attar

Cover by **Justin Matejka**
Layout by **Michael Glueck**

A methodological study of environmental simulation in architecture and engineering. Integrating daylight and thermal performance across the urban and building scales.

Peter Andreas Sattrup¹, Jakob Strømann-Andersen²

¹Royal Danish Academy of Fine Arts
School of Architecture
Philip de Langes Allé 10,
DK-1435 Copenhagen K, Denmark
peter.sattrup@karch.dk

²Technical University of Denmark
Department of Civil Engineering
Brovej 118,
DK-2800 Kgs. Lyngby, Denmark
jasta@byg.dtu.dk

Keywords: Integrated design methodology, holistic design, architectural theory, design process, energy optimization, environmental simulation

Abstract

This study presents a methodological and conceptual framework that allows for the integration and creation of knowledge across professional borders in the field of environmental simulation. The framework has been developed on the basis of interviews with leading international practitioners, key theories of environmental performance in architecture and engineering, and a range of simulation experiments by the authors. The framework is an open structure, which can continuously be renewed and contributed to by any author.

The value of the framework is demonstrated, using it to map a series of simulation studies, emphasising the multidimensionality of environmental performance optimization. Clarifying the conceptual interconnectivity between architecture and engineering, - agency and physics, - not only enhances communicative power and the dissemination of knowledge, but becomes instrumental in pointing out the need for improving metrics, software and not least the performance of the built environment itself.

1. INTRODUCTION

Though environmental simulation software has been around for decades, developed and used mainly by engineers, it has only recently become widely available to

architects without an extreme specialization in physics and computation. Following this introduction of technology into the field of architecture, comes a stimulating shift of attention in terms of the aims of simulation research: that of studying the relations between different spatial scales, exploring form and material organization as means to produce desirable human environments, rather than the singular optimization of specific technical subsystems. Architecture can in itself be considered an open system of environmental technology that is not just technical but informational, social and cultural too.

A problem in current energy optimization in architecture and engineering is a certain blindness towards the multiple facets of performance of each part of the complex systems of built environments. Buildings failing to use form and materials to direct nature's forces for the benefit of the occupants get wrapped up in sub-optimized comfort and energy delivery systems to compensate for their lack of environmental qualities. Technical systems, that is, that have high embodied energy and a much shorter lifespan than the building structure and its skin, and as a consequence a higher detrimental impact on the environment.

There is a need for a holistic view and an integrated approach that emphasizes that the layers, scales, components, materials, uses etc. of a building or a built environment plays multiple roles, and must be understood in temporal dimensions that include the day to day, seasonal,

yearly and lifetime dimensions. This holistic view should embrace the multidisciplinarity of the design professions, and establish a common conceptual framework.

The research questions behind this paper are:

How can a conceptual framework be devised, that allows for the synthesis and integration of environmental performance information in the built environment across the architecture/engineering professions? How can the dual aspects of operational and embodied energy in architecture be linked? How can the spatial and temporal dynamics of the performance of the built environment be highlighted, to improve communication, software and metrics in environmental simulation?

To answer these questions, 3 principal approaches are used, including interviews with leading practitioners in architecture and engineering, a literature review and the simulation experience of the authors – an architect and an engineer. The framework devised can potentially be used to guide future research, mapping the impact of design variables on environmental performance, and act as a support when establishing the decision hierarchies necessary in any design project regardless of scale, to meet the demands of rapid decision making and efficiency of solutions required today.

2. METHODS AND METHODOLOGY

A distinction between methods and methodology needs to be made. Methods are ways of using tools or techniques using a prescribed procedure towards a certain aim. Following a tutorial of how to do a daylight analysis could be an example. Methodology instead considers multiple methods, critically examining the assumptions behind them and examines the interrelationships between output from different methods. Though architects rarely claim to follow specific design methodologies, a new attention to design methods and processes is emerging in order to deal efficiently with the realization that even the first sketches potentially carries a strong impact on the energy and environmental performance of the design. In particular engineers have begun to promote ‘integrated design processes’ in which the architect-engineer collaboration is shifted forward into the initial design phases, instead of the traditional process of engineers following up on designs already elaborated by architects. This could possibly result in some rivalry for position and influence on design among

the professions, but the view taken in this paper is that collaboration is necessary and beneficial for the overall good of the built environment. The paper is a result of a collaboration of an architect and an engineer, and the methodological framework proposed here is intended to clarify the basis for the use of environmental simulation in the early design phases as a common platform across the professions.

