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DAYLIGHT & ARCHITECTURE MAGAZINE BY  
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FORWARD THROUGH FEEDBACK





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# FORWARD THROUGH FEEDBACK

Public health is gaining increasing attention worldwide. Yet one important aspect of it is still largely disregarded – the impact of buildings on the health and well-being of people who spend 90% of their time indoors.

Sir Winston Churchill already acknowledged that just as we shape our buildings, buildings shape us. This also has economic consequences; for every euro spent by a company on the construction of an office building, five euros are spent on operating costs during the life cycle of the building – and 95 euros on the salaries of the people who work in the building. The well-being and productivity of the workforce are thus major assets, which crucially depend on the quality of the spaces.

Buildings are there to be used; their success largely depends on what happens after their construction or renovation. Yet the data and knowledge about the actual building performance is not yet available in the planning and acquisition phase. As a consequence, clients are often unsure what specifically to ask for. What experiences can be applied to inform future decisions in building design and engineering? Which tools are available to ensure that a building is beneficial to its users?

You can't manage what you can't measure – this business advice by the U.S. economist Peter Drucker is at the heart of *Daylight/Architecture 29*. In three major chapters, the magazine explores how we can move forward through feedback.

The first chapter presents some of the science around buildings and their impact on human beings in a light and accessible way. Here the Danish cartoonist Halfdan Pisket has

staged a fictitious dialogue between a building user and the space around him. Together they discuss how, according to Winston Churchill, buildings 'shape' their users in terms of health, physical well-being and emotions.

Then follows an overview of the planning schemes and evaluation methods that building owners and planners can use to design and document building performance. Some schemes focus mainly on the design and construction of buildings, while others also include building monitoring and user surveys during occupancy.

We believe that such a reality check is essential if buildings are to fulfil the promises of their clients and the expectations of their users. In addition, vital lessons can be learnt from building evaluation, which will increase the quality of the construction industry in the long term.

With science and theory in place, and the necessary tools at hand, the third chapter of this issue shows 15 buildings in which the indoor climate, air quality and occupant satisfaction have been verified during operation. We cannot yet derive benchmarks from these examples but we hope that they will encourage building professionals and their clients to demand feedback, and learn from it. This is a key tool to release the huge social and economic benefits in healthier buildings.

Enjoy the read!  
The VELUX Group



# D/A

"Buildings are the places where we express our culture, share our traditions and nurture our bodies and minds. Yet, the way we design, construct and operate our buildings determines if they will be an assault on our health or promote our wellbeing."

Joseph G. Allen

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## HOW OUR BUILDINGS SHAPE US

Why is a building never equally comfortable for all people? What are the decisive factors for indoor air quality? And how do indoor spaces psychologically affect us? These and other questions are discussed in the cartoon by the Danish comic artist Halfdan Pisket.

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## SCHEMES FOR HEALTHY BUILDINGS

A variety of planning tools for healthy and sustainable buildings such as LEED, WELL or Active House has been developed over the past 20 years. Daylight/Architecture presents the most important of them in short portraits. The accompanying photographs by Daniel Blaufuks show seminal buildings by the Portuguese architect Álvaro Siza in Porto from an unusual angle.

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## HEALTHY BUILDINGS IN PRACTICE

It is only in building operation that the actual state of indoor comfort and energy efficiency becomes apparent. The final chapter of this issue portrays a number of new buildings and renovations that have all undergone thorough monitoring after completion. In the future, such reality tests will be indispensable for real innovations in the construction industry.



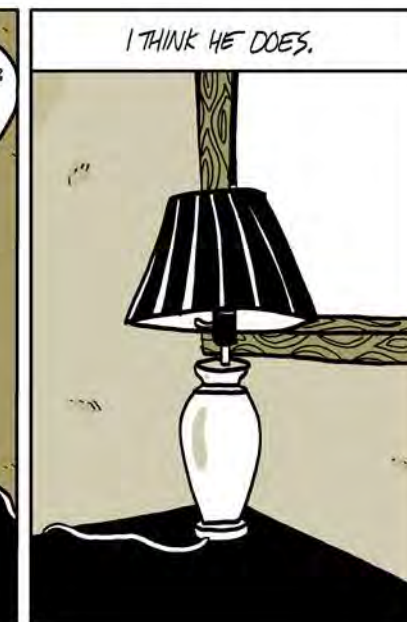
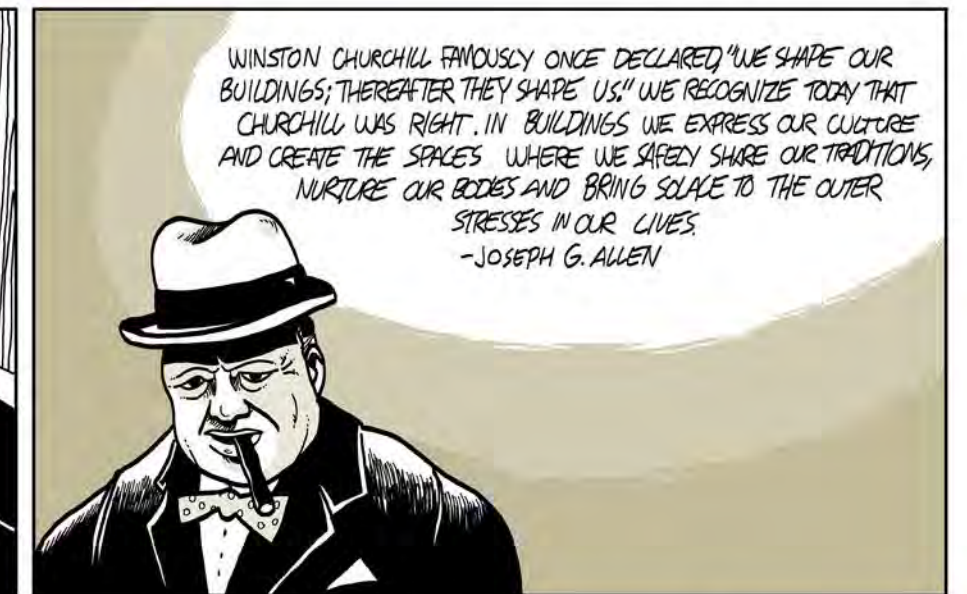
If rooms could speak – what would they tell us? This question is the starting point of the following graphic novel by the Danish comic artist Halfdan Pisket. The two protagonists talk about how buildings affect our well-being, our health and our emotions. The latest scientific findings show that the three areas are closely interlinked. Together, they form the basis for successful building design and operation.

Cartoon by Halfdan Pisket  
Text by Jakob Schoof



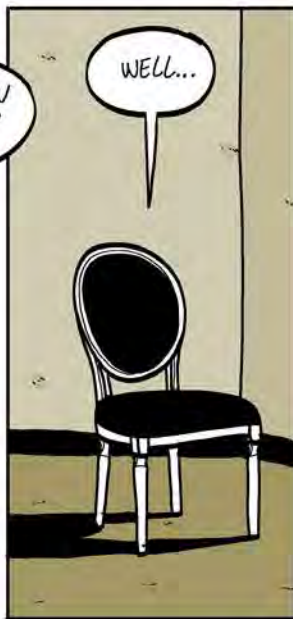
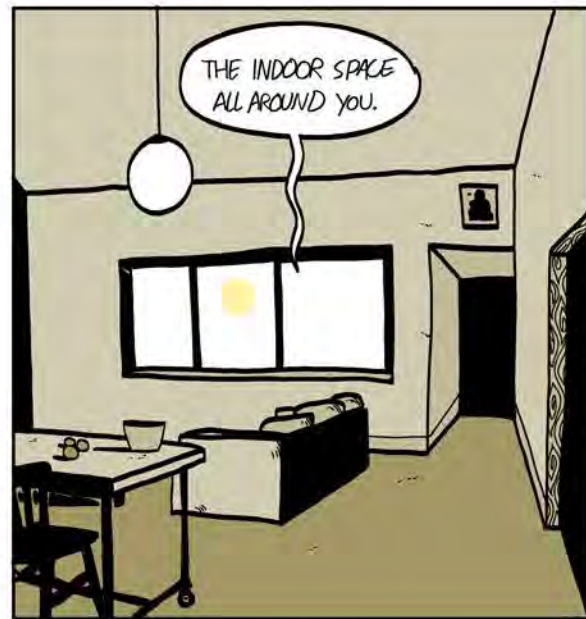


**Halfdan Pisket** (born 1985) is a Danish artist, graphic novelist and VJ. He graduated from the Royal Danish Academy of Arts in 2009 and, in the following years, published a number of underground comics: Violence (with author Hans Otto Jørgensen, 2009), Hail the Darklord (2012) and Locksmith Files (2012). His recent books, Desert Eagle (2014) Cockroach (2015) and Dansker (2016) form a graphic novel trilogy that deals with the life of Pisket's father. In 2015, the Danish Arts Foundation awarded Halfdan Pisket a three-year scholarship, the first time ever that a graphic novelist received this recognition.

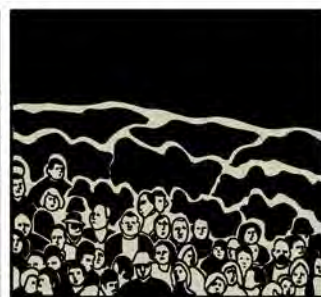


HALFDAN PISKET '18



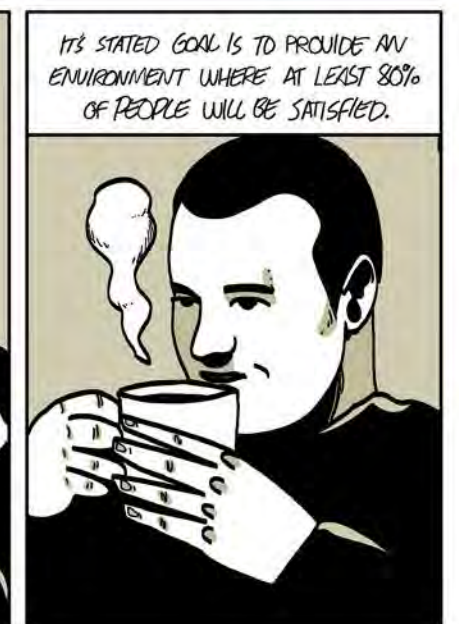
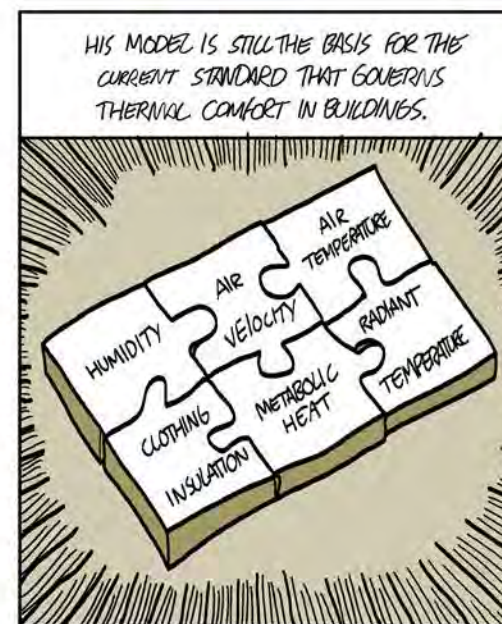
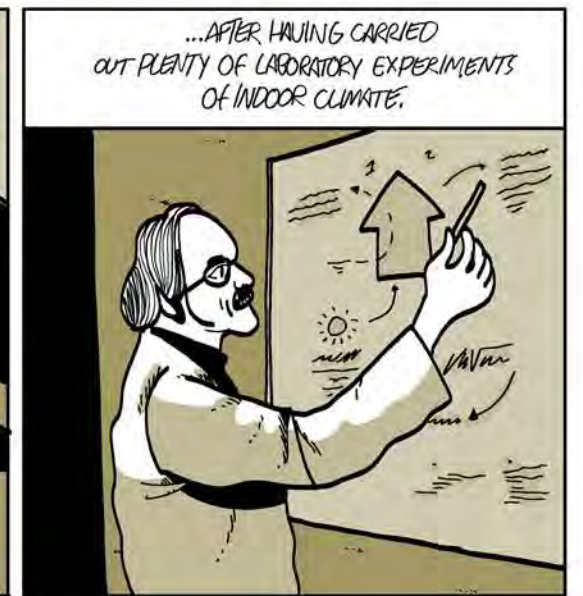
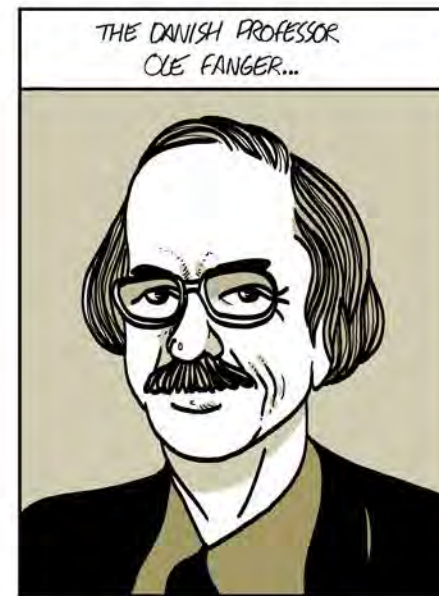
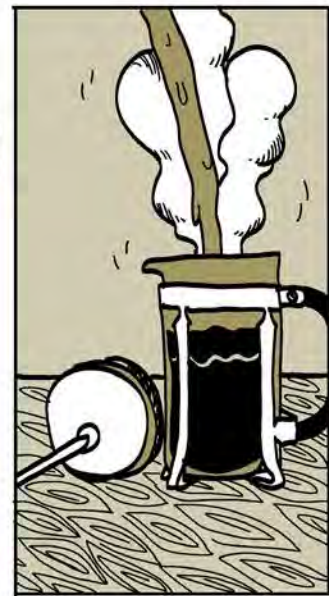


YOU GUYS IN INDUSTRIALISED COUNTRIES SPEND UP TO 90% OF YOUR TIME IN INDOOR SPACES. AND THERE'S MORE AND MORE OF US: IN THE EU AROUND 400 MILLION M<sup>2</sup> OF FLOOR SPACE IS ADDED IN BUILDINGS EVERY YEAR.

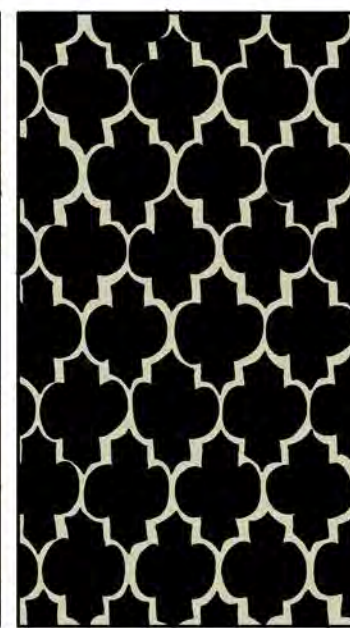
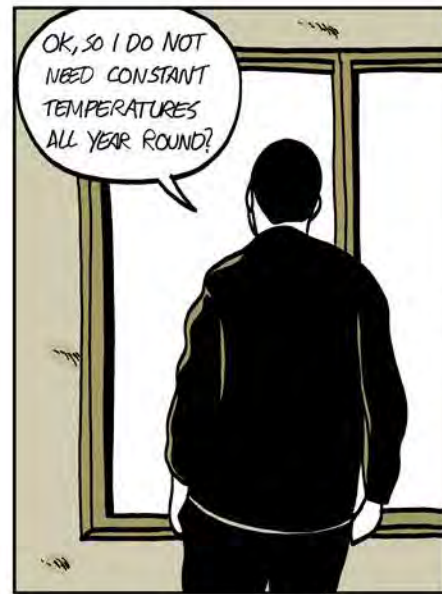