The methodological framework presented in this paper, is in itself the outcome of different research methods: The hypothesis that architectural scale is a key factor in energy efficient design, connecting both integrated design processes, operational efficiency and lifecycle analysis, was derived from interviews with leading practitioners in architecture and engineering from the offices of Foster and Partners (Behling and Evenden 2009), Baumschlager & Eberle Architekten (Eberle 2008) and Transsolar (Schuler 2008). The theory behind the hypothesis was developed through a literature review. A series of simulation studies using Copenhagen as a reference were carried out by the authors to test the hypothesis in regards to solar access, daylight, thermal and energy performance in urban and basic building design, some of which are presented in the demonstration case below.

3. ARCHITECTURAL PRACTICE

While their architectural interests and formal expression differ significantly, the architect offices of Foster and Partners and Baumschlager and Eberle share the notion based on their experience in design and built work, that the greatest environmental impacts come with design decisions taken at the scale of the city, and that impacts decrease with minor scale decisions. Argued this way, optimization of the basic formal and material properties of a design, takes priority compared to the optimization of technical service systems, - conveniently weighting the influence of the architect’s design responsibilities over those of the engineers. Both offices employ specialists working with simulation, and have developed tailor-made software applications to suit the offices’ workflows. Fig. 2 shows a diagram by Foster and Partners presented with the Masdar project, expressing the notion that design decisions taken at the largest scales of a project impact the environment the most, and are inverse proportional to the costs of the solutions. While ‘environmental gain’ includes other factors than energy, - it could be interpreted aesthetically, - energy plays the dominant role in the diagram’s highlighting of

passive and active measures and the implementation of renewable energy systems.



Figure 1: Foster and Partners: Scale, systems, costs and environmental gain diagram.

In the design approach of Dietmar Eberle attention towards the durability of the different layers that constitute a building govern a hierarchy of design decisions. Each layer: place, load bearing structure, envelope, programme and materiality carry weight in the design process according to their relative permanence, so as to preserve the resources invested in them. Where Foster and partners employ advanced form to harness the benefits of nature's forces, Baumschlager and Eberles approach highlights architecture's generality and its adaptivity over time as a sustainable strategy. Eberle explicitly states the need for design methodology to integrate knowledge in the design process (Simmendinger and Schröer 2006).

But what lies behind these assumptions and notions?

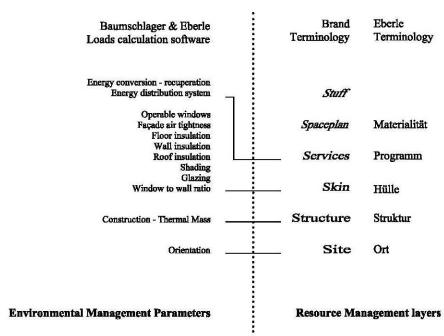


Figure 2: Comparison of design variables in environmental management to shearing layers and the layers of the design theory by Dietmar Eberle of Baumschlager & Eberle Architekten.

4. ARCHITECTURAL THEORY – RESOURCE AND ENVIRONMENTAL MANAGEMENT

Two key references seem to have spawned several subsequent architectural research enquiries. While research

has developed since then, it is nevertheless the original concepts that remain fundamental to sustainability in architecture. Taking a step back does not ignore the progress of knowledge since then, rather it allows us to identify design issues at the macro level of sustainable design that must be addressed simultaneously and coherently by designers, including specialists working with environmental simulation.

In the book 'The Architecture of the Well-tempered Environment' (Banham 1984) 'structure' and 'power' solutions are defined as the two fundamental ways to mediate the environment through the use of resources. Structure solutions are resources invested in built space that is able to 'conserve' energy (eg. heat). Power solutions are energy resources used to 'regenerate' environmental condition artificially, as when burning a timber resource to provide heat rather than burning it. The 'selective' mode in between, is the building features that allows the occupant to choose among environmental stimuli, natural or artificial. The distinctions are not exclusive, - many building components perform and can be used in different modes. Banham was able to set the stage for later introduction of the technical distinctions between embodied and operational energy, and the environmental performance associated with the building fabric, user behaviour and energy use through service systems.

The second key reference is 'How Buildings Learn' (Brand 1997). Drawing on the theory of the shearing layers, originally developed in forestry and ecology studies, Brand establishes the idea that buildings have metabolism, and that the rate of metabolism is connected to layers of scale and activities that change a building over its lifetime. The layers that Brand identify are Site, Structure, Skin, Services, Spaceplan and Stuff, - their sequence referring to their durability and expected lifetimes, - Site being the most durable, almost permanent condition governing a building and Stuff, - furnitures and the like - being the most ephemeral with the highest metabolic rate (Fig. 3). It is perfectly possible for parts of buildings to fulfil more purposes, though it should preferably be avoided to allow better adaptability in the long term. Similarly at the urban scale spatial, legislative, regulative and ownership layers with different permanence can be identified that frame the evolution of the city. (Fig. 4)

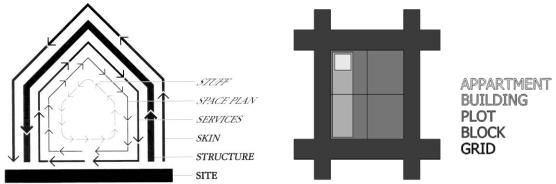


Figure 3: Brand: Shearing Layers. Organizing a building according to the permanence of its different functional layers becomes instrumental in the resource management of buildings' material lifecycle.

Figure 4: Sattrup: At the urban scale, regulatory layers can be identified on the basis of the spatial, property and planning framework that governs the development of cities over time.

Brand identifies two ways of ensuring that a building achieves a long life – thus ensuring the maximum benefit of the resources and energy invested in its construction and maintenance – the ‘high’ way of investing a high cultural value in a building, and the ‘low’ way of ensuring the practicality of adapting the building to changing uses, by consciously using the shearing layers as a way to organize the building functionally and tectonically. This has spawned subsequent research enquiries in architecture aimed at minimizing the environmental impact of waste associated with buildings’ materials and the embodied energy invested in them, through ecologically and lifecycle oriented approaches (Berge 2009), (Braungart and McDonough 2009).

5. A METHODOLOGICAL FRAMEWORK FOR ENVIRONMENTAL SIMULATION

What does Banham’s Environmental Management and Brand’s Shearing Layers have in common, how are they differentiated, - and how can they be linked?

Brand’s Shearing Layers primarily addresses the long term use of resources – what Banham terms solutions of Structure. But the layers also differentiate between different building scales, and the uses associated with them, opening up a connection to Banham’s secondary concepts of the conservative, selective and regenerative modes of environmental management. Shifting Banham’s definition of the selective mode slightly, so as to specifically describe the selective behaviour of the occupant rather than the properties of building components, Brand’s layers: Site, Structure and Skin can be specifically linked to the Conservative mode, and the Selective mode used to describe the occupants’ behaviour regarding the operation of the Skin and the Services layers. Now several frameworks can be

defined that link the different scales surrounding a building project (Fig. 5).

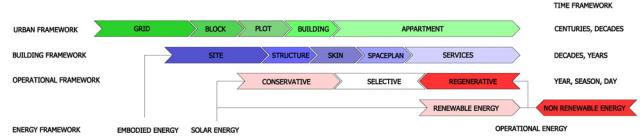


Figure 5: Connection of frameworks: Urban, Building, Operation, Time and Energy. The relative position of layers imply their relatedness.

Within the regulatory layers of the Urban Framework, we can use Brand’s layers to describe the Building Framework, which again frames the Operational Framework, which we can describe using Banham’s terms. Each of these operate at different time scales, so the Time Framework indicates the rate of change of the others: from the Urban Framework that can potentially last for centuries, to the daily rhythms of people in the Operational Framework. The Energy framework describes how embodied energy is stored in the fabric, solar energy potential for heating and lighting is mediated through the urban and building layers, and how operational energy is dispersed through the service systems. By organizing these visually it is made clear how the Frameworks influence each other, so as to create an awareness of the multiple aspects of the built environment that designers need to navigate to create truly environmentally and culturally sustainable buildings. The Spaceplan layer involves the organization of the building’s programme, and is connected to the patterns of occupation and operation. The Services layer is associated with the energy loads for heating, cooling and lighting and the process of optimizing the plant and distribution systems. This categorization allows us to identify six domains of performance optimization: *Form, Material, Programme, Operation, Loads and Service Systems*. Each has different design variables that interact as complex systems and sometimes overlap between domains (Fig 6 & 7).

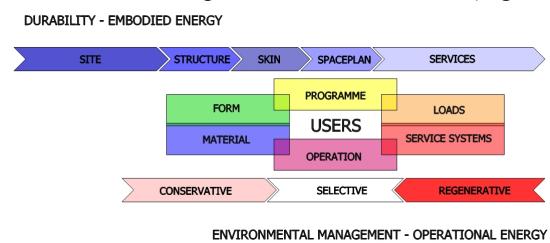


Figure 6: Design domains in between the Building and Operational framework. The domains can be described using specific design variables.