# REDEFINING COMFORT



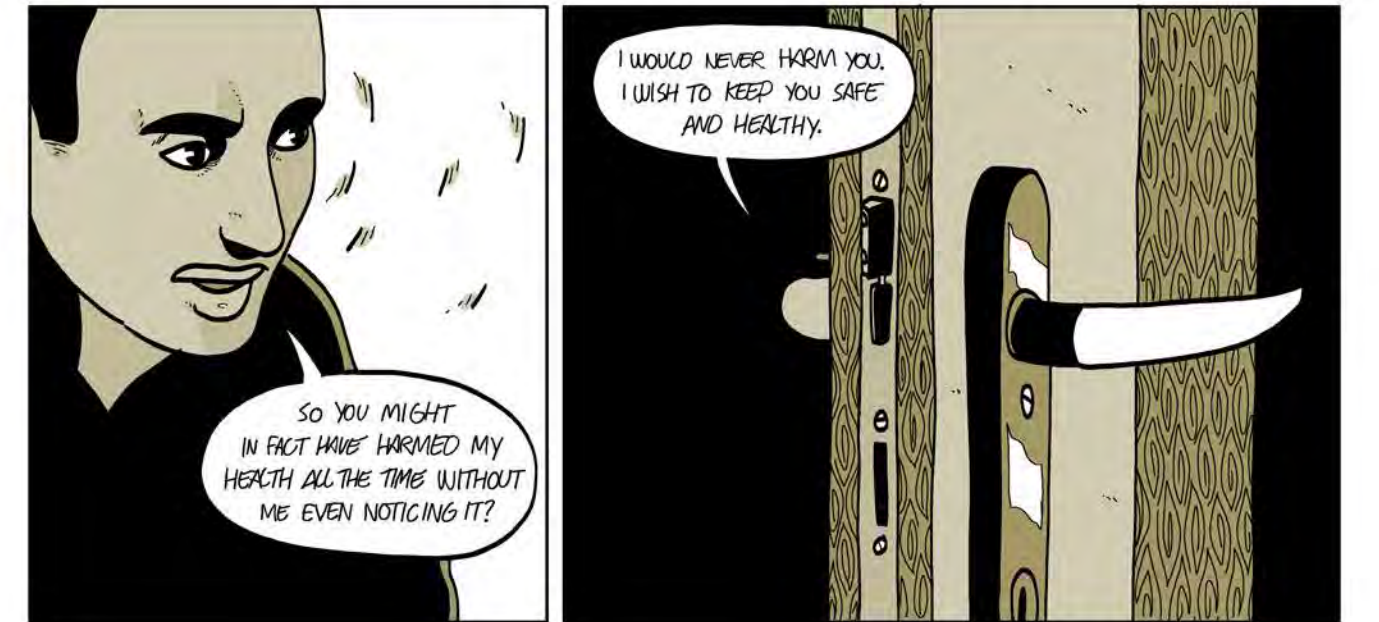
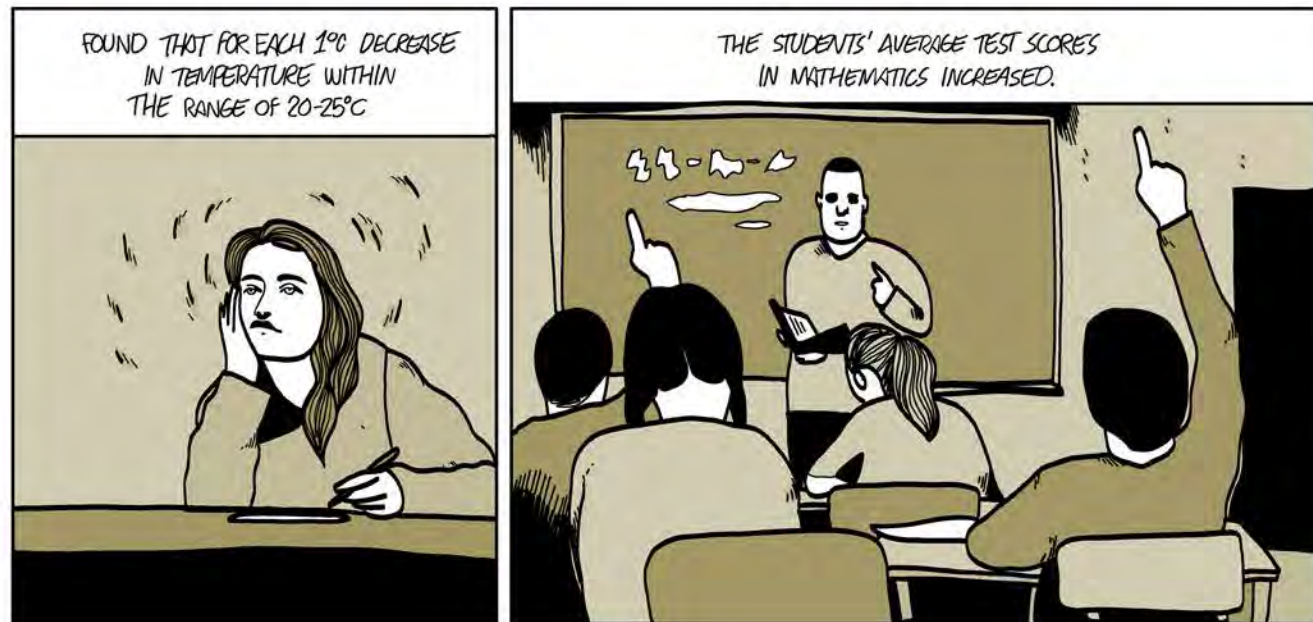
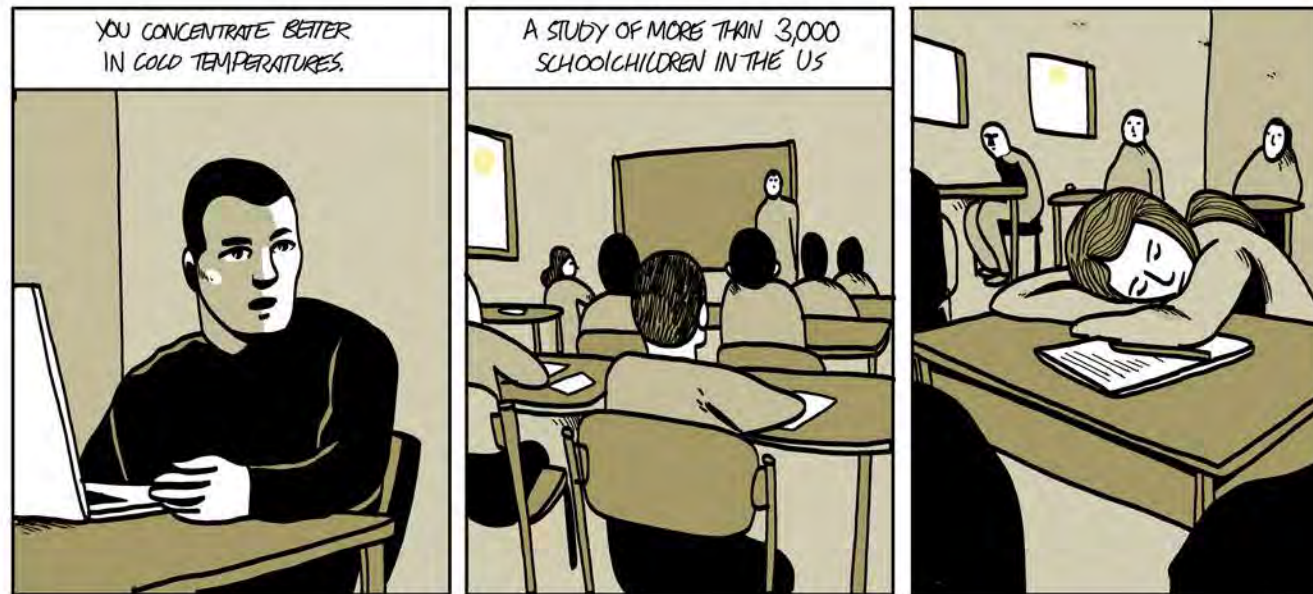
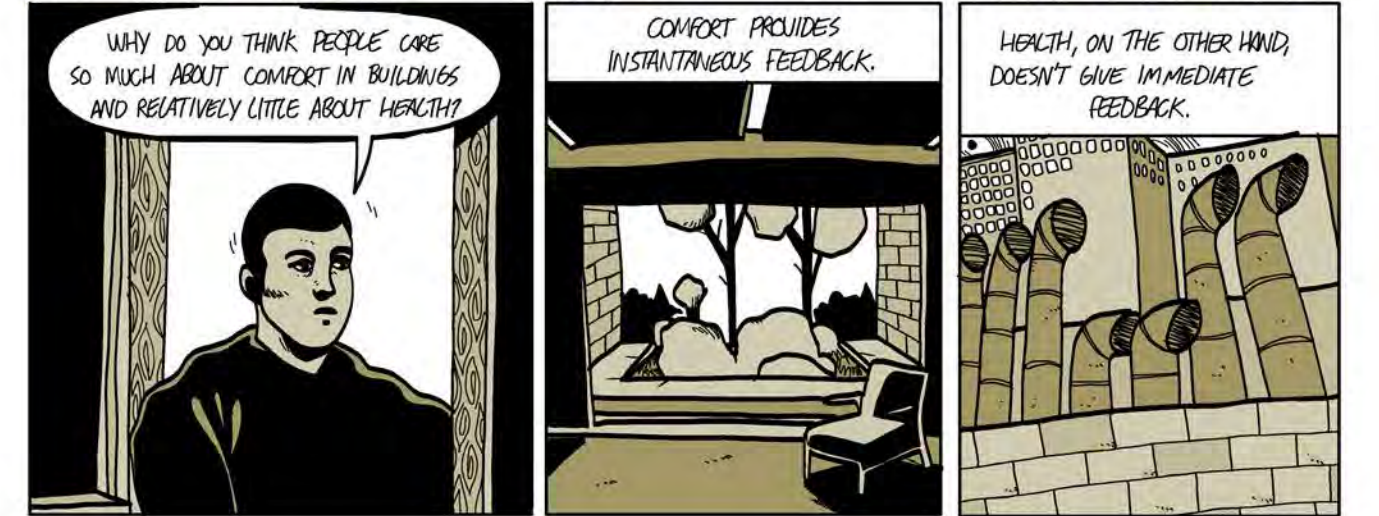




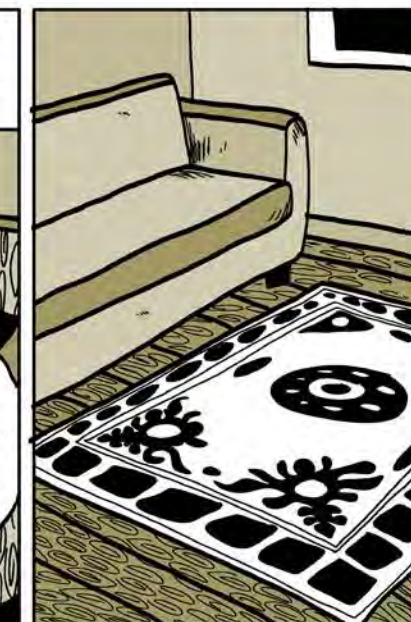
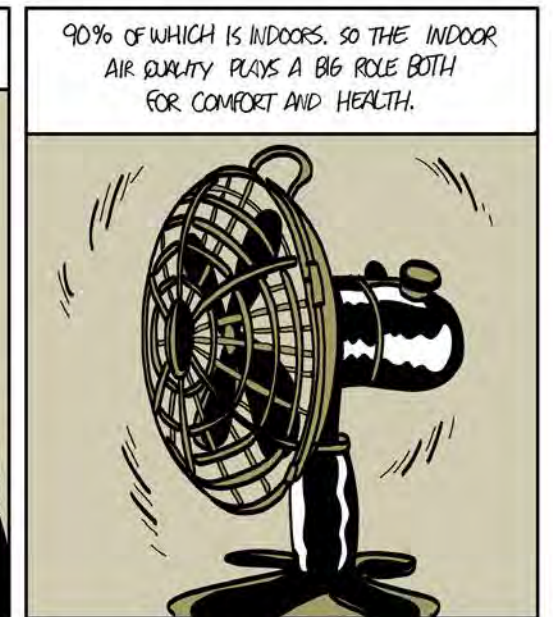




# HEALTHY INDOOR CLIMATE











CAN YOU QUANTIFY THAT?



OUTDOOR AIR POLLUTION ONLY CONTRIBUTES ONE-FOURTH OF THE TOTAL PARTICULATE CONCENTRATION IN PRIVATE HOMES.



SECOND AVOID USING CANDLES.



AND FINALLY VENTILATE YOUR HOME AT LEAST TWICE A DAY FOR 5-10 MINUTES.



SIMPLY SPEAKING...



...WHAT CAN I DO TO IMPROVE INDOOR AIR QUALITY?



I AM GLAD YOU ASKED.



ESPECIALLY WHEN COOKING...



...AND AFTER YOU'VE TAKEN A BATH OR SHOWER.



TO CUT IT SHORT.



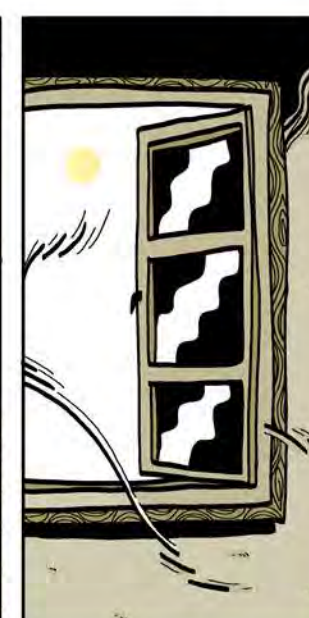
HERE ARE THREE RECOMMENDATIONS FOR BETTER INDOOR AIR:



FIRST DO NOT SMOKE INDOORS.



THAT'S A GOOD IDEA.



YOU WANT TO KNOW WHAT WOULD BE EVEN BETTER?



TO REALLY GET RID OF PARTICLES AND MOISTURE.



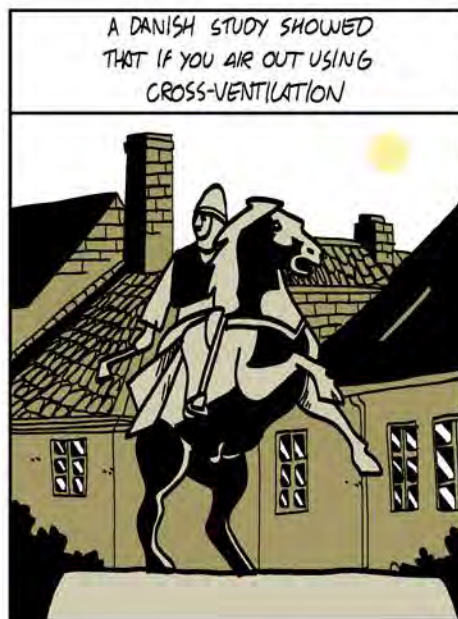
YOU NEED CROSS-VENTILATION.



IF ONLY ONE WINDOW IS OPENED, ONLY A VERY SMALL PART OF THE INDOOR AIR IS EXCHANGED.



A DANISH STUDY SHOWED THAT IF YOU AIR OUT USING CROSS-VENTILATION



YOU WILL REMOVE THREE TIMES MORE POLLUTANTS...



...THAN IF YOU HAVE JUST ONE WINDOW OPEN FOR THE SAME AMOUNT OF TIME.



THE SUN IS SHINING OUTSIDE. I WANT TO GO FOR A WALK.



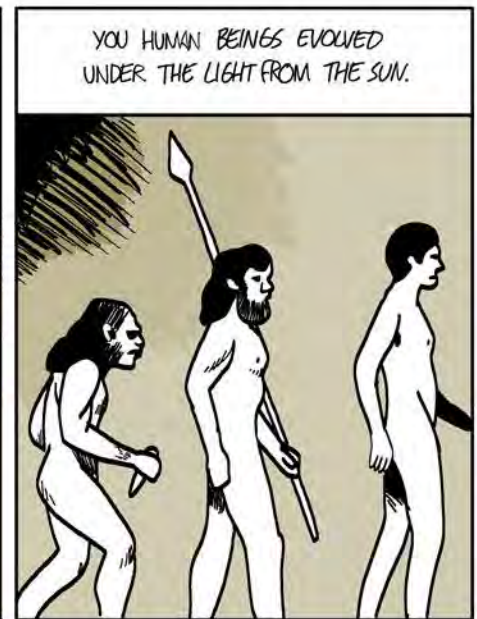
DO YOU WANT TO JOIN ME SO THAT WE CAN KEEP ON TALKING?



AHH THE SUNLIGHT FEELS SO GOOD.



YOU HUMAN BEINGS EVOLVED UNDER THE LIGHT FROM THE SUN.



THAT'S WHY YOU NEED BRIGHT DAYS AND DARK NIGHTS TO STAY HEALTHY.



YOU ALSO NEED COOL LIGHT IN THE MORNING AND WARM LIGHT IN THE EVENING FOR HEALTHY SLEEP.



HOW MUCH LIGHT DO WE NEED DURING THE DAY?



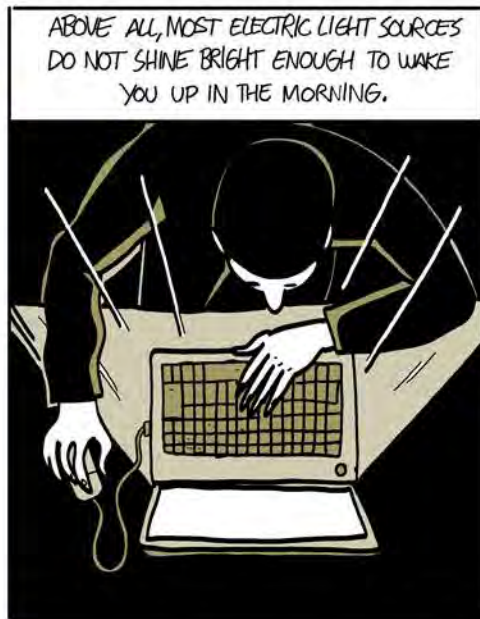
PEOPLE WHO GET MORE THAN 2 HOURS OF DAYLIGHT PER DAY NEED LESS SLEEP



AND TEND TO GO TO BED SLIGHTLY EARLIER THAN THOSE WHO DON'T.

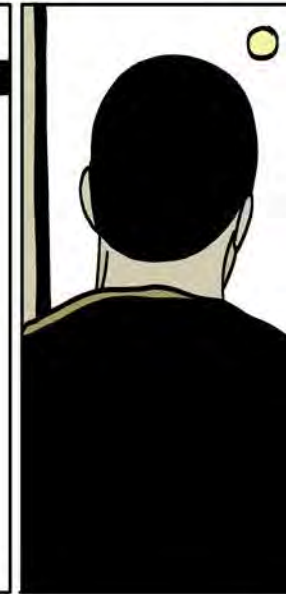






# ARCHITECTURE & OUR SENSES

A FEW DAYS LATER





WELL YOU KNOW—THE PLACES WHERE YOU SPEND YOUR TIME TEND TO HAVE A STRONG INFLUENCE ON YOUR MOOD AND BEHAVIOUR.



INDEED. I FREQUENTLY EXPERIENCED THAT.