SITE	STRUCTURE	SKIN	SPACEPLAN	SERVICES
FORM	PROGRAMME		LOADS	
overshadowing height/width ratio orientation density	aspect ratio orientation building pattern	shading orientation window/wall ratio	comfort level activities schedules spatial program	mech ventilation heating cooling artificial light
reflectivity absorption	thermal mass	reflectivity transmissivity insulation values air tightness	natural ventilation blinds operation systems automation	fuel use photovoltaics solar heating thermal storage
MATERIAL	OPERATION		SYSTEMS OPTIMIZATION	
CONSERVATIVE		SELECTIVE	REGENERATIVE	

Figure 7: Design domains with detailed design variables. Variables can be added according to design or simulation interest.

6. DEMONSTRATION CASE – INTEGRATING DAYLIGHT AND THERMAL PERFORMANCE ACROSS THE URBAN AND BUILDING SCALES

In the following demonstration case Site, Structure and Skin layers are investigated for the impact of Form on energy use, differentiating thermal performance according to Conservative, Selective and Regenerative modes of operation. The framework is used to map and interrelate a series of simulation studies undertaken by the authors. The aim of the studies is to clarify the following:

- 1) The impact of Form on the energy performance, investigating orientation and window size design variables of the Site, Structure and Skin layers.
- 2) Using the Conservative, Selective and Regenerative modes as conceptual and analytical tools to pinpoint the influence of Form and Material properties on the daylight and thermal performance related to Building Skin.

The studies focus on the integration of daylight and thermal performance tracing the impact of generic formal design decisions from the urban to the building scale, investigating how the temporal and spatial dimensions of solar access in the urban environment affect thermal and daylighting performance of apartments with different window to wall ratios. The climatic context of the study is Copenhagen (N56,E12) in Northern Europe, a climate that is marked by the relative scarcity of sunlight due to high latitudes, a predominance of overcast skies and the low solar altitude in the winter months. Sketch-up was used to create the models, which were exported to IES-VE for thermal, artificial light and energy analysis. Ecotect was used to analyse and visualize the spatial and temporal distribution of

solar radiation in the urban environment exporting the model for daylight autonomy analysis using DAYSIM. In all studies a design reference year (DRY) weather file for the city of Copenhagen was used. The material specifications are equal to the minimum current requirements in Danish Building regulations. See appendix.

6.1. SITE, STRUCTURE and SKIN

A first step in understanding the conditions of the Site was an analysis of the temporal and orientational distribution of radiation. A ‘solar rose’ was invented to visualize the yearly and seasonal radiation on vertical surfaces compared to the global radiation on a horizontal surface, as passive solar energy usually is distributed through vertical facades. Using the solar rose both seasonal and daily variations can be grasped at a glance, as the intensities are also connected to the time of the day. As can be seen, the intensity differs greatly, but due to the angle of incidence, some surprising facts are found: the solar potential on facades in spring is equal to that of summer, and offers a potential to shorten the heating season as temperatures have not risen yet. In Autumn and winter the low inclination of the sun means that the intensity of radiation on south facades can rival those of the yearly average though the exposure times are shorter, and the sensitivity to overshadowing in urban contexts increases greatly.

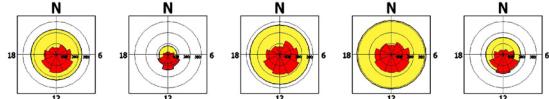


Figure 8: SITE: Solar roses, Copenhagen. From left to right: average hourly radiation on vertical (red) and horizontal (yellow) surfaces, - yearly, winter, spring, summer and autumn averages. Range 0-300wh/m2.

Previous studies by the authors examining solar envelopes (Knowles 1985) for the city of Copenhagen suggest that a maximum eaves height at 5 stories is advisable in dense urban districts at the same latitude, - a fact that corresponds very precisely to the actual densities of the inner city of Copenhagen. Above these densities, solar and daylight access are so restricted that denser urban patterns risk becoming unattractive, unless other attractions are associated with them.

To find out the seasonal intensity variations, the solar potential of the facades of a 5 story 50x50m urban perimeter

block was calculated. As can be seen (fig. 11) the patterns of overshadowing by the surrounding buildings are gradients of intensities with great directional and temporal variations.

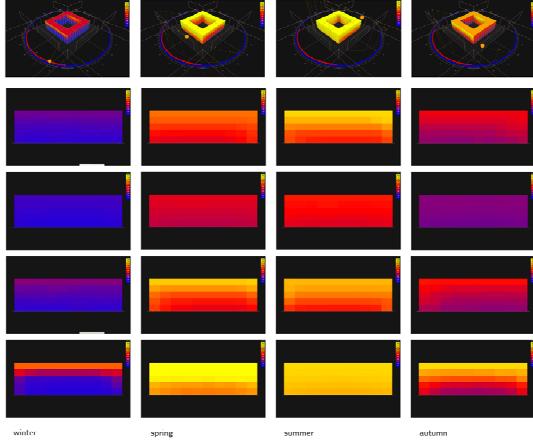


Figure 9 SITE+STRUCTURE & TIME: solar exposure on 5 story 50x50m perimeter block. Top to bottom: SE view, W, N, E & S facades. Left to right: winter, spring, summer and autumn exposure. Range 0-200wh/m².

As the urban grid and planning regulations often limit the formal exploration on a given site, geometry and orientation can still be used by designers to increase or decrease the radiation intensity through working at the building Structure and Skin scales. Orientation is investigated as a design variable through either rotating the block 45 degrees or folding its skin, so as to increase solar intensity hitting glazed areas of the façade in the winter season /Fig. 10).

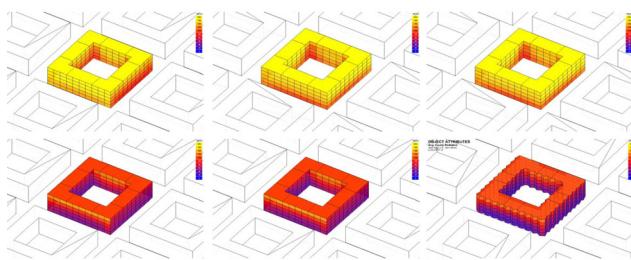


Figure 10: SITE+STRUCTURE+SKIN & TIME:

North/south, rotated 45degrees and North/South faceted façade block. Radiation levels during warm season April-Oct and cold season Oct-April. Radiation levels 0-200wh/m².

The radiation levels are so low due to the high latitude and low sun angles in Copenhagen which cause overshadowing in winter, that only the top 3 stories can

pursue solar strategies for low-energy consumption with interesting local differences: South facing apartments have higher solar solar exposure in winter, but lower in summer than the others, due to the changing inclination of the sunpath. East-West facing apartments have high exposure in the summer and very little in the winter, which can be mediated using faceted facades, shifting the gains towards the season where they are needed. The rotated block has medium-high solar gains throughout the year when compared to the others. But changes to orientation carry very little weight on the overall energy demand, even given today's standard of construction. Heating demand for a 100m² apartment with a window to wall ratio of 40% changes insignificantly when averaged over all 5 levels of the model, stabilizing at 44kwh/m²yr as the 3 bottom levels are totally overshadowed during winter at the urban density studied in this model. The 45 degree rotated block has a more even spread of the solar potential, more apartments benefit from the heat gains and a greater diversity of climatic situations and sunshine hours than in a north/south facing block, faceted or not.

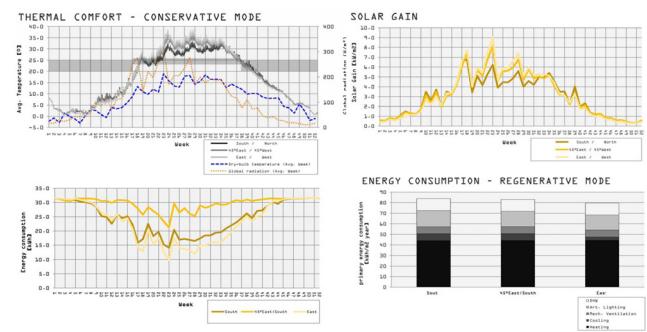


Figure 11 Thermal comfort, daylight, solar gains and Energy.
North/south, rotated 45degrees and East/West facing buildings.

Surprisingly the rotated block does not get the energy savings for daylight that the high radiation levels would make one think, it performs much worse than the north/south and east/west oriented buildings. A careful examination using a sunpath tool reveals why: As the buildings are used for housing, the occupants are not at home during weekdays at the hours where the sun delivers its energy. In the morning and afternoon the sun angles are so low that the main bulk of the building lies in shadows.

Linking the energy use calculation for artificial light to climate based daylighting metrics such as the Daylight Autonomy is not so straight-forward. Using IES-VE

radiance to set up an artificial light control system that switches on light when natural light levels fall below 200lux in the occupied hours applying a 30% switched-on percentage, is not quite the same, though it is climate based, as it is linked to the climate file's radiation data, converted to lighting. IES-VE automatically places the sensor point in the middle of the zone, (if one uses the thermal engine's control system for switching as is done here) when generic models such as the ones presented here are studied.