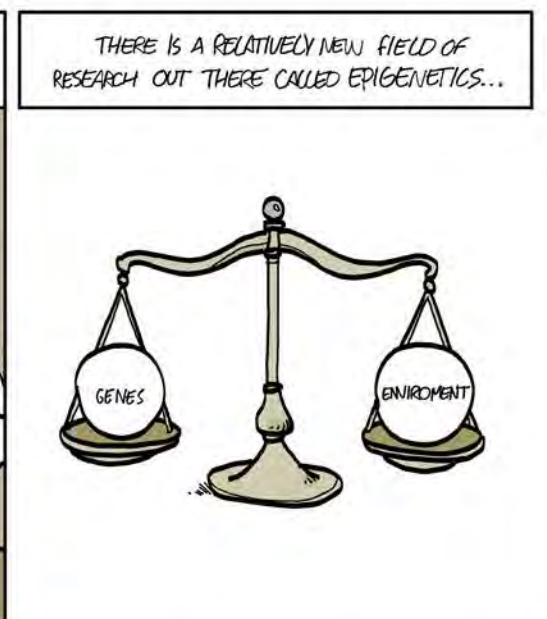
IS THAT TRUE?



WELL, THAT'S WHAT THE SCIENTISTS SAY.



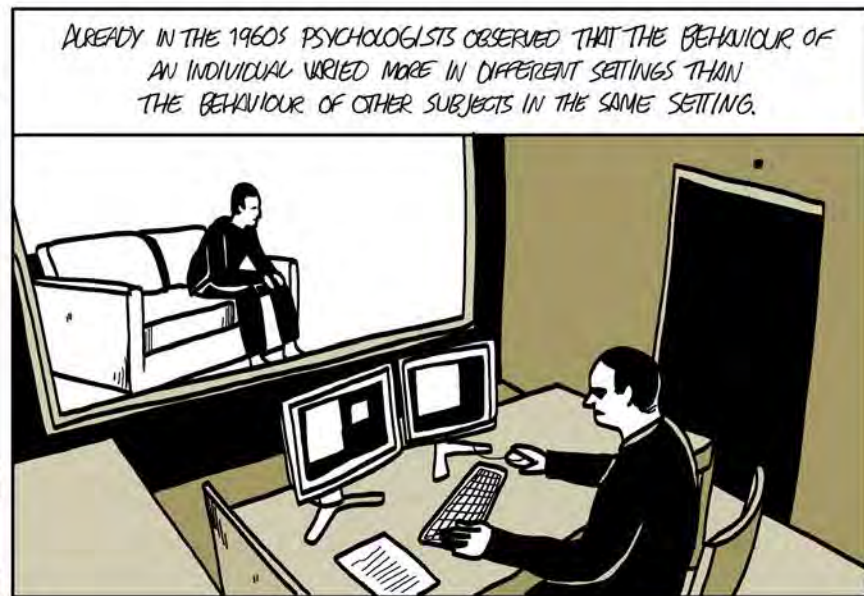
THERE IS A RELATIVELY NEW FIELD OF RESEARCH OUT THERE CALLED EPIGENETICS...



THERE IS ALSO SOME SCIENCE TO BACK IT.



ALREADY IN THE 1960S PSYCHOLOGISTS OBSERVED THAT THE BEHAVIOUR OF AN INDIVIDUAL VARIED MORE IN DIFFERENT SETTINGS THAN THE BEHAVIOUR OF OTHER SUBJECTS IN THE SAME SETTING.



...THAT DEALS WITH PRECISELY THESE QUESTIONS.



WHILE THE BRAIN CONTROLS OUR BEHAVIOUR AND THE GENES CONTROL THE BLUEPRINT FOR THE DESIGN AND STRUCTURE OF THE BRAIN.



AND IT GOES FURTHER.



YOUR LIVING ENVIRONMENT CAN EVEN PROVOKE LASTING CHANGES IN YOUR GENES.



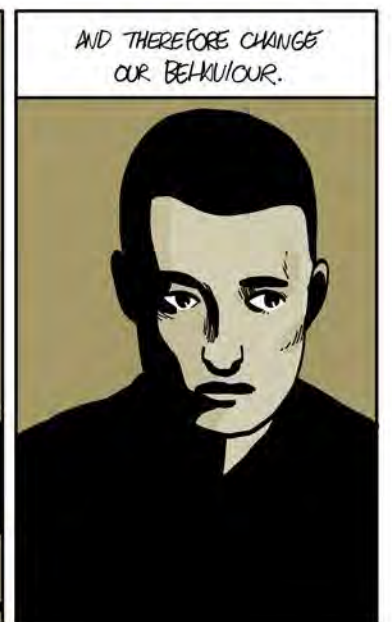
THESE ARE PASSED DOWN FROM ONE GENERATION TO THE NEXT.



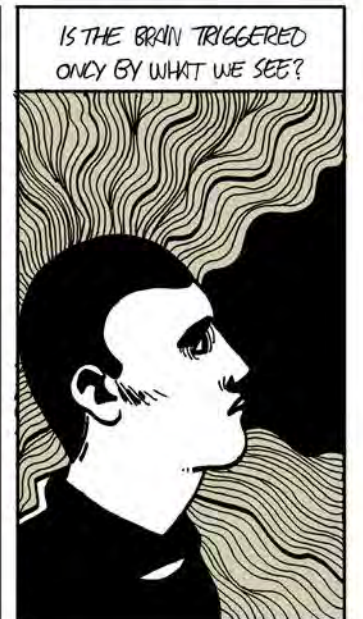
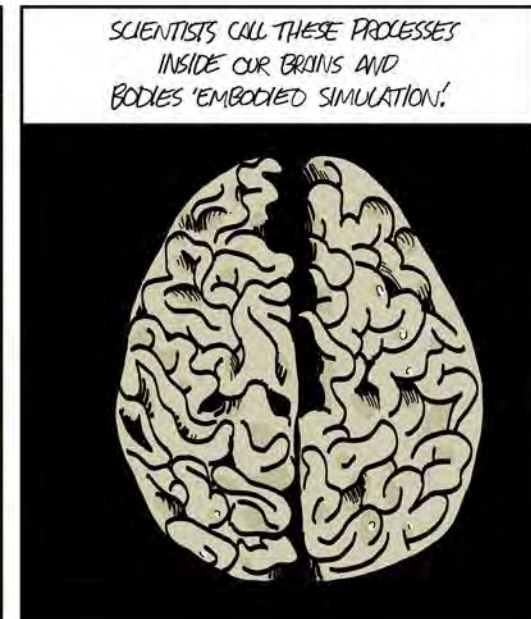
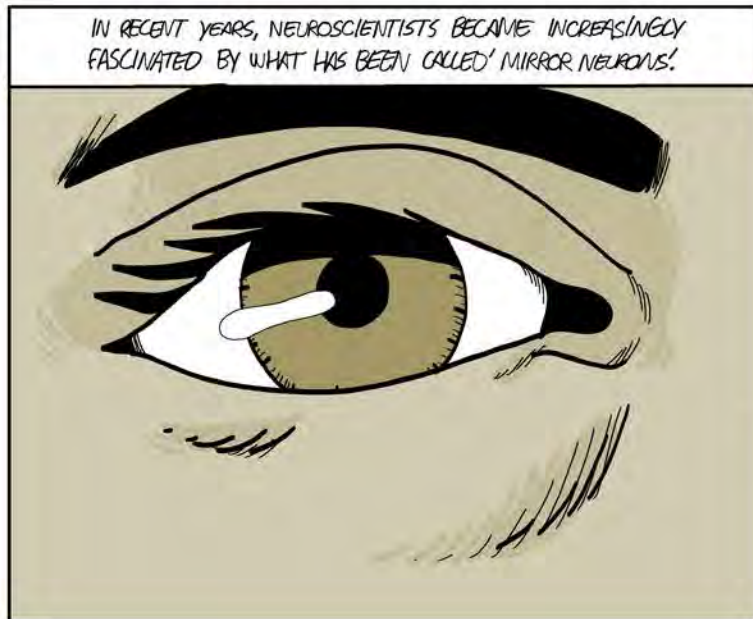
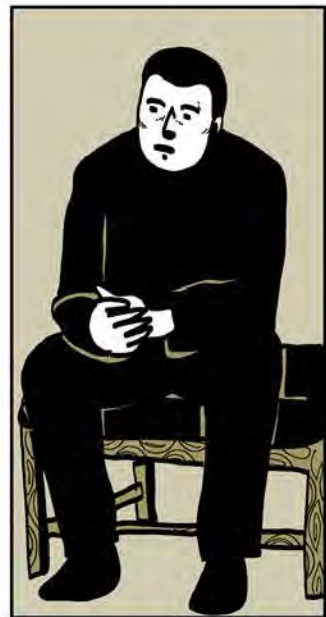
THE ENVIRONMENT CAN MODULATE THE FUNCTION OF GENES AND, ULTIMATELY, THE STRUCTURE OF OUR BRAIN.



AND THEREFORE CHANGE OUR BEHAVIOUR.



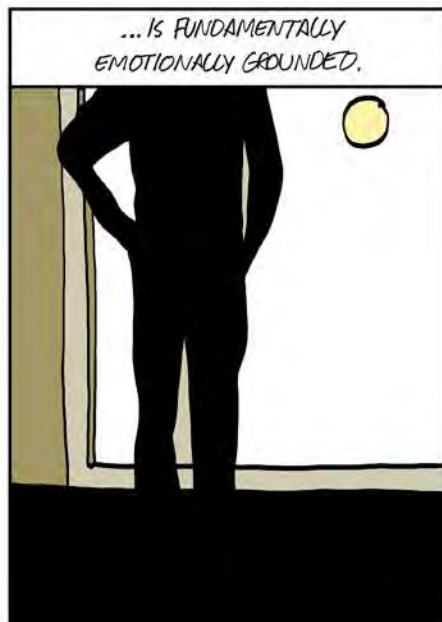








# THE WAY FORWARD





AND THERE ARE MANY EXAMPLES OF BUILDINGS THAT FOSTER SOCIAL COHESION IN OUR SOCIETY.

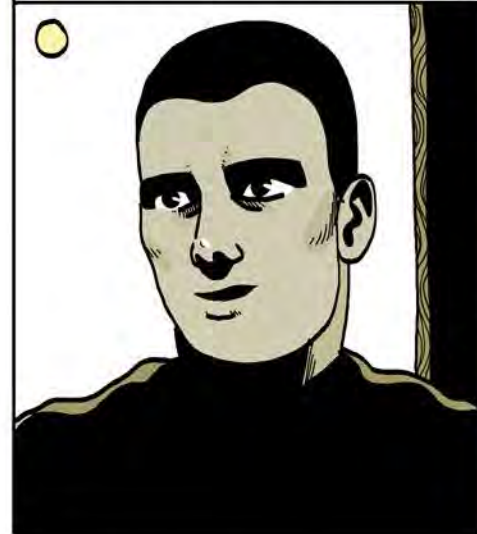


SO...



WHAT IS THE CHALLENGE?

WHAT PEOPLE DO AND WHAT THEY EXPERIENCE INSIDE THEM.



I COULD GO ON FOREVER TELLING YOU HOW INDOOR SPACES AFFECT PEOPLE IN GENERAL.



YOU NEED TO MAINSTREAM THE GOOD PRACTICE, AND CONTINUE TO LEARN FROM IT.



THIS REQUIRES A MUCH CLOSER COLLABORATION OF ALL STAKEHOLDERS.



BUT IF I SPECIFICALLY WANTED TO KNOW HOW I AFFECT YOU



WELL DO YOU WANT TO KNOW?

SCIENTISTS, ARCHITECTS, AND THE BUILDING INDUSTRY THROUGHOUT THE LIFECYCLE OF A BUILDING.



AND ABOVE ALL, YOU NEED TO FOCUS ON HOW BUILDINGS ARE USED IN REAL LIFE.



I THINK YOU ALREADY TOLD ME.



THANK YOU FOR LISTENING TO ME.



LET US TALK ANOTHER TIME.





# SCHEMES FOR HEALTHY BUILDINGS

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## Further reading

Active House alliance (ed.) Active House – The Guidelines. Brussels 2015

Allen J G et al: Green Buildings and Health. Current Environmental Health Reports 2015; 2(3): 250–258. doi: 10.1007/s40572-015-0063-y

Allen J G et al: The 9 Foundations of a Healthy Building. Cambridge/Mass. 2017

Arbib M A: Brains, machines and buildings; towards a neuromorphic architecture. Intelligent Buildings International, iFirst article 2012, 1–22

Burnett D: Daylight: Nature's Prescription for Health, Productivity and Sleep. Daylight/Architecture, issue 26, pp. 90–98. Hørsholm 2016

Gallese V, J Pallasmaa, and S Robinson: Architecture and Empathy. A Tapio Wirkkala – Rut Bryk Design Reader. Helsinki 2015.

Holzer P: Health Matters: Beyond Indoor Comfort. Daylight/Architecture, issue 26, pp. 82–90. Hørsholm 2016

Levin H: Re-constructing Thermal Comfort. Proceedings of the 9th Windsor Conference, 2016, pp. 40–142.

Lowden A, G Kecklund, T Åkerstedt, L Magnusson Hansson, H Westerlund: Daylight Exposure in Relation to Sleep, Wakefulness and Health. Paper presented at the 6th VELUX Daylight Symposium, London 2015

Pallasmaa J, H F Mallgrave, and M A Arbib: Architecture and Neuroscience. A Tapio Wirkkala – Rut Bryk Design Reader. Helsinki 2013.

Realdania/Center for Indeklima og Sundhed I Boliger (CISBO): Indeklima og sundhed I boliger. Copenhagen 2016

Van Marken Lichtenbelt W, M Hanssen, H Pallubinsky, B Kingma, L Schellen: Healthy excursions outside the comfort zone. Proceedings of the 9th Windsor Conference, 2016, pp. 137–142.

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How do you design and operate a healthy building? Answers to these questions can be found in an increasing number of methodologies and rating schemes that have seen the light around the world in recent years. They all share the ambition to strengthen the health and well-being of building users. Yet they vary widely in terms of their overall scope, the metrics they use as proof of performance, and the weight that they put on the different phases in a building's life cycle. The following chronological overview presents a selection of the most important and forward-looking tools, as well as their underlying methodologies.

By Jakob Schoof  
Photography by Daniel Blaufuks

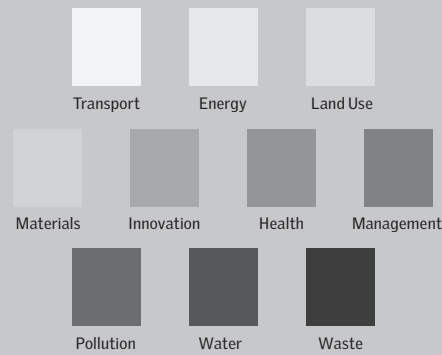


This overview shows the seven planning tools and their respective structures at a glance. Most of the tools pursue a holistic strategy that encompasses energy and other environmental issues as well as indoor climate. Life cycle costing also plays a role in the DGNB and AktivPlus systems. The WELL Building Standard focuses only on aspects of health and well-being. Most schemes offer several levels of certification (such as Silver, Gold and Platinum) whereas others, such as Active House or AktivPlus, put a stronger emphasis on planning guidance.

## BREEAM

Initiated by	BRE (Building Research Establishment) Group
Year	1990
Website	<a href="http://www.breem.com">www.breem.com</a>

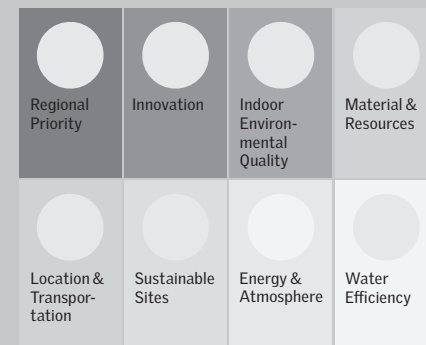
Structure



## LEED

Initiated by	U. S. Green Building Council
Year	1999
Website	<a href="http://www.usgbc.org">www.usgbc.org</a>

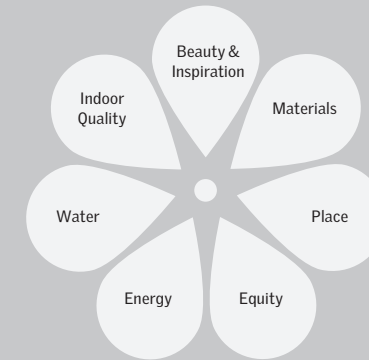
Structure



## THE LIVING BUILDING CHALLENGE

Initiated by	International Living Future Institute
Year	2006
Website	<a href="http://www.living-future.org">www.living-future.org</a>

Structure



## DGNB

Initiated by	German Sustainable Building Council (Deutsche Gesellschaft für Nachhaltiges Bauen/DGNB)
Year	2008
Website	<a href="http://www.dgnb.de">www.dgnb.de</a>

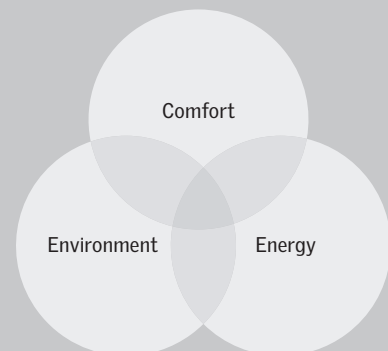
Structure

Environmental Quality	Economic Quality	Sociocultural and Functional Quality
Technical Quality		
Process Quality		
Site Quality		

## ACTIVE HOUSE

Initiated by	Active House Alliance
Year	2012
Website	<a href="http://www.activehouse.info">www.activehouse.info</a>

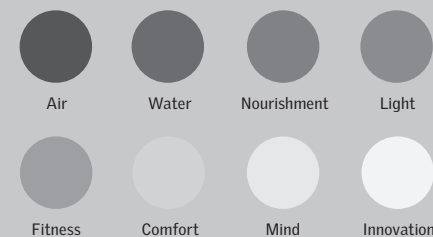
Structure



## WELL BUILDING STANDARD

Initiated by	International WELL Building Institute (IWBI) and Delos Living LLC
Year	2014
Website	<a href="http://www.wellcertified.com">www.wellcertified.com</a>

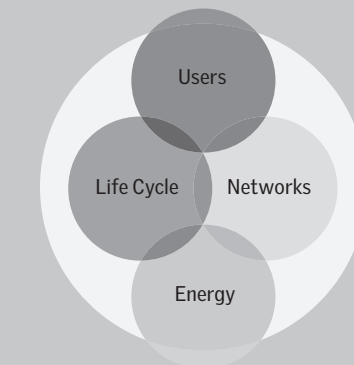
Structure



## AKTIVPLUS

Initiated by	AktivPlus e. V.
Year	2014
Website	<a href="http://www.aktivplusev.de">www.aktivplusev.de</a>

Structure





In future, BRE intends to further develop the certification scheme to include quality of life issues such as views, landscape, connections to nature (through biophilic design) and biological rhythms (through circadian lighting). Another aspect to be included concerns indoor and outdoor environments that encourage healthier lifestyles. Recently, BRE also engaged in a collaboration with the International WELL Building Institute to better align the BREEAM and WELL standards.