The true benefit from working with the orientation lies in the temporal dimension of the solar exposure seen in accordance with the building's rhythms of occupation. But as minimum insulation values will increase over the next decade, even the small increases in average radiation observed in this simulation are likely to carry a larger weight on comfort levels and energy use in future construction. Returning to the Urban Framework, it may well be worth opting for an optimization of solar potential through orientation though it carries little weight in the energy budget today. In the long term perspective of the Site, a 10% better solar potential which is more evenly shared among neighbours can prove a valuable asset as cities develop, building technologies are upgraded and social patterns change.

6.2. CONSERVATIVE, SELECTIVE and REGENERATIVE mode analysis.

Further investigating the performance of the Building Skin, the influence of different Window to Wall ratios was defined, using the same model properties as in the previous study. To be able to identify precisely the influence of the building fabric, the behaviour associated conditions and the systems energy loads on the thermal performance, the settings of the model were varied using the Conservative, Selective and Regenerative mode:

In the **Conservative** mode the empty building envelope is simulated. This allows a very accurate analysis of the influence of the Form and Material design domains on the thermal performance, as the influence of user patterns is excluded.

In the **Selective** mode the building is basically free-running, including internal gains from occupants and equipment and natural ventilation in summer. This adds the probabilistic user patterns of the Programme and Operation design domains to the model. No climatization is included.

In the **Regenerative** mode the building is fully conditioned, adding the influence of all three modes. Total primary energy use is calculated using fully dynamic IES-VE radiance climate based thermal and lighting simulation.

The practically unobstructed apartments at the 5th floor were subjected to a comparative study using the conservative, selective and regenerative modes to analyze their thermal performance. Some interesting facts emerge: The building fabric alone (conservative) is able to shorten the heating season by 6 weeks in spring and delaying it in autumn by 4 weeks totalling 2½ months when comparing the 20% window to wall ratio with 80%, though this comes with the risk of serious overheating unless measures are taken to limit summertime heat gains, as natural ventilation (Selective mode) is not sufficient, or cooling (Regenerative mode) will be necessary (Fig. 11).

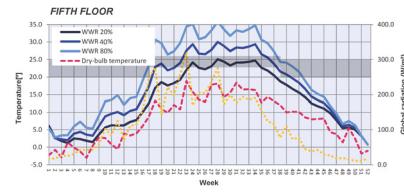


Figure 11 CONSERVATIVE: 5th floor apartment types with 20, 40 and 80% window to wall ratio. Thermal performance of the empty building envelope.

During winter, the average temperature performance favours large windows, showing that the higher conductive losses from larger windows can be balanced by the heat gains from the solar radiation, even though it should be noted that daily temperature swings are much more pronounced the larger the glass areas, a fact that is masked by the weekly averages shown by the graphs. The 40% wwr apartment is better balanced, and the selective mode shows, that the heating season can be shortened equally to 80% wwr, when the internal gains from the occupants are included in the energy balance (fig. 12).

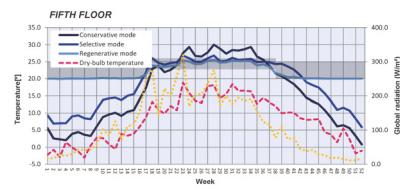


Figure 12 CONSERVATIVE+SELECTIVE+REGENERATIVE: 5th floor apartment with 40% window to wall area. Thermal analysis

The daylight autonomy metric (Reinhart, Mardaljevic, and Rogers 2006), - that could be considered a ‘selective’ mode analysis in this context, - can be rendered using DAYSIM. It shows the yearly percentages of time where the light distribution levels are above a certain threshold deemed adequate for given tasks (fig. 13).

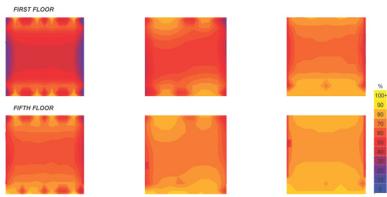


Figure 13 SELECTIVE: DAYSIM Daylight autonomy renderings of the yearly percentage of time where daylight levels exceed 200lux during occupancy hours 6-18.

When compared to a likewise temporal analysis of the energy use for lighting, the connection between the two figures is hard to see. Though each method uses radiance to calculate the time that light levels are above 200lux in a sensor point, the spatial imagery of DAYSIM is more visually communicative of the spatial qualities of the light. Though the new climate-based daylight metrics are greatly superior to the daylight factor, the analytical control of light's temporal dimensions should be improved in simulation so as to be able to grasp and communicate more of this variation. (fig. 13).

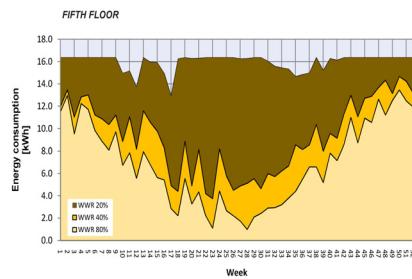


Figure 13 REGENERATIVE: graph showing the temporal dimension of energy use for artificial lighting dependent on window to wall ratio.

7. CONCLUSION

A methodological framework was developed, derived from interviews with leading practitioners and key references from architectural theory. The framework establishes a holistic view and an integrated approach that emphasizes that the layers, scales, components, materials uses etc. of a building or a built environment plays multiple roles, and must be understood in temporal dimensions that

include the day to day, seasonal, yearly and lifetime dimensions. The framework is structured according to a reinterpretation and expansion of Brand's and Banham's original concepts to differentiate and connect building performance analysis of the built environment, the influence of occupants behaviour and the optimization of service systems, showing ways to connect the areas of operational and embodied energy, environmental management and resource management.

The framework is used to map a series of studies ranging from the urban scale to the facades, integrating thermal and daylighting performance dynamically, while tracing the impact of the urban context on building performance. The mapping of this particular study, points out the need for future research in the ‘blank’ spaces of the framework: Specific studies across the boundaries of the operational/embodied energy fields, further investigations of the temporal potentials in climatebased daylighting metrics, and a continual evolution of conceptual clarifications that allows knowledge to be integrated and disseminated across professional borders.

References

- BANHAM, R. 1984. *Architecture of the Well-tempered Environment*. 2nd ed. Chicago University Press.
- BEHLING, STEFAN, AND EVENDEN. 2009. Foster and Partners Interview by P. A. Sattrup. *Green Architecture for the Future*.
- BERGE, BJØRN. 2009. *The ecology of building materials*. Architectural Press.
- BRAND, STEWART. 1997. *How Buildings Learn: What Happens After They're Built*. New edition. Weidenfeld & Nicolson.
- BRAUNGART, MICHAEL, AND WILLIAM McDONOUGH. 2009. *Cradle to Cradle*. Vintage.
- EBERLE, DIETMAR. 2008. Arkitekter, Arkitektur og Ressourcer Interview by P. A. Sattrup. *Arkitekten* 11.
- KNOWLES, R. L. 1985. *Sun, Rhythm, Form*. New edition. MIT Press,
- REINHART, CHRISTOPH F., JOHN MARDALJEVIC, AND ZACK ROGERS. 2006. Dynamic daylight performance metrics for sustainable building design. *Leukos* 2006, no. 3. *Leukos* (July): 1-25.
- SCHULER, MATTHIAS. 2008. Paven af Integreret Design Interview by P. A. Sattrup. *Arkitekten* 12.
- SIMMENDINGER, PIA, AND ULRIKE SCHRÖER. 2006. ‘City and House – a Strategy Of Teaching Design’. In *The Complexity of the Ordinary*. Copenhagen: Royal Danish Academy of Fine Arts

Appendix

		CONSERVATIVE MODE	SELECTIVE MODE	REGENERATIVE MODE
CONSTRUCTION				
Opaque Construction				
External Walls		0.2 W/m ² K	0.2 W/m ² K	0.2 W/m ² K
Roofs	U-value	0.15 W/m ² K	0.15 W/m ² K	0.15 W/m ² K
Exposed floors		0.15 W/m ² K	0.15 W/m ² K	0.15 W/m ² K
Thermal capacity		140 kJ/(m ² K)	140 kJ/(m ² K)	140 kJ/(m ² K)
Thermal bridging coefficient		0.035 W/m ² K	0.035 W/m ² K	0.035 W/m ² K
Glazed Construction				
External Windows	U-value	1.5 W/m ² K	1.5 W/m ² K	1.5 W/m ² K
	g-value	0.6	0.6	0.6
Visible light normal transmittance		0.7	0.7	0.7
USE OF THE BUILDING				
People				
Internal heat gain		-	1.5 W/m ²	1.5 W/m ²
Lighting				
Lighting level			200 lux	200 lux
Maximum Power			6 W/m ²	6 W/m ²
Variation Profile		-	6am–9am & 3pm–10pm (weekday) 9am -10pm (weekend)	6am–9am & 3pm–10pm (weekday) 9am -10pm (weekend)
Switched-on-percentage			30 %	30 %
Dimming profile			Manuel/on-off, (200 lux)	Manuel/on-off, (200 lux)
Miscellaneous				
Maximum Sensible gain		-	3.5 W/m ²	3.5W/m ²
Variation Profile			on continuously, 50 %	on continuously, 50 %
AIR EXCHANGES				
Infiltration				
Min Flow		0.13 l/s m ²	0.13 l/s m ²	0.13 l/s m ²
Variation Profile		on continuously	on continuously	on continuously
Natural ventilation				
Max Flow			0.9 l/(s m ²), t > 25 °C	0.9 l/(s m ²), t > 25 °C
Variation Profile			(week 19 – week 37)	(week 19 – week 37)
Mechanical ventilation				
Min Flow				0.3 l/s m ²
Variation Profile				on continuously
System specific fan power (SFP)		-	-	1.0 W/(l/s)
Vent. Heat recovery effectiveness				65%
Cooling efficiently				COP=2.5
HEATING AND COOLING				
Heating set point	winter	-	-	20 °C (on continuously)
Cooling set point				25 °C (on continuously)
Heating set point	summer	-	-	23 °C (on continuously)
Cooling set point				26 °C (on continuously)