# BREEAM

Initiated by	BRE (Building Research Establishment) Group
Year	1990
Website	www.breeam.com
Main categories	Management, Health and Wellbeing, Energy, Transport, Water, Materials, Waste, Land Use and Ecology, Pollution, Innovation

## Background and goals

Initiated in 1990, BREEAM was the world's first comprehensive sustainability rating scheme for the built environment. According to the BRE Group, "BREEAM schemes aim to set performance based on criteria that are outcome focussed rather than overly prescriptive in terms of design solutions. ... [They] do not include issues where there may be a questionable evidence base, or where it is difficult to demonstrate the value associated with specific outcomes. With respect to health and well-being, this means that issues like building layout or aesthetics ... are not currently included."

## Application

New and refurbished residential and non-residential buildings, as well as commercial buildings in use, communities and infrastructure. Projects that do not fall within these categories may be certified according to a custom-tailored scheme (BREEAM Bespoke).

## Structure

BREEAM measures sustainable value in up to ten categories depending on the project type. These are each sub-divided into a range of assessment issues or criteria, each with its own target and benchmarks. The latest version of BREEAM New Construction comprises a total of 49 individual assessment issues. Compliance with these is verified by a third party BREEAM assessor.

## Design approach

### Indoor air quality and ventilation

To ensure healthy indoor air, BREEAM requires design teams to set up an indoor air quality plan that contains strategies for the removal and control of contaminant

sources, procedures for pre-occupancy flush out, third party testing and maintaining good indoor air quality in-use.

Projects are awarded additional credits if they fulfil requirements regarding the overall ventilation strategy, user control of the fresh air supply, emissions from building products and post-construction measurement of the indoor air quality.

Key aspects of the ventilation concept are the air exchange rate and the placement of air inlets or windows, which should be away from external pollutant sources. The use of CO<sub>2</sub> sensors is recommended in spaces with large and unpredictable occupancy patterns. For interior paints and coatings, flooring materials, wood-based products and insulation materials, BREEAM specifies the maximum formaldehyde and total VOC content, as well as specific testing procedures. Additional credits are awarded for formaldehyde and VOC measurements carried out in the finished building before the users move in.

### Daylight

Two alternative options can be used within BREEAM New Construction to quantitatively assess the daylight provision. Either the project team ensures that a specific proportion of each type of space (usually 80%) achieves an average daylight factor of 2%. In addition, BREEAM stipulates that a specific uniformity in the daylight distribution be achieved in this case.

Alternatively, a dynamic daylight simulation can be carried out. In this case the relevant metric is the area that achieves a given natural illuminance (usually at least 300 lux) for a specific number of hours per year.

Adequate glare control according to BREEAM can be provided both by building integrated measures such as overhangs or fins, or by specific types of moveable shading devices. Design studies are recommended to verify that these eliminate glare to a sufficient degree both in summer and winter.

To assess the quality of views, BREEAM uses the room depth and wall-to-window ratio as criteria. As a rule, permanently occupied spaces should be at most 8 m (in residential buildings, 5 m) from a facade, and the window-to-wall ratio should be at least 20%.

## Building operation and evaluation

In its Management category, BREEAM New Construction specifies best-practice procedures for the commissioning and handover of buildings, as well as the verification of their performance.

For handover, BREEAM recommends two different guidebooks and two different training schedules to be set up – one for facilities management and one for less technically adept building users. An additional credit is awarded if a post-occupancy evaluation (POE) is carried out one year after users move in.

In the operation phase, the BREEAM In-Use scheme can be used to improve the performance of the building and the quality of the building management. In the field of health and well-being, the evaluation is largely based on qualitative parameters such as the degree of control that the users have over temperature, glare, illumination levels and air supply. Quantitative measurements are only specified for illuminance levels achieved indoors.



How do you assess the quality of views out of windows? In its "Quality Views" credit, LEED provides a tentative answer: a project can gain points if 75% of all regularly occupied floor area achieves a direct line of sight to the outdoors through clear glazing. Further criteria for a good view, according to LEED, include lines of sight pointing in two different directions, as well as views of fauna, flora, sky, movement and distant objects placed at least 7.5 metres away from the building.

# LEED

Initiated by	U. S. Green Building Council
Year	1999
Website	www.usgbc.org
Main categories	Location and Transportation, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation, Regional Priority



## Background and goals

First launched around the change of millennium, today LEED is the most widely applied comprehensive green building ratings system internationally. LEED certified buildings exist in more than 140 countries and territories world-wide. Here is how the U.S. Green Building Council describes its own mission: "to transform the way buildings and communities are designed, built and operated, enabling an environmentally and socially responsible, healthy and prosperous environment that improves the quality of life."

## Application

Currently LEED comprises 21 different rating systems that apply to different types of projects. These include new buildings (ten rating systems), new interiors (three rating systems), the operation and maintenance of existing buildings (six rating systems) and neighbourhoods (two rating systems).

## Structure

LEED BD+C New Construction is made up of 8 categories with a total of 12 prerequisites and 46 credits. While prerequisites are mandatory to meet certification requirements, the credits offer project teams a choice of where to put the focus in the optimisation of their building or neighbourhood.

## Design approach

### Indoor air quality and ventilation

As a prerequisite, LEED stipulates air exchange rates compliant with either the ASHRAE 62.1-2010 or the EN 15251/EN 13779 standards.

For manually ventilated spaces, measurement devices that measure the

exhaust airflow and CO<sub>2</sub> concentrations in indoor spaces must be supplied. In residential buildings, carbon monoxide monitors in each dwelling unit are also mandatory, and indoor fireplaces and woodstoves must have solid enclosures or firmly sealing doors.

Additional credits are available if the ventilation rate exceeds the minimum requirement by at least 30% or, in the case of natural ventilation, if a room-by-room calculation of the ventilation rate has been carried out. Points can also be gained by specifying low-VOC materials for furniture and interior fit-outs. These should have been tested against the Californian CDPH Standard Method v1.1-2010 or against the German AgBB scheme.

### Daylight

To optimise daylight conditions in a LEED-certified building, project teams can either perform a dynamic computer simulation or carry out on-site measurements. In both cases, the certification schemes specify lower limits (to ensure sufficient daylight provision) as well as upper limits (to prevent excessive glare) for daylighting levels.

In simulations, two different sets of metrics can be used: either the spatial daylight autonomy (sDA300/50%) in combination with the annual sunlight exposure (ASE1000,250), or daylight illuminance levels (which have to be between 300 and 3000 lux for a given proportion of the regularly occupied floor area). In measurements, only the natural illuminance is used as the relevant metric.

### Building operation and evaluation

In order to improve air quality, LEED for New Construction (LEED-NC) stipulates

a smoking ban both inside buildings and outdoors – except in designated outdoor smoking areas. Further credits reward building owners for carrying out an indoor air quality assessment after construction and before occupancy, but under ventilation conditions typical for occupancy. This includes measurements of formaldehyde, particulates, ozone, VOCs and carbon monoxide, as well as a number of other potentially harmful chemicals. Alternatively, building owners can choose to 'flush out' the building with large volumes of air just before users move in.

LEED for Operation & Maintenance (LEED O&M) specifies further measures that building owners can carry out during occupancy, such as: measurements of the actual air exchange rates, a permanent monitoring of thermal comfort parameters, and an occupant comfort survey carried out every two years with at least 30% of the building's occupants. If more than 20% of all respondents are unhappy with the building, corrective action needs to be taken.

To ensure healthy indoor air quality during occupancy, LEED recommends establishing a green cleaning policy that comprises both the tools and chemicals used for cleaning, as well as the cleaning process, and implementing an indoor air quality management programme based on the I-BEAM model developed by the U. S. Environmental Protection Agency (EPA).



# THE LIVING BUILDING CHALLENGE

Initiated by	International Living Future Institute
Year	2006
Website	<a href="http://www.living-future.org">www.living-future.org</a>
Main categories	Energy, Water, Materials, Place, Health & Happiness, Equity, Beauty

## Background and goals

“The world’s most ambitious green building standard,” reads the self-proclaimed ambition of the Living Building Challenge. According to the International Living Future Institute, “as such the program is a philosophy first, an advocacy tool second, and a certification program third ... Living Buildings strive for net-zero or net-positive energy, are free of toxic chemicals, and lower their energy footprint many times below the generic commercial structure.”

The Living Building Challenge sets stringent requirements particularly in terms of water, energy and waste, where buildings are required to achieve a net zero or net positive balance. The requirements in terms of place, health & happiness, equity and beauty are somewhat less difficult to achieve.

## Application

New buildings, renovations, landscape and infrastructure projects.

## Structure

The Living Building Challenge consists of seven performance categories, or ‘petals’. These are in turn subdivided into a total of 20 Imperatives, each of which focuses on a specific sphere of influence. All 20 Imperatives are required for new buildings, 16 for renovations, and 17 for landscape and infrastructure projects.

Two core rules apply in the Living Building Challenge: firstly, all Imperatives are mandatory. Secondly, Living Building Challenge certification is based on actual, rather than anticipated, performance. Therefore, projects must be operational for at least one year prior to evaluation in order to verify compliance.

## Design approach

### *Indoor air quality and ventilation*

The Living Building Challenge requires all regularly occupied spaces to have operable windows that let in daylight and fresh air. Furthermore, Living Buildings must achieve ventilation rates compliant with the ASHRAE 62 standard. Only materials and products that have been tested for VOC emissions may be installed in interior spaces.

A ‘red list’ bans, among others, bisphenol A (BPA), cadmium, chloroprene, added formaldehydes, halogenated flame retardants, phthalates and PVC from the building materials. Kitchens, bathrooms and janitorial areas are to be equipped with dedicated exhaust systems.

### *Daylight*

Daylight is addressed qualitatively rather than quantitatively in the Living Building Challenge. This is done through the requirement for operable windows and through the ‘Biophilic Environment’ imperative. The latter requires project teams to set up a biophilic framework and plan for the project that includes the incorporation of environmental features, natural light and natural shapes.

### *Aesthetics and contact to nature*

Beauty and the connection to the natural environment are key issues in the Living Building Challenge. Amongst other things, the biophilic plan has to ensure that the building provides sufficient and frequent human-nature interactions, both in the interior and exterior spaces.

The ‘Beauty and Spirit’ imperative requires design teams to “meaningfully integrate public art and contain design features intended solely for human delight and the celebration of culture.”

## Building operation and evaluation

Projects have to be operational for at least twelve consecutive months before a certification is possible. 12 of the 20 imperatives can be verified after construction through a preliminary audit. In the other eight imperatives, which include Health & Happiness, performance is verified after the first year of operation and based on quantitative data.

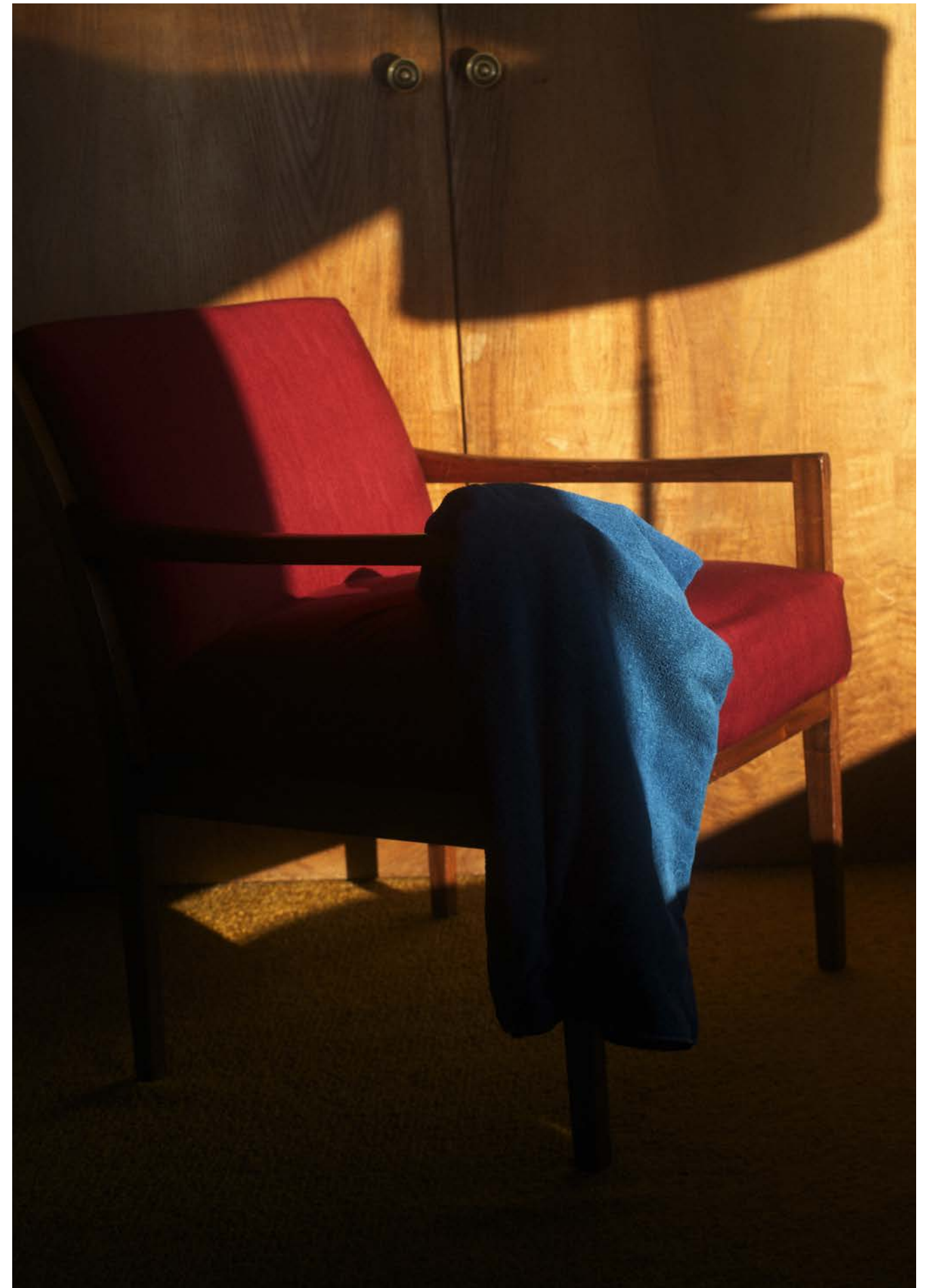
Both before the users move in and nine months after full occupancy, the indoor air quality is tested for particulate matter, VOCs, formaldehyde and other common pollutants. Basic comfort parameters such as temperature, humidity and CO<sub>2</sub> levels are also permanently monitored. Smoking is banned from all Living Buildings and the building management has to set up a cleaning protocol that uses cleaning products compliant with the EPA Design for the Environment label.

In-use monitoring even extends to the ‘Beauty & Inspiration’ petal: in the first year of occupancy, a survey of at least 10% of the building users is carried out to evaluate whether the project lives up to the claims of the designers in terms of beauty.

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“The program has always been a bit of a Trojan horse – a philosophical worldview cloaked within the frame of a certification program.”

From the Introduction to the Living Building Challenge, Version 3.1







# DGNB

Initiated by	German Sustainable Building Council (Deutsche Gesellschaft für Nachhaltiges Bauen/ DGNB)
Year	2008
Website	<a href="http://www.dgnb.de">www.dgnb.de</a>
Main categories	Environmental quality, Economic quality, Sociocultural and functional quality, Technical quality, Process quality, Site quality

## Background and goals

First launched in a pilot phase in 2008, the DGNB system is a relative newcomer among the comprehensive building rating systems. Its criteria were initially developed by the German Sustainable Building Council together with the German Ministry of Construction. Meanwhile the two institutions each pursue their own further development of the system; DGNB is also being applied internationally.

## Application

New construction, existing buildings and urban districts. Within these fields, a total of 22 different schemes are currently available for specific types of buildings and districts. Amongst other things, DGNB has separate schemes for existing buildings, refurbished buildings and the management of existing buildings.

## Structure

All schemes in the DGNB system are based on a uniform evaluation method that is then adjusted to match individual types of buildings or different requirements. The scheme most frequently used is 'New Construction Offices', which currently encompasses 37 assessment criteria grouped into six categories.

## Design approach

### *Indoor air quality and ventilation*

To prevent contamination of the indoor air in the first place, all relevant elements and materials in the building are assessed against a matrix of indicators. This contains limits and target values for substances such as VOCs, solvents, flame retardants, plasticisers, heavy metals and other potentially harmful substances. Beyond maximum permissible limits for each product category, buildings can gain

additional points if materials contain less pollutants or have been awarded more ambitious environmental product labels.

Additionally, DGNB uses three key indicators to assess indoor air quality: the total VOC and the formaldehyde content, as well as the ventilation rate. While VOCs and formaldehyde are measured shortly after building completion, the approach used to determine the ventilation rate depends on the type of building and the ventilation system. For residential buildings, DGNB stipulates a ventilation concept according to DIN 1946-6. For most other buildings, design teams can choose between computational fluid dynamics, an assessment according to DIN EN 15251 for mechanical ventilation or, in the case of natural ventilation, a simplified calculation. The latter evaluates ventilation rate based on the height and depth of each space, as well as the size of operable windows.

### *Daylight*

The DGNB system considers a total of six aspects in terms of daylight and visual comfort: daylight availability in the building as a whole and at the workplace, views to the outside, glare protection, the colour rendering index of the glazing and solar shading, as well as direct sunlight. In the case of daylight availability, the maximum number of points is awarded if 50% of the usable area achieves a daylight factor of at least 2%. With regard to views outside, the evaluation also takes into account whether visual contact is still possible whilst the blinds are drawn. Glare protection is only assessed for non-residential buildings, whereas direct sunlight is only taken into account for residential buildings and hotels.

### *User control and well-being*

DGNB recognises the fact that the more people can directly influence their environment, the more likely they will be satisfied with it. In its 'User control' criterion, the system therefore rewards designers and building owners if the air exchange, shading systems and temperature can be separately regulated in each room, and directly influenced by the users. In residential buildings, the highest rating is given to buildings with a demand-controlled ventilation system (e.g. via CO<sub>2</sub> sensors) that the residents can overrule if they wish to.

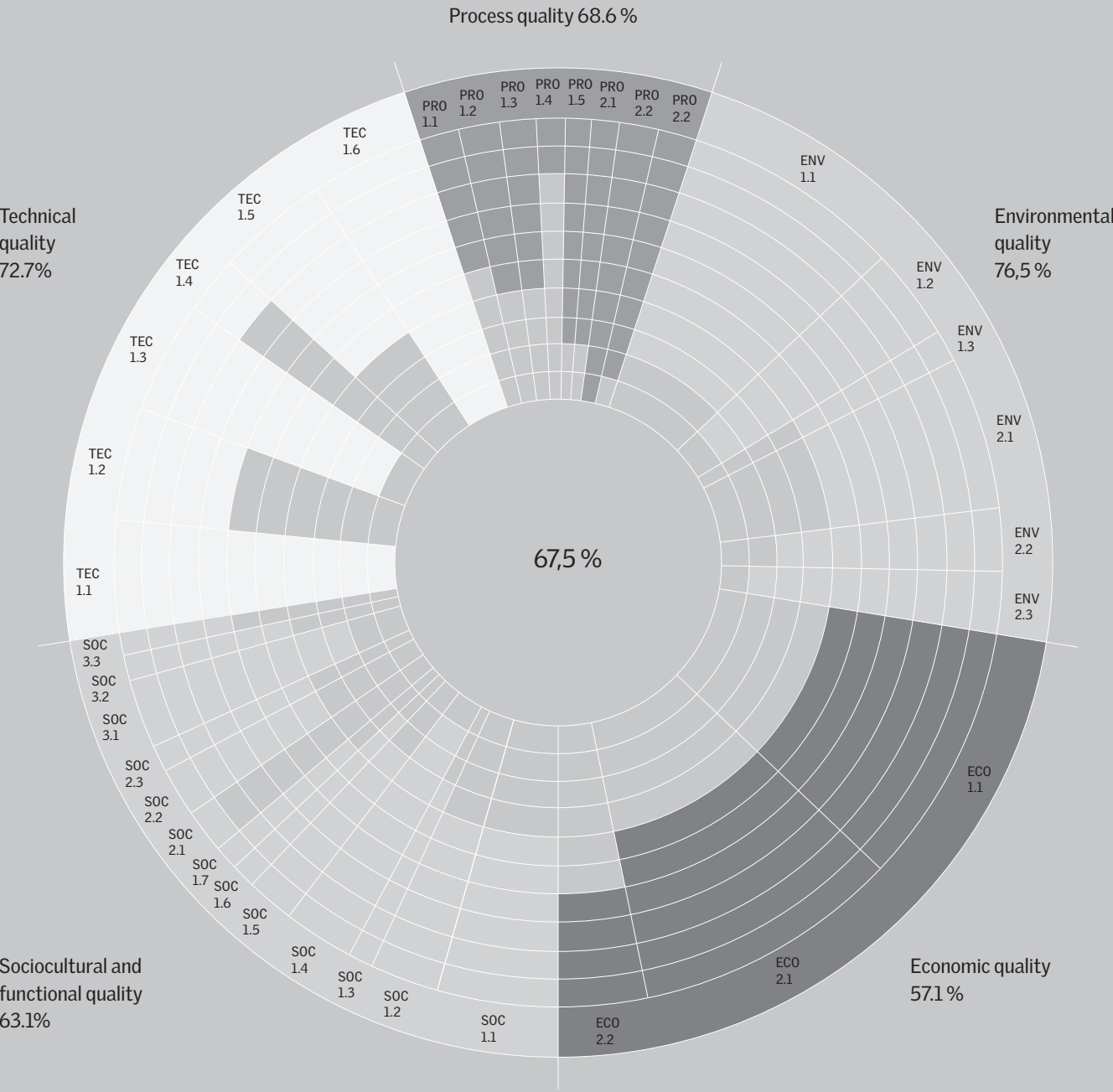
## Building operation and evaluation

The DGNB schemes for new buildings stipulate a VOC and formaldehyde test of the indoor air only after completion of the building, before the users move in. Further requirements are specified in a newly introduced scheme for office and shop interiors. Here, owners are awarded extra points for continuous monitoring of CO<sub>2</sub>, particulate matter and ozone levels, as well as the relative humidity of the indoor air. However, the DGNB system does not specify limits or benchmark values for any of these parameters.

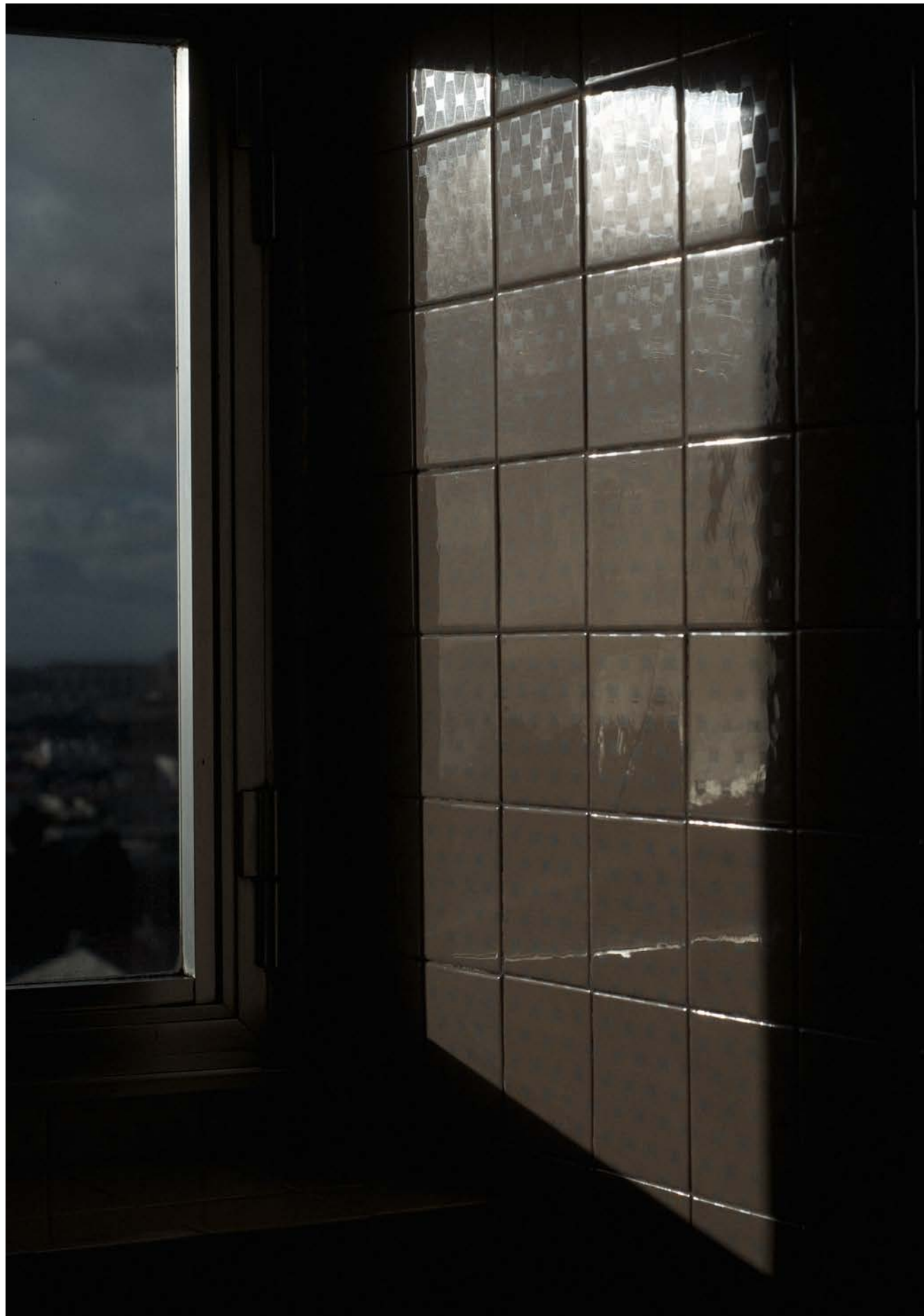
Instead, the DGNB scheme for the operation of existing buildings takes into account user satisfaction with the indoor environment. While no minimum requirements are set for the frequency and scope of post-occupancy evaluations, the certification result significantly depends on the extent and number of participants in such evaluations, as well as on how complaints are dealt with.



The evaluation diagram provides an easily comprehensible overview of the performance of a specific building in the different DGNB criteria.







# ACTIVE HOUSE

Initiated by	Active House Alliance
Year	2012
Website	www.activehouse.info
Main categories	Comfort, Energy, Environment

## Background and goals

Under the headline “Buildings that give more than they take”, Active House promotes the vision of healthy and comfortable living in buildings without negatively influencing the climate and environment. Active Houses seek to provide an answer for the three main challenges facing the building industry today: comfort, energy and environment.

## Application

New and refurbished buildings

## Structure

The Active House Specifications contain both quantitative and qualitative criteria. The quantitative parameters represent the nine most important topics for an Active House evaluation, such as indoor air quality, daylight and environmental load. Each parameter is evaluated individually and displayed in the Active House Radar diagram. The qualitative parameters represent additional concerns that should be included in the global performance assessment for an Active House.

The Active House Radar is an indication of how ‘active’ the building has become. The diagram shows the level of ambition in each of the nine quantitative parameters on a scale from 1 to 4, where 1 is the highest level and 4 is the lowest.

## Design approach

### *Air quality and ventilation*

The only quantitative measure of air quality in an Active House relates to the CO<sub>2</sub> concentration in the indoor air. This is determined using dynamic simulation tools at the design stage. To achieve level 1 in the Indoor Air Quality parameter, the ventilation of the main rooms should be designed

in a such way that the CO<sub>2</sub> concentration does not rise more than 500 ppm above the outdoor CO<sub>2</sub> concentration.

Among its qualitative parameters, Active House also recommends using materials with indoor climate labels and ensuring that there is sufficient air extraction from kitchens and bathrooms. Building users should be able to manually adjust the air change rate by opening windows, and mechanical ventilation systems should allow at least three levels of adjustment.

### *Daylight*

Active House takes two aspects into account when assessing the daylight quality of buildings: the daylight factor (DF) and the direct sunlight availability. To achieve level 1 in the Daylight parameter, the DF should be at least 5% on average in the main rooms of the house, and at least one of the main rooms should receive direct sunlight for at least 10% of the probable sunlight hours between autumn and spring equinox.

Qualitative recommendations in terms of daylight include: locating windows for optimum views, using glazing with the highest possible light transmittance and managing glare with appropriate building-integrated measures or dedicated shading devices. Furthermore, daylight provision should also be extended to secondary rooms such as kitchens and bathrooms.

### *Thermal environment*

To objectify the risk of overheating, a dynamic thermal simulation tool is used to determine hourly values of indoor operative temperature in each room. In dwellings without mechanical cooling systems,

adaptive temperature limits are used in the summer months. This means that the maximum allowable temperature inside is linked to the weather outside: limits go up during warmer periods.

In its qualitative recommendations Active House emphasises user control over the thermal environment. Residents should be able to control heating temperatures at room level and manually counteract overheating in summer by opening windows or operating shading devices. Draught should be prevented by a suitable placement of ventilation outlets.

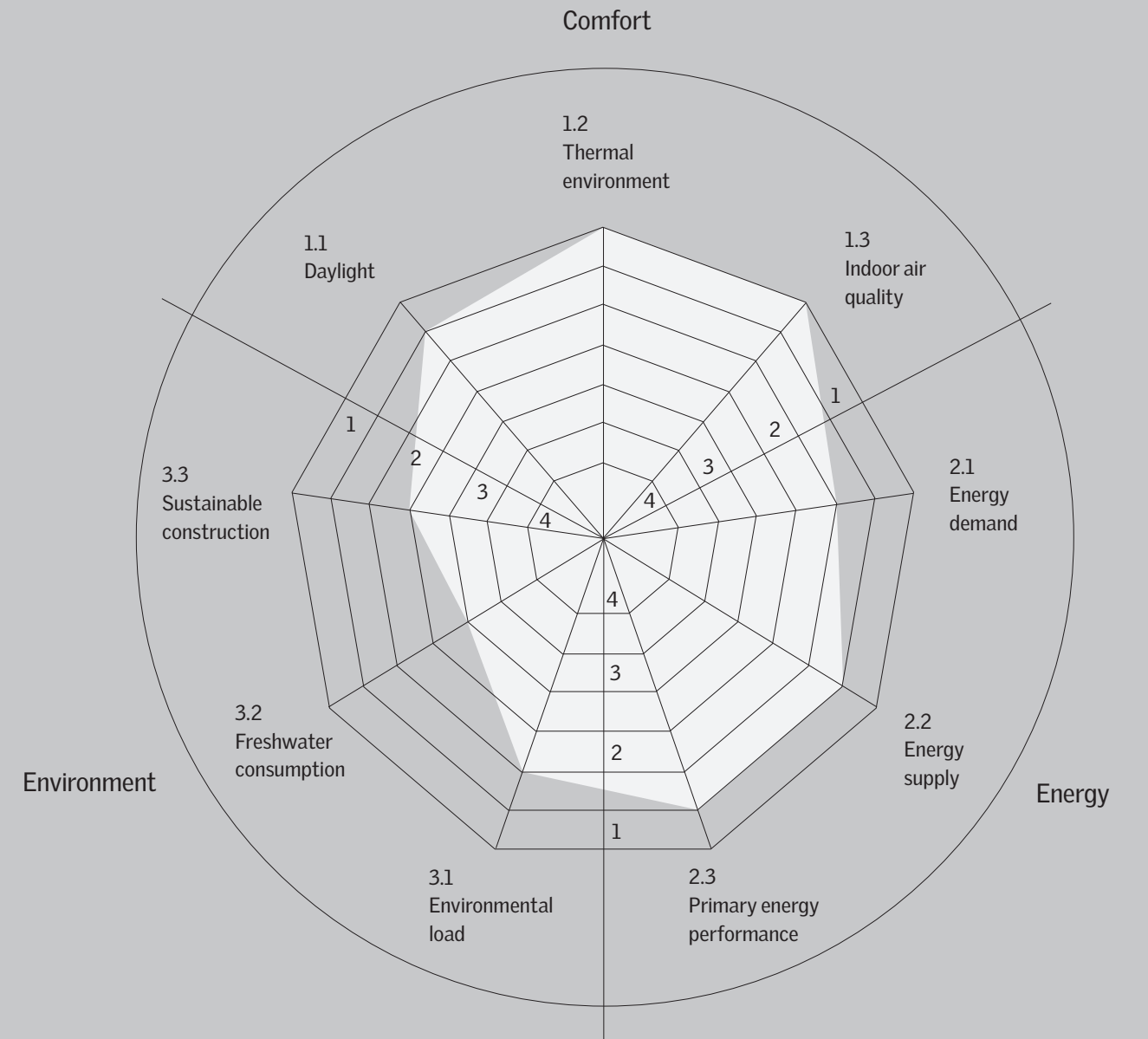
## Building operation and evaluation

In order to ensure that the final project meets the expected level of ambitions, Active House recommends that building owners monitor their project. The monitoring process should last for one year as minimum (ideally two) and the differences between the calculated performance and the actual performance can be visualised in the Active House Radar. Follow-up is recommended, with adjustments made when necessary.





The Active House Radar shows the performance of a building in each of the nine quantitative parameters on a scale from 1 to 4, where 1 is the highest level and 4 is the lowest.





The scope of WELL extends beyond the building itself. The standard rewards employers for providing paid parental leave and on-site child care centres for their staff. In addition, a dedicated 'altruism' optimisation encourages companies to grant their staff paid time off work in order to participate in volunteer activities.

# WELL BUILDING STANDARD

Initiated by	International WELL Building Institute (IWBI) and Delos Living LLC
Year	2014
Website	www.wellcertified.com
Main categories	Air, Water, Nourishment, Light, Fitness, Comfort, Mind, Innovation



## Background and goals

WELL is the first standard of its kind that focuses solely on the health and wellness of building occupants. The scope of WELL extends significantly beyond the building fabric as such.

## Application

New and Existing Buildings, New and Existing Interiors, and Core and Shell. Pilot programmes are available for other building types such as multifamily residences, retail, and restaurants.

WELL is also designed to work harmoniously with other, more comprehensive green building rating systems such as LEED, BREEAM, and the Living Building Challenge. The initiators of the standard "encourage projects to pursue both WELL and standards that address environmental sustainability".