Table 1 Simulation systems settings



Kerri Henderson

Kerri Henderson is currently completing her Masters of Architecture at the Graduate School of Architecture, Planning and Preservation, Columbia University. Kerri is a Teaching Assistant at Columbia where she teaches Architectural Drawing and Representation II and Introduction to Architecture (design studio). She has been a guest critic at Parsons and Columbia. Her recent projects include: Proof Tower (a mixed-use tower in Masdar using multi-objective optimization), a lunar rover (collaboration with NASA) and Lean Urbanism (a master plan integrating urban development and sugar cane-based Ethanol production in Santo Domingo, DR). Kerri graduated from the University of Waterloo in Canada, with a Honours Bachelor of Architectural Studies. She has worked in New York, Toronto and Paris.



Laëtitia Arantes

Laëtitia Arantes is a French PhD candidate at the CRAterre laboratory at the School of Architecture in Grenoble and the CSTB (French Scientific Centre for Building Science). She holds a graduate degree in civil Engineering from the ENTPE (Ecole Nationale des Travaux Publics de l'Etat in Lyon, France) and a graduate degree in Architecture from the ENSAG (Ecole Nationale Supérieure d'Architecture de Grenoble, France). Her current research lies in the interface between Architecture and Engineering: it deals with the design of sustainable high-building and cities.



Lilli Smith

Lilli Smith, AIA, LEED® AP is a Senior Product Designer at Autodesk. After practicing architecture for several years, Lilli joined Revit Technology in its infancy. She was involved in creating much of Revit's core functionality including the conceptual design tools before turning her focus to sustainable design. She was the lead product designer on the Conceptual Energy Analysis feature in Revit Architecture and is currently working on Project Vasari, a spin-off of Revit which is focused on conceptual design and analysis.



Naai-Jung Shih

Naai-Jung received his Doctor in Architecture in University of Michigan with a focus on Computer Aided Design in Architecture. He has been teaching in the Department of Architecture, National Taiwan University of Science and Technology, for years.

Recent projects have been related to urban scans in Taipei and the historical preservation of temples and township in northern Taiwan, sponsored by National Science Council and local government departments.



Peter Andreas Sattrup

Peter Andreas Sattrup is a Danish architect and educator. With a background in architectural practice, Peter Andreas Sattrup is currently (2011) pursuing a PhD in Architecture on the subject of environmental simulation modelling. Having designed and worked on cultural, commercial and housing projects in Denmark and the UK for the past decade and a half, he applies his practical knowledge of the profession in his research. As an architect he takes the position that a holistic view on building performance is of greater value to the built environment than the optimization of technical sub-systems. Combining qualitative and quantitative analysis methods are essential to achieve that.



Robert Aish

Robert Aish studied Industrial Design at the Royal College of Art in London and has a Ph.D. in Human Computer Interaction from the University of Essex. He has developed engineering software with Arup, architectural software with Rucaps, naval architecture software with Intergraph and the GenerativeComponents parametric design software with Bentley. In 2005 the UK, 'Building Design' Magazine named Robert Aish as one of the top ten innovators in British Architecture. In 2006 he received the 'Association for Computer-Aided Design in Architecture' (ACADIA) Society Award. He is a co-founder of the SmartGeometry Group and visiting professor of Design Computation at the School of Architecture at the University of Bath, in the UK. His research interests include: the design of end-user programming languages

Symposium on Simulation for Architecture and Urban Design 2011