## Structure

The WELL Building Standard is organised into seven categories of wellness called Concepts: Air, Water, Nourishment, Light, Fitness, Comfort and Mind. These are comprised of a total of 105 features.

Some WELL features are categorised as preconditions that must be fulfilled for all levels of WELL certification. So-called optimisations, in contrast, are not mandatory for basic (Silver level) certification but create a flexible pathway towards higher levels of certification.

WELL is largely performance based; in most cases, specific, measurable 'markers' (thresholds) must be met. In other cases, particular strategies are required, as strong evidence suggests there are benefits to implementation.

## Design approach

### Indoor air quality and ventilation

With 29 single features, this is by far the most comprehensive of the seven concepts in WELL. The standard sets limits for formaldehyde and VOC emissions, as well as particulate matter and radon emissions in the indoor air. VOC emissions are also tackled at source by specifying low-VOC interior paints and coatings, sealants, floorings and furniture. Operable windows or a demand controlled ventilation system have to be installed to keep CO<sub>2</sub> levels permanently below 800 ppm. A voluntary optimisation feature requires that the ventilation system be capable of maintaining relative humidity between 30% and 50% at all times by adding moisture to or removing it from the air.

### Daylight

Alongside requirements for visual task lighting (min. 300 lux at the work plane) and glare control, WELL also comprises a dedicated feature that deals with circadian lighting design. The metric used here is 'equivalent melanopic lux' – which corresponds to the vertical illumination at eye level multiplied by a weighting factor that depends on the spectral composition of the light source. According to WELL, "this light level [of 200 melanopic lux] may incorporate daylight, and is present for at least the hours between 9:00 AM and 1:00 PM for every day of the year." Three more optimisation features (Right to Light, Daylight Modelling and Daylighting Fenestration) also make direct reference to daylight. Among other things, they limit the distance from regularly occupied spaces to windows and set minimum requirements for the spatial daylight autonomy, as well as the window-to-wall ratio.

## Mental health

WELL recommends a number of measures aimed to improve users' mental health and well-being. These include designated quiet spaces and facilities for short naps in office buildings. Furthermore, design teams are encouraged to integrate design features and artwork that stimulate human delight and celebrate culture, spirit and place.

## Building operation and evaluation

In order to achieve WELL certification, the building must undergo a process that includes an on-site assessment and performance testing by a third party.

Smoking is banned from all WELL-certified buildings and the use of pesticides has to be eliminated in the outdoor areas. Owners are required to set up a cleaning plan for all occupied spaces. A voluntary optimisation feature recommends that the building is 'flushed' with large volumes of fresh air after completion and prior to occupancy. Additional points can be gained by monitoring particulate matter, CO<sub>2</sub> and ozone levels in the indoor air, and by displaying temperature, humidity and CO<sub>2</sub> to building users in real time.

The Mind category also comprises measures that can be applied to increase users' satisfaction and health. Post-occupancy surveys have to be conducted annually with at least 30% of the users. Furthermore, employers are encouraged to subsidise wearable health sensors (e.g. for activity and heart rate, as well as sleep duration and quality) for the use of their employees. WELL also rewards companies for limiting late-night work, night-time business flights and the overall travel time on business trips.



Initiated by	AktivPlus e. V.
Year	2014
Website	www.aktivplusev.de
Main categories	Energy, Users, Networks, Life cycle

## Background and goals

AktivPlus has been conceived as a simple planning principle for the four areas of energy, users, networks and life cycles in the built environment. Design, construction and operation of buildings are all considered. According to AktivPlus e. V., AktivPlus buildings offer “all the prerequisites for a high level of comfort and interaction with users while focusing on their requirements and needs. The buildings are further optimised after the design stage in a way that provides constant feedback to users.”

## Application

Residential, office and educational buildings. An extension to additional uses such as commercial and industrial buildings is intended in the future.

## Structure

The catalogue of requirements is divided into four categories with a total of 14 criteria, six of which are quantitative and eight qualitative. Quantitative criteria must not only be fulfilled in planning, but also after the 1st and 2nd year of operation. Some of the criteria – such as CO<sub>2</sub> emissions per capita – are not currently considered in any other standard in this form. The achievement of the ActivePlus objectives is presented in a segmented ‘ActivePlus Flower’ diagram.

## Design approach

### Indoor air quality and ventilation

AktivPlus requires a ventilation concept that provides sufficient air exchange for every room in the building. This can be done mechanically or through facade openings and the fresh air supply should be individually adjustable by the user.

In addition, AktivPlus recommends creating a concept for low-pollutant construction and using construction materials that have been tested for harmful substances (e. g. according to the AgBB test scheme). AVOC measurement should be carried out in a building ready for occupancy with floor coverings but without furniture.

### Daylight

Adequate daylight supply must be ensured in AktivPlus buildings. A daylight simulation is recommended for all rooms that have been designed for permanent occupancy. The number of windows and skylights should be selected in such a way that an average daylight factor of at least 2% is achieved in these rooms. Natural lighting is also recommended in bathrooms and, in particular, kitchens. According to AktivPlus, residents must be able to adapt the amount of daylight to their individual needs.

### Architectural quality

Optionally, AktivPlus buildings can be submitted to a design advisory board for evaluation. This jury meets once a year and evaluates, among other things, the urban integration, organisation of floor plans, facade design and material concept as well as the longevity and ease of maintenance of the building. Other aspects include the flexibility and adaptability of the spaces, as well as qualitative aspects of the daylighting concept and the views outdoors.

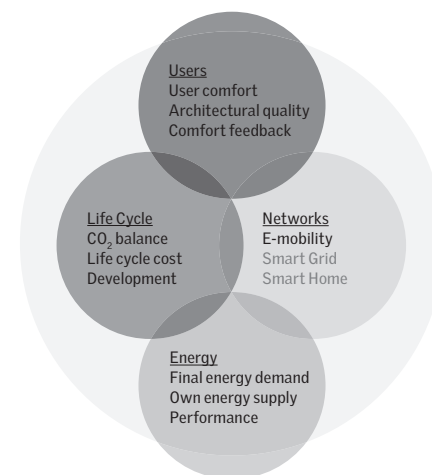
### Building operation and evaluation

A special feature of AktivPlus is that a two-year monitoring programme is carried out in all 14 categories. This applies

not only to the energy performance of the building but also to indoor air quality, indoor temperatures and occupants’ satisfaction, which is recorded via regular user surveys.

In order to ensure good indoor air quality even during operation, AktivPlus recommends automatic ventilation control via CO<sub>2</sub> sensors or (in the case of manual ventilation) simple CO<sub>2</sub> displays to indicate the air quality in the room.

The AktivPlus evaluation scheme consists of four main categories, or focus areas, with a total of 12 criteria. A further 2 criteria are currently under development.



In contrast to almost all other rating systems, the energy requirements and CO<sub>2</sub> emissions of AktivPlus buildings are calculated not only per square metre but also per person. In this way, users should be able to assess the properties of the building in relation to a metric that they can understand. Furthermore, besides a focus on efficiency and the use of renewable resources, AktivPlus also recognises strategies of sufficiency and economical use of spaces with this strategy.





# HEALTHY BUILDINGS IN PRACTICE

The proof of the pudding is in the eating, as an old English proverb says. In other words: even the best design concepts are just as good as they turn out to be in practice, confronted with real users in the day-to-day operation of buildings. This realization is key to the projects on the following pages. All of them were designed to achieve optimal indoor comfort, and their performance has undergone a thorough reality check after completion. The results provide valuable insight into the hidden links between building design and operation and human health and well-being.

By Jakob Schoof

No	Project	Country	Location	Market	Typology	Evaluation methods described in this issue	Additional evaluation methods
01	Green Solution House	Denmark	Rønne	Conference	Hotel + conference	DGNB, Active House	Cradle to Cradle, project-specific monitoring (SenseMaking)
02	Derwenthorpe	United Kingdom	York	Residential	Homes / Community	-	Lifetime Homes, Innovate UK Building Performance Evaluation, post-occupancy evaluation
03	Centennial Park	Canada	Toronto	Residential	One family house	Active House	project-specific monitoring
04	Siemens Headquarters	Denmark	Ballerup	Office	Office	LEED	project-specific monitoring
05	Wilkinson Primary School	United Kingdom	Wolverhampton	Education	School	-	Passive House, Soft Landings
06	Aktiv-Stadthaus	Germany	Frankfurt	Residential	Rental multifamily house)	AktivPlus	Effizienzhaus Plus, post-occupancy evaluation
07	2226	Austria	Lustenau	Office	Office	-	project-specific monitoring
08	ASID Headquarters	USA	Washington	Office	Office floor in an existing building	LEED, WELL	3C Design, CAPTIW
09	Omega Center for Sustainable Living	USA	Rhinebeck	Education	Seminar center + water purification plant	LEED, Living Building Challenge	
10	De Poorters van Montfoort	Netherlands	Montfoort	Residential	Row house renovation (social housing)	Active House	project-specific monitoring
11	Effizienzhaus Plus refurbishment	Germany	Neu-Ulm	Residential	Renovation of small multifamily houses	AktivPlus	Effizienzhaus Plus
12	Living Planet Centre	United Kingdom	Woking	Office	Office + exhibition	BREEAM	project-specific monitoring
13	Swiss Living Challenge /NeighborHub	USA Switzerland	Denver Fribourg	Living Lab	Residential + community space	-	Solar Decathlon Rules + project-specific monitoring concept
14	VELUXlab	Italy	Milan	Research	Laboratory	Active House	project-specific monitoring
15	Sunde Boliger	Denmark	Holstebro	Residential	Courtyard homes	-	Indeklimahjulet





# 01 GREEN SOLUTION HOUSE

Place	Rønne, DK
Year	2015
Client	Green Solution House
Architects	3XN, Steenbergs Tegnestue
Consultants and engineers	GXN, SLA, Ramboll, Leapcraft, VELUX
Evaluation methods	DGNB, Active House, Cradle to Cradle, SenseMaking
Duration of monitoring	Ongoing

## Design approach

The former Hotel Ryttergården from 1973 has been renovated and supplemented with a daylight congress centre that directly adjoins the newly landscaped grounds at the back of the building. Three sustainability concepts inspired the building design: the DGNB system, the cradle-to-cradle principle aimed at a circular flow economy, and the Active House specifications, with a focus on healthy indoor climate and daylight supply.

While the new foyer has a modular glass roof with integrated PV cells, sun tunnels and flat roof windows also bring light deep into the building elsewhere. Daylight factors

of 6.6% in the conference centre and 30% in some of the hotel rooms are achieved. In order to ensure a good indoor air quality, the building is fitted with various new kinds of air-cleaning products such as dust-absorbing carpets, wall panels that neutralise formaldehyde, and a 'green' wall that cleans the air. Two of the hotel rooms were fitted out as 'smart rooms' in which a custom-designed app tracks the impact of the guest's stay, monitoring water and energy consumption, daylight levels and air quality, as well as temperature and humidity levels.

## Further information

[www.greensolutionhouse.dk](http://www.greensolutionhouse.dk)  
[www.activehouse.info/cases/green-solution-house/](http://www.activehouse.info/cases/green-solution-house/)  
[gsh.leapcraft.dk](http://gsh.leapcraft.dk)



PHOTOGRAPHY: STAMERSKONTOR, LAURASTAMER

A formal post-occupancy evaluation is not being carried out at Green Solution House but according to hotel director Trine Richter, conference guests regularly report that, thanks to the pleasant indoor climate and plenty of daylight, they feel fresh even after a long day with numerous slideshows. "This means that the return on investment on a conference is a lot higher here," says Richter.

## Results

In the Active House evaluation, the Green Solution House scored the highest level in terms of thermal environment, indoor air quality and sustainable construction, and level 2 out of 4 in terms of daylight.

Since September 2017, the foyer and conference spaces have also been equipped with sensors for a live monitoring of comfort parameters such as CO<sub>2</sub>, temperature and humidity. Results are available in real time at [gsh.leapcraft.dk](http://gsh.leapcraft.dk). For an easily comprehensible evaluation of the indoor climate, Leapcraft has developed the Comfort Economy Wheel. This graphic displays the measurements of eight parameters (from daylight levels to VOCs) from the past seven days, and compares them to the calculated results from the design phase on a scale derived from the Active House specification. The

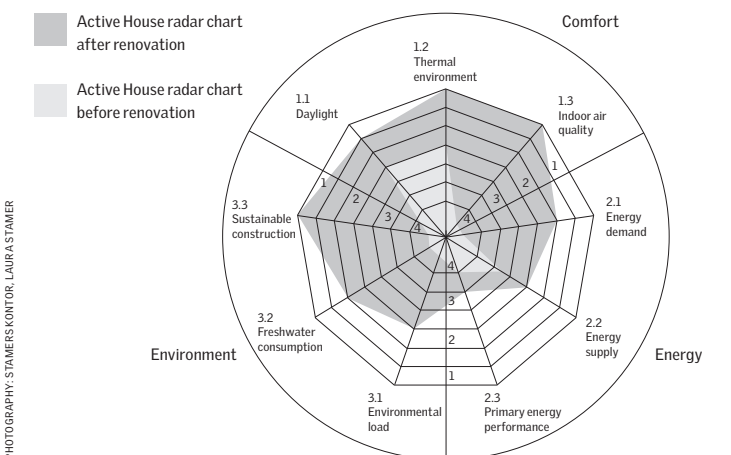
centre of the wheel indicates an overall evaluation of how well the building is doing, from Poor (Level 4) to Good (Level 1)

During the first four months of the monitoring, CO<sub>2</sub> levels in the conference area were almost always less than 500 ppm above outdoor levels. Only in some instances with higher occupancy were levels closer to 1,000 ppm reached. Indoor temperatures remained within the 22–26°C bracket during the entire period.

In the foyer, the measured air quality was even better, which may be due to the natural influx of fresh air through the opening and closing entrance doors. Temperature fluctuations tended to be larger in this area, though, with indoor temperatures dropping below 18 °C occasionally in winter.

"I like the Active House approach to sustainability. Compared to other certification schemes, Active House emphasises comfort much more coherently. This made it easier to think about how people were actually going to experience the building."

Trine Richter, hotel director





## 02 DERWENTHORPE

Derwenthorpe was designed in such a way as to foster social cohesion between different types of tenure, with a mix of private homes and houses for social rent. According to the post-occupancy evaluation report, this strategy had mixed success. "Early interviewees were generally positive, but later ones pointed to an emerging sense of difference between tenure types. There were disproportionately more contacts among home owners than between owners and social renters, although links existed across all tenures."

"This is a truly sustainable approach from inception to completion, and can only be described as exemplary and what all housing developments should aspire to"

RIBA Judging Panel,  
Derwenthorpe Phase One, RIBA National Award winner 2017

Place	York, UK
Year	2012– (ongoing)
Client	Joseph Rowntree Housing Trust
Architects	Studio Partington
Consultants	DSP Architects, MDA Consulting, Alan Wood and Partners, Arup, FIRA, Leeds Beckett University, York University Centre for Housing Policy, UCL
Evaluation methods	Lifetime Homes, Standards and quality in development, Innovate UK Building Performance Evaluation, project-specific post-occupancy evaluation
Duration of monitoring	Three years

### Design approach

Due for completion in 2018, Derwenthorpe is a mixed-tenure sustainable community of 540 energy-efficient homes on the eastern periphery of York. The two- to four-bedroom (90 m<sup>2</sup> to 120 m<sup>2</sup>) homes have flexible rooms, designed in accordance with the Lifetime Homes Standard. Dual-aspect main living rooms and 2.60- to 2.70 m-high ceilings bring natural light deep into the houses and allow cross ventilation throughout the year. The larger facade windows generally face south and many houses have sunspaces to maximise useful solar gain. These act as a thermal buffer throughout the year, collecting solar energy in the winter and helping to cool the houses in summer, and make use of the stack effect for ventilation.

### Results

The first phase of Derwenthorpe (built 2012–2013) has been thoroughly evaluated, both in terms of energy performance and user satisfaction. It turned out that the design of the homes, particularly daylight and space standards, as well as the location were the main factors that drew new residents to the community. Derwenthorpe's green credentials were usually only a subsidiary factor or added bonus.

Nine out of ten residents were satisfied with their homes. The post-occupancy evaluation also revealed that residents' level of connectedness within the community was very high. As a result of the energy efficiency standard of the homes, residents had lower than average carbon foot

prints from energy use in their homes compared with national survey respondents. However, it turned out that residents often did not know how to operate the energy-efficiency measures such as the sunspaces, MVHR systems or the communal heating systems properly. It was also difficult to change travel patterns, despite efforts to support more sustainable options e. g. with bicycle vouchers, an electric bus to the city centre and an on-site car club. Few households had substantially reduced their car use after moving to Derwenthorpe.

### Further information

[www.studiopartington.co.uk/projects/derwenthorpe](http://www.studiopartington.co.uk/projects/derwenthorpe)  
[bit.ly/derwenthorpe](https://bit.ly/derwenthorpe)  
Richard Partington, Simon Bradbury: Better Buildings. Leaning from Buildings in Use. RIBA Publishing, 2017



PHOTOGRAPHY: TIM CROCKER



PHOTOGRAPHY: TIM CROCKER







# 03 ACTIVE HOUSE CENTENNIAL PARK

According to Russell Ibbotson, living in Active House Centennial Park enabled him to connect physical measurements and subjective well-being for the first time. "It wasn't until I was able to measure the quality of the air in the house and correlate this with how I felt that I realised how much I was personally affected by indoor air quality. I now appreciate how poor air quality makes me unfocused and even drowsy. I also noticed that I wake more frequently when the air quality is poor ..."

Place	West Toronto, CA
Year	2016
Client	Great Gulf Homes
Architects	superkül
Consultants and engineers	Quail Engineering, VELUX Building Science Team
Evaluation methods	Active House + project-specific monitoring concept
Duration of monitoring	Six months

### Design approach

This private home in the suburban West End of Toronto is the world's first certified Active House. Its C-shaped floor plan is arranged around a central courtyard that brings daylight into the central stair and core area. When the windows are open, the home's overall design supports cross- and stack ventilation, thereby minimising the need for air conditioning. The ground floor living room,

dining area and kitchen are laid out in an open plan, with no barriers to obstruct daylight other than a see-through fireplace system dividing the dining and living areas. Double-height spaces (e. g. in the living room) vertically connect the two levels of the house. Ten roof windows and four sun tunnels bring natural light even into the secondary rooms of the upper floor.

### Evaluation concept

After completion of the building, Russell Ibbotson, Technical Manager at VELUX Canada, moved into the house together with his family for half a year and reported his personal experience in a blog. Alongside this, a

third-party research group equipped the house with sensors to take quantitative measurements of daylight, energy and the indoor climate.

### Results

In the Active House evaluation, the house scores particularly high on indoor air quality, the thermal environment, energy supply and freshwater consumption. The average daylight factor has been calculated at 3.4 % using the VELUX Daylight Visualizer software. In the living room and in the upstairs bedrooms, daylight factors above 4% are achieved.

During the half-year stay of the test family in late 2016, Active House Centennial Park provided excellent thermal comfort, particularly in the cold season. With one minor exception, the house also performed amazingly well in summer, as Russell Ibbotson reports – "Most of the house was very comfortable, even on those super-hot 30°C+ days that Toronto had so many of this year. The only space of concern was the family room on hot sunny afternoons."

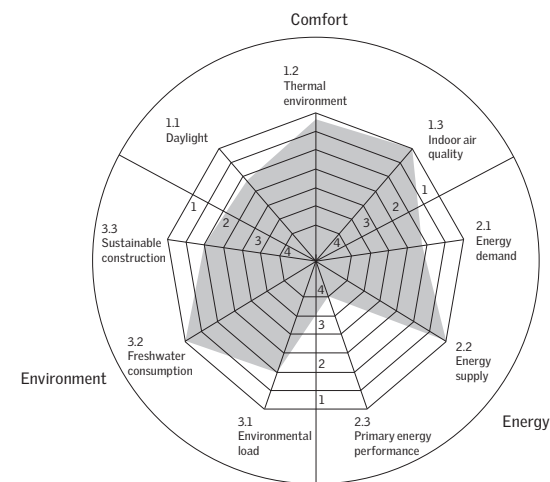
According to Ibbotson, external blinds in front of the southwest facing window could have solved this issue „but most North Americans wouldn't accept the aesthetic".

Indoor air quality also proved to be good throughout the monitoring period. Only in a bedroom with two children sleeping in it did CO<sub>2</sub> levels regularly climb over 1,000 ppm. The spells of intense heat in summer also proved to be a challenge. The energy recovery ventilation tended to drive humidity levels in the house up, and the air conditioning lead to high CO<sub>2</sub> levels after a day of uninterrupted operation without any ventilation. "In the end, it was easier to manage the air quality and humidity by opening the windows for 10–15 minutes on the hot and humid days for a good old European airing," writes Russell Ibbotson in his blog.

### Further information

[www.greatgulf.com/activehouse/](http://www.greatgulf.com/activehouse/)  
[www.activehouse.info/cases/active-house-centennial-park/](http://www.activehouse.info/cases/active-house-centennial-park/)

### Active House evaluation results











## 04 SIEMENS HEADQUARTERS

Place	Ballerup, DK
Year	2013
Client	PenSamLiv & Pension
Architects	Arkitema
Consultants and engineers	KPC København, MidtConsult, VELUX
Evaluation methods	LEED + project-specific monitoring concept
Duration of monitoring	Ongoing

### Design approach

The new Siemens Denmark headquarters replaces the former office building of the technology company, located on the same site in a suburban industrial area west of Copenhagen. 900 employees work inside the abstract, five-storey cube, which is clad with white and dark grey concrete panels on the outside. Inside the building, the reception, canteen, showrooms and seminar rooms are located on the ground floor, while offices occupy the majority of

the upper floors. A central, full-height atrium supplies the interior with daylight through six glazed ridgelights, each measuring 17 metres in length, which comprise a total of 228 fixed modular skylights. Shading in the central space is provided by awnings that are automatically controlled by sensors depending on seven different parameters, including the position of the sun and the lux levels in the atrium.

### Evaluation concept

The Siemens headquarters was one of the first buildings in Denmark to achieve LEED Gold certification. The building has been equipped with temperature-, CO<sub>2</sub>-, electricity- and other sensors from the beginning. This allows the facility management team

to monitor the energy consumption in the building, as well as the indoor comfort in any room they choose to, in order to be able to adjust the systems accordingly.



PHOTOGRAPHY: STAMERSKONTOR, LAURASTAMER

“The value of a building depends on the quality of the technology and the solutions that are used to manage the building. Light, ventilation, safety etc. must play together in accordance with the purpose of the building – whether it is used for learning, development, treatment or growth. Data plays a vital role in that interplay. And there’s no doubt in my mind that it will come to play an even bigger role.”

Jesper Skov, CEO, Siemens Building Technologies

### Results

So far, the selective monitoring has allowed the technicians to understand the thermal behaviour of different spaces much better and to fine-tune the cooling and ventilation systems. The diagrams below are an example: they show the CO<sub>2</sub> levels and indoor temperature in a meeting room for 30

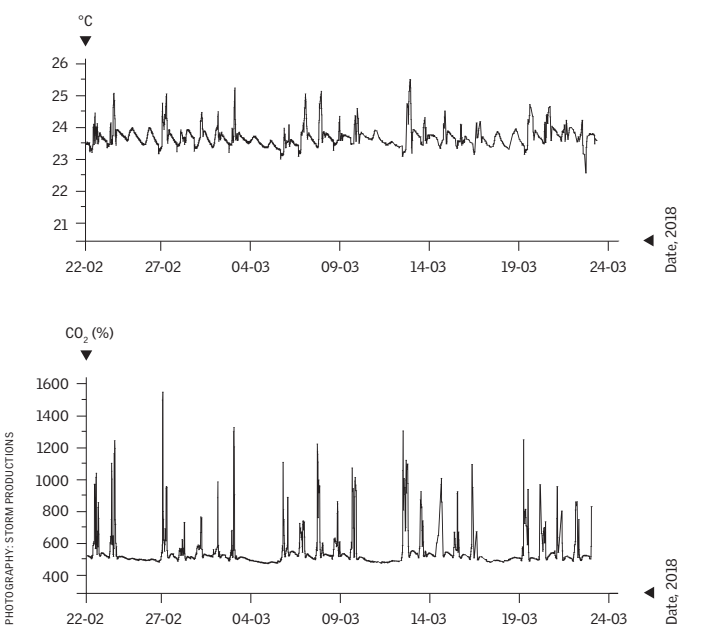
days in March 2018. Both curves rise rapidly once the room is occupied, but only to the point where the ventilation system (which is controlled by sensors) automatically reacts by increasing the volume, as well as lowering the temperature, of the incoming fresh air.

### Further information

[bit.ly/siemens\\_ballerup](http://bit.ly/siemens_ballerup)  
[www.arkitema.com/da/arkitektur/erhverv/siemens-hq](http://www.arkitema.com/da/arkitektur/erhverv/siemens-hq)

The LEED certification also includes an evaluation of the volume of daylight in the building, which can be difficult to predict at the planning stage. To help document the effect, the VELUX Group has developed a number of building simulation tools, which can be used to simulate the impact of the modular skylights.

### Temperature and CO<sub>2</sub> measurements in a conference room in March 2018







## 05 WILKINSON PRIMARY SCHOOL

Place	Wolverhampton, UK
Year	2014
Client	Wolverhampton City Council
Architects	Architype
Consultants and engineers	Price & Myers, E3 Consulting Engineers, Coe Design, Thomas Vale Construction, The Local Education Partnership, Smith Thomas Consulting, Elemental Solutions, WARM
Evaluation methods	Passivhaus, Soft Landings
Duration of monitoring	One year

### Design approach

This primary school for 430 pupils, which also includes a 30-place nursery, is located on a former ironworks site that dates back to the time of the Industrial Revolution. The new building replaces a former school that had been badly damaged in an arson attack. Its section rises to the south, providing two floors of classrooms with south-facing windows. Clerestory windows on both sides provide natural light to the double-height hub space in the building centre. The south facade features extensive roof overhangs and projecting canopies that shade the windows from the summer

sun but reflect low sun deep into the building in winter. The ventilation is based on a centralised MVHR system that operates throughout the year to assure a supply of fresh air to the occupied spaces at all times. In summer mode, the heat exchanger of the MVHR system is bypassed. Additionally, the classrooms have a number of low level windows that enable the occupants to experience air flow from the outside. In summer nights, ventilation flaps in the facades and high level vents in the central hub space can be opened to help cool down the building for the next day.

With a timber frame construction, wood wool ceilings and carpet tiles made of recycled rubber tires, Architype also sought to minimise the embodied carbon content of the building. The Corten steel cladding is a nod to the industrial heritage of the site.

### Results

Building monitoring was undertaken by Architype in collaboration with Coventry University, and the building was fine-tuned in a Soft Landings process that also involved post-occupancy evaluation. The temperatures in the classrooms turned out to be very stable. During a typical week in summer, peak temperatures in a test classroom remained around 3°C lower than in a conventional school from the 1970s, and around 2°C lower than those in previous schools designed by Architype. The architects attribute this to a slight reduction and more balanced distribution of glazing in the facades, and to the night time purge ventilation in the new school.

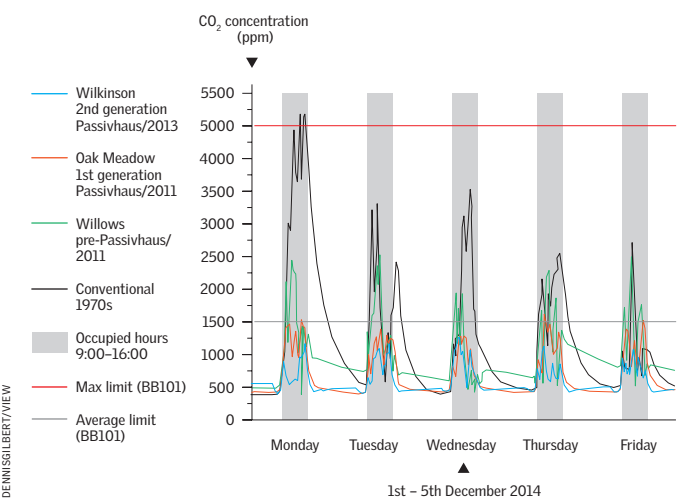
Air quality also turned out to be much better than in the previous

schools, where the architects had still relied entirely on manual ventilation in summer – but experience showed that the teachers were not opening the windows frequently enough. With the continuous mechanical ventilation in place, CO<sub>2</sub> levels in the test classroom remained below 1,000 ppm most of the time during a typical winter week, and well below the 1,000 ppm threshold in summer.

The measured energy consumption matched the design stage predictions much more closely than in average buildings. Primary energy use in the first year was at 143 kWh/m<sup>2</sup>a, compared to a calculated figure of 120 kWh/m<sup>2</sup>a.

### Further information

[www.architype.co.uk/project/wilkinson-primary-school/](http://www.architype.co.uk/project/wilkinson-primary-school/)  
[bit.ly/wilkinson1](https://bit.ly/wilkinson1)  
[bit.ly/wilkinson2](https://bit.ly/wilkinson2)  
 Richard Partington, Simon Bradbury: Better Buildings. Leaning from Buildings in Use. RIBA Publishing, 2017









The building draws an unusual heat source for its heating: The in-house heat pump is connected to a nearby urban sewer in which a 55-metre long heat exchanger has been installed. The sewage water has a temperature between 15 and 20°C all year round. In this way, the Aktiv-Stadthaus uses an efficient energy resource that is still completely ignored in most cities around the world.

Place	Frankfurt, DE
Year	2015
Client	ABG Frankfurt Holding
Architects	HHS Planer + Architekten
Consultants and engineers	EGS-plan, B + G Ingenieure Bollinger und Grohmann, schneider + schumacher, Steinbeis-Transferzentrum, Technical University of Darmstadt, Berliner Institut für Sozialforschung
Evaluation methods	Effizienzhaus Plus, AktivPlus
Duration of monitoring	Two years

**Design approach**

This new build with 74 apartments is the first multi-storey apartment building in Germany to meet the Efficiency House Plus standard. Over the course of the year, it is expected to generate more energy on its own property than its residents consume. The shape of the building results from the dimensions of the property: 150 metres long, but only nine metres deep and flanked by a busy inner-city street in the south. Due to these boundary conditions, all apartments have an extremely strong relation to the outside world.

In order to achieve a positive energy balance during operation, buildings and users must work together

optimally. Each tenant has a specific energy budget, which is included in the rental price. Only when the residents consume more do they have to pay extra. On touch panels in each apartment, residents can read their energy consumption in real time and compare it to the available budget, the energy production of the photovoltaic system and an anonymous energy efficiency ranking of all apartments. On request, the system can also provide them with situational energy saving tips. The residents can also control the heating, ventilation system and sun protection via the touch panel.

**Further information**

[bit.ly/aktiv\\_stadthaus](http://bit.ly/aktiv_stadthaus)  
[bit.ly/aktiv\\_stadthaus2](http://bit.ly/aktiv_stadthaus2)  
[bit.ly/aktiv\\_stadthaus3](http://bit.ly/aktiv_stadthaus3)

**Results**

For two years, technical monitoring and several user surveys with questionnaires were carried out in the Aktiv-Stadthaus. It turned out that some of the residents preferred much higher room temperatures in winter than expected. The demand for hot water in the summer, on the other hand, was significantly lower than forecast. All in all, the Aktiv-Stadthaus achieved the targeted plus energy standard after its first year of operation by a slim margin.

In the survey, more than 60% of all respondents said that their homes were warm enough in the autumn, even without heating. Only a good one-fifth complained that the apartments quickly heated up in summer. However, the majority of residents described underfloor heating as sluggish and wanted a higher surface temperature. Satisfaction with

mechanical ventilation decreased over time: after the first summer, only 43% of respondents said that the system always ensured good air quality. Most residents therefore also rely on window ventilation.

The overwhelming majority of residents in the Aktiv-Stadthaus find it important to know their own energy consumption – with a slightly decreasing tendency, which indicates a certain habituation effect. While, initially, more than half of the residents used the interface at least once a day, most of them have now settled on a weekly use. The most interesting question for them is how their own electricity and heat consumption compares to the energy budget and how they score on the internal energy efficiency ranking list.



PHOTOGRAPHY: KONSTANTIN MEYER



PHOTOGRAPHY: KONSTANTIN MEYER







"History teaches us that buildings have to be robust. Robust refers to the materiality of the building and its simplicity but also to the architectural qualities of the building; arrangement and dimension of the rooms, daylight — the ability to provide comfort and well-being. This type of robustness guarantees a long life for the building instead of assigning the users a kind of compulsory happiness."

Dietmar Eberle in: be 2226 Die Temperatur der Architektur / The Temperature of Architecture

Place	Lustenau, AT
Year	2013
Client	AD Vermietung OG
Architects	Baumschlager Eberle Architects, Lustenau
Consultants and engineers	Mader & Flatz, Lars Junghans, Elmar Graf GmbH, Peter Stefan Widerin
Evaluation methods	Project-specific monitoring concept
Duration of monitoring	Ongoing

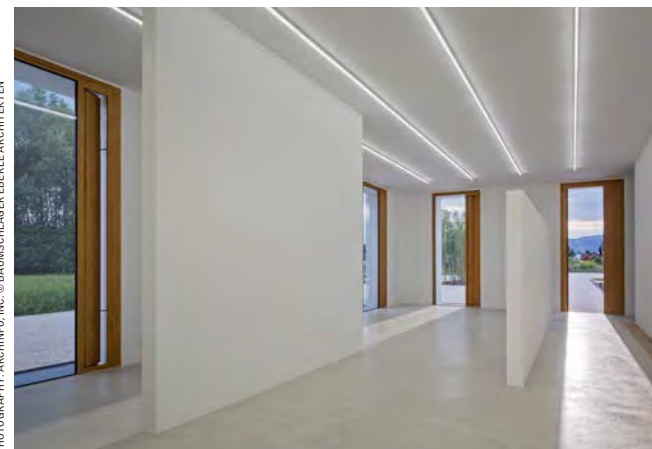
**Design approach**

The architect's office Baumschlager Eberle has designed a house with no heating, cooling or mechanical ventilation system as their new headquarters. The six-storey, white plastered cube stands in a suburban industrial area and houses an art gallery, a restaurant, a dwelling unit and several office floors. Its square floor plans are divided by inner walls, staircase and elevator cores in such a way that each room receives daylight and fresh air from two sides. The clear room height of 3.36 metres in the offices also contributes to good ventilation.

Automatically controlled ventilation flaps next to the windows ensure fresh air supply and summer cooling. The only heat source is the people present and their electrical appliances, such as computers, photocopiers and coffee machines. If necessary, users can open the ventilation flaps manually at any time. After a few minutes, they close automatically so that the space does not heat up or cool down unnecessarily. In this way, indoor temperatures of between 22 and 26°C are expected to prevail in the building all year round; hence the name of the project – 2226.

**Further information**

[www.baumschlager-eberle.com/werk/projekte/projekt/2226/](http://www.baumschlager-eberle.com/werk/projekte/projekt/2226/)  
Dietmar Eberle, Florian Aicher: be 2226 Die Temperatur der Architektur / The Temperature of Architecture. Birkhäuser, 2016



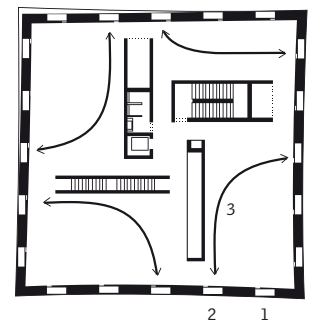
**Results**

Sensors distributed throughout the house measure energy consumption, indoor temperature, humidity and CO<sub>2</sub> content of the indoor air every 10 minutes. In addition, experts determined the microbiological quality of indoor air during the first year of operation. The result: all measured values were within the optimum comfort range (IDA 1 = high indoor air quality) in accordance with EN 13779, and the temperatures in the house were always between 22° and 26°C in the first year – even during an intensive, three-week period

of high temperatures shortly after moving in. The CO<sub>2</sub> content of the air only rose to a maximum of 1,200 ppm as the ventilation flaps open automatically beyond this limit value. Compared to conventional office buildings with ventilation systems, the number of germs in the room air in house 2226 was two to three times lower than in conventional office buildings. In theory, this would mean that the indoor air quality in 2226 would even meet the demanding requirements for food processing.

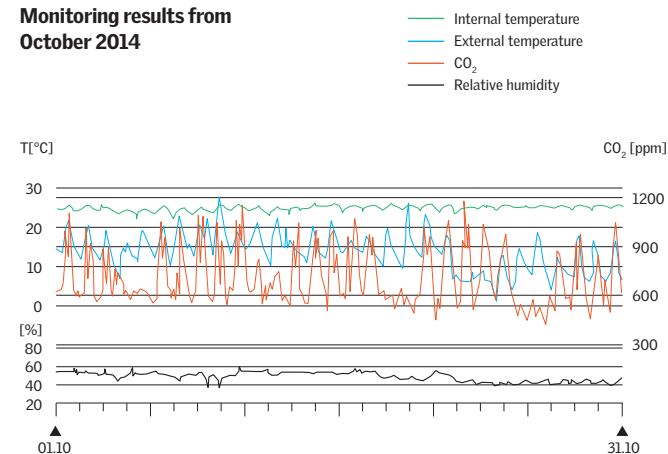
**Typical floor plan with ventilation scheme**

- 1 Manual casement windows
- 2 Automatic casement windows
- 3 Cross ventilation



CONCEPT: DIETMAR EBERLE; DRAWING: JÜRGEN STOPPEL

**Monitoring results from October 2014**



How do you encourage your employees to move during a long office day? In ASID's new head office, common areas are centralised so that people have to walk only a few steps to get there. Furthermore, the café and copy room also happen to be the only two areas with trash bins so that the employees have to walk there in order to dispose of their waste.

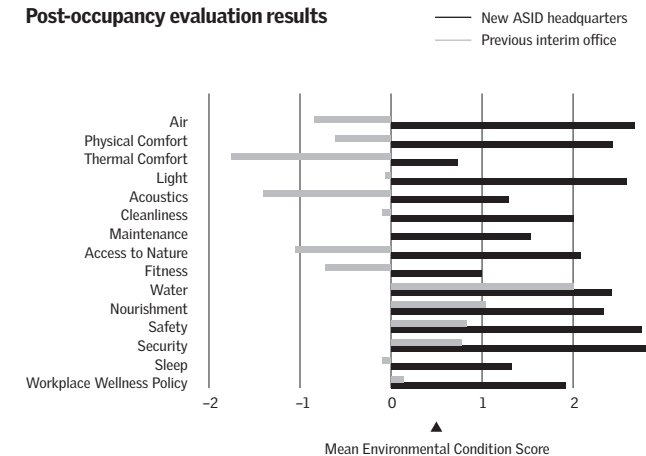
Place	Washington D.C., US
Year	2016
Client	American Society of Interior Designers (ASID)
Architects	Perkins + Will
Consultants and engineers	Savills Studley, GHT Limited, Cerami, Benya Burnett, Terrapin Bright Green, Bios, Innovative Workplace Institute, Cornell University, Delos Living
Evaluation methods	LEED, WELL, 3C Design + CAPTIW
Duration of monitoring	One year

**Design approach**

Located in central Washington D.C., the new headquarters of the American Society of Interior Designers (ASID) occupies the northwest corner of a multi-tenant floor in a pre-existing office building. The 700 m<sup>2</sup> office space has been conceived as a 'free address' environment without assigned seating. Employees can select from a variety of workspaces, depending on what best supports their specific tasks that day. All workspaces have access to daylight and views outdoors. This is complemented by a circadian lighting system that mimics the daily colour cycle of natural daylight and provides a minimum of 250 melanopic lux for all work spaces with the help of colour-changing lamps. Daylight responsive controls ensure that the electric

light is dimmed down depending on the daylight levels outside. Solar sensors mounted on the facade automatically track the position and intensity of the sun to adjust the automated shades accordingly. As the facade has no operable windows, the design team took great care to ensure a good indoor air quality. All highly occupied office spaces were equipped with demand-controlled ventilation that keeps CO<sub>2</sub> levels below 800 ppm all of the time. Carbon filters in the air, handling units of the building, provide enhanced filtration of VOCs and large particulates. The majority of the materials and furniture used in the office have either Health Product Declarations, DECLARE, or Cradle to Cradle certification.

**Post-occupancy evaluation results**



**Evaluation concept**

The ASID headquarters is the first space in the world to receive Platinum-level certification both in the LEED and WELL standards. Both before and after moving in, the client undertook four interdisciplinary research projects to evaluate how the

new spaces would affect the employees' health and performance, their mutual interaction and a number of other factors.

**Results**

The indoor climate, employees' satisfaction and work performance were all monitored in the new office space and then compared to the values achieved in ASID's previous, interim office in a co-working space. This comparison yielded a 50% reduction in loudness, a 63% increase in brightness and a 60% reduction in indoor CO<sub>2</sub> levels. In a post-occupancy evaluation, employees said that they were significantly happier with 14 out of 15 parameters

(including air quality, thermal comfort, and light) than in the previous spaces. It was also found that people in the new office now work, on average, 19% longer hours than before. This may be due partly to their greater motivation but also to less sickness-related absence. Self-reported productivity has increased by 16% in the new offices.

**Further information**

[www.asid.org/impact-of-design/asid](http://www.asid.org/impact-of-design/asid)  
[www.perkinswill.com/work/american-society-interior-designers-headquarters](http://www.perkinswill.com/work/american-society-interior-designers-headquarters)





# 09 OMEGA CENTER FOR SUSTAINABLE LIVING

The specification of healthy, local and recycled materials played a major role in the design of the Omega Center. This also involved unconventional solutions; for example, the project team had to make their own pipe insulation because they could not find any free of toxins. Re-used materials employed in the construction include doors from an office building, bathroom partitions salvaged from a church, and even plywood from former President Barack Obama's inaugural stage.

Place	Rhinebeck, New York, US
Year	2009
Client	Omega Institute for Holistic Studies
Architects	BNIM
Consultants and engineers	BGR Consulting Engineers, Chazen Companies, Conservation Design Forum, Tipping Mar + Associates, John Todd Ecological Design, Natural Systems International
Evaluation methods	LEED + Living Building Challenge
Duration of monitoring	One year

### Design approach

The Omega Center for Sustainable Living combines an environmental education facility and natural water reclamation plant on the client's 80-hectare campus in upstate New York. Wastewater from the campus is cleaned here by the earth, plants and sunlight in a 600-m<sup>2</sup> greenhouse, and courses on environmental subjects are taught in an indoor and outdoor classroom. In order to create an indoor environment that is both comfortable for people and fertile for the plants, the building incorporates both passive (daylight, passive solar heating, natural ventilation) and mechanical (geothermal, fans, electric lighting) systems. With the main facades pointing north and south, the building's orientation allows optimal control of

daylight and solar heat gain. Solar tracking skylights were installed in the greenhouse to accurately optimise daylight levels. Manually operable windows are provided in each occupied space, and the plants in the wastewater treatment system remove CO<sub>2</sub> from the air while producing oxygen. High-level clerestory windows ventilate the lobby, mechanical room and restrooms using the stack effect. Fresh air enters through windows in the south facade, channelling prevailing breezes that have been cooled whilst moving over the wetlands into the building. Four of the rooms have been equipped with sensors that trigger an alarm if CO<sub>2</sub> levels rise above 800 ppm, thus reminding the users to open a window.

### Evaluation concept

The Omega Center for Sustainable Living was the first building to achieve both LEED Platinum and Living Building Challenge certification.

### Results

During the first year of operation, the Omega Center fulfilled all relevant criteria for Living Building Challenge certification. Net Positive Water was achieved thanks to the in-house water treatment facility and on-site wells, so that water is both taken from and returned clean to the water table. Also, rainwater is collected in a cistern and re-used for toilet flushing and irrigation of the grounds.

With its photovoltaic solar panels on the roof and geothermal heat pump system, the Omega Center achieved an energy surplus of 9,000 kWh in the first year of operation.

As part of the Living Building Challenge certification, a user survey was conducted on whether the design features in the building contributed to "human delight and the celebration of culture, spirit and place appropriate to the function of the building". The results were almost unanimously positive. Praise was given particularly to the light and spaciousness of the interior spaces, the beautiful views outside, the sense of closeness to nature evoked by the plants inside and the used timber cladding of the building's facades.

### Further information

- [www.eomega.org/the-building?nid=17962](http://www.eomega.org/the-building?nid=17962)
- [www.living-future.org/lbc/case-studies/omega-center-for-sustainable-living/](http://www.living-future.org/lbc/case-studies/omega-center-for-sustainable-living/)
- [www.aiatopten.org/node/109](http://www.aiatopten.org/node/109)
- [bit.ly/omega\\_center1](http://bit.ly/omega_center1)
- [www.usgbc.org/projects/omega-center-sustainable-living](http://www.usgbc.org/projects/omega-center-sustainable-living)

"I find the combination of light, water and flourishing plants makes for a truly uplifting space, especially when you know its purpose. It's one of my favorite places on campus"

Response from the user survey



PHOTOGRAPHY: BNIM © ASSASSI PRODUCTIONS





# 10 DE POORTERS VAN MONTFOORT

One of the residents, Gioya Bouwman, reports that she now pays 65 € per month for energy in her new house, whereas she paid 230 € in her previous home. In the meantime, Gioya Bouwman has also closed off the previously open staircase with an additional door. She admits that the daylight from the roof windows flooding downstairs through the stairwell had been nice but the downside of the open space was that kitchen odours and noise also spread throughout the entire house.

Place	Montfoort, NL
Year	1974 (original buildings), 2014 (refurbishment)
Client	GroenWest
Architects	BouwhulpGroep
Consultants and engineers	Nieman Raadgevende Ingenieurs, Grontmij, BAM Woningbouw, SamenGroen
Evaluation method	Active House
Duration of monitoring	Two years

### Design approach

In Montfoort, near Utrecht, the first ten row houses in the Netherlands have been refurbished to Active House Standard, and now achieve an A+ label for energy performance. New rooftop extensions add 17 m<sup>2</sup> of living space to the previously unused attic floor of each house. The new roofs are equipped with roof windows on both sides as well as 19.5 m<sup>2</sup> of PV panels and 4.5 m<sup>2</sup> of solar collectors per house. The size of the facade windows remained unchanged but the new roof windows, together with the open staircase, result in average daylight factors between 3.6% and 11% in the various rooms. All the facades were fitted with new insulation, new brick facing and new weatherboarding carefully selected to make

the houses blend in with the rest of the residential district.

To ensure optimum air quality, the houses rely on a hybrid ventilation system. For most of the year, they can be cross-ventilated via the facade windows, and the automatically operated roof windows, together with the open staircase, create a chimney effect in the centre of the house that 'sucks' stale air out of the building. In winter, a mechanical ventilation system with heat recovery (controlled by CO<sub>2</sub> sensors) comes into operation. Heating is supplied by electrical ground source heat pumps, allowing the previous gas heating system to be discarded entirely.

### Evaluation concept

The electricity consumption of the various houses and the electricity production from the solar panels were measured for two years, and questionnaires handed out among the tenants every half year in order to be able to

better interpret the monitoring results. Alongside this, touchscreens are installed in every home so that the residents can keep an eye on their energy consumption themselves.

### Results

The energy monitoring comprised both the Active Houses and seven similar houses in the neighbourhood that had undergone a standard refurbishment to energy class A at the same time. This made a comparison of the different refurbishment approaches possible.

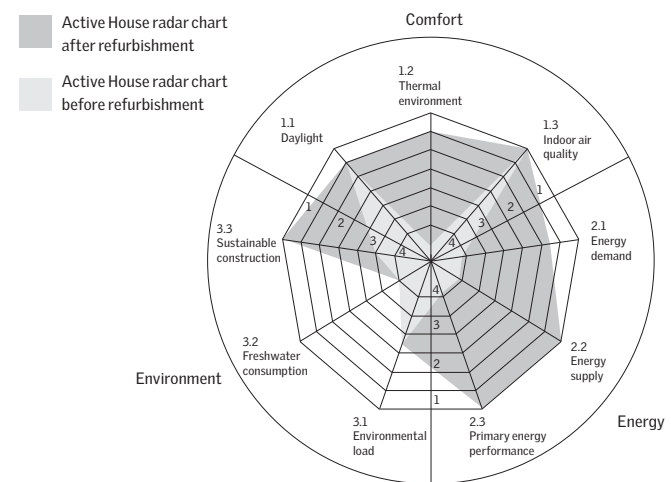
Over the two-year period, the Active Houses consumed 68% less

energy than an average, unrefurbished Dutch row house of the same size, and 40% less than the refurbished 'Class A' houses in the neighbourhood. Half the energy consumption in the Active Houses was met by solar energy from their own roofs.

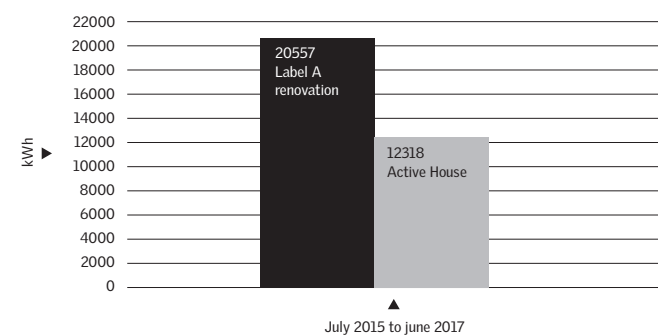
### Further information

[www.activehouse.info/cases/de-poorters-van-montfoort/](http://www.activehouse.info/cases/de-poorters-van-montfoort/)  
Jakob Schoof: Daylight for All. Daylight/Architecture 19, p. 39 ff.  
Available for download at [da.velux.com](http://da.velux.com)

### Active House evaluation results before and after the refurbishment



### Total energy consumption over a two-year monitoring period











## 11 EFFIZIENZHAUS PLUS REFURBISHMENT

Place	Neu-Ulm, DE
Year	2015
Client	NUWOG Wohnungsgesellschaft der Stadt Neu-Ulm
Architects and general planners	o5 Architekten BDA – Raab Hafke Lang
Consultants and engineers	ina Planungsgesellschaft, EGS-plan, B + G Ingenieure Bollinger und Grohmann, G. Linder + Partner, RWTH Aachen/Department for Energy-Efficient Construction E3D, Berliner Institut für Sozialforschung Effizienzhaus Plus, AktivPlus
Evaluation methods	
Duration of monitoring	Two years

### Design approach

Just a few years ago, the three apartment buildings from 1938 were dilapidated and hardly inhabitable. Today, they are the first existing buildings of their kind in Germany to be renovated to the Effizienzhaus Plus (Efficiency House Plus) standard as part of a pilot project. Over the course of the year, they are expected to generate more energy on site than their residents consume.

Almost the entire southern surface of the roof is now seamlessly covered with photovoltaic modules. The only exception is eight roof windows, which have been fitted flush with the solar system. The outer walls and the roof received new insulation, the cellars were drained and a new heat pump heating system installed. Other decentralised heat pumps use the heat from the exhaust air to generate hot water. Fresh air enters the rooms through valves that are integrated behind the radiators in the outside walls. In addition, residents can

manually operate the windows to let in fresh air (hybrid ventilation system).

Inside the houses, the apartments have become larger and brighter, not least due to the addition of two new, two-storey annexes on the north side of the building. The windows are now floor level and allow much more daylight into the apartments than before. The attics, which were previously used for storage and laundry drying, have been transformed into fully-fledged living spaces. They were combined with the apartments on the upper floor to form generous maisonnettes. The architects had the false ceiling removed above the dining areas, so that a two-storey air space connects both levels and daylight falls through the roof windows down to the dining table.

### Further information

[www.forschungsinitiative.de/effizienzhaus-plus/modellvorhaben/effizienzhaus-plus-wohnbauten/neu-ulm-12-14/](http://www.forschungsinitiative.de/effizienzhaus-plus/modellvorhaben/effizienzhaus-plus-wohnbauten/neu-ulm-12-14/)  
[www.aktivplusev.de/portfolio/effizienzhaus-plus-im-altbau-neu-ulm/](http://www.aktivplusev.de/portfolio/effizienzhaus-plus-im-altbau-neu-ulm/)

The design concept for the houses was developed in a competition organised by the German Federal Ministry of Construction, Transport and Urban Development (BMVBS) in 2012. In total, two adjacent rows of three apartment buildings were each renovated according to the Efficiency House Plus standard.

### Results

During the first year of operation, energy consumption in the houses was higher than anticipated. This was mainly due to deficiencies in the construction, incorrect settings and the optimisation process, which had not then been completed. The problems were solved after the first year of operation. The optimisation process will continue, particularly in the area of heat pump settings.

For these reasons, the targeted positive energy balance was not quite achieved after the first year of operation. However, the engineers expect

that future measures to optimise operations will lead to a positive annual balance.

Parallel to the technical measurements, the Berlin Institute for Social Research also conducted tenant surveys. However, due to the small number of people surveyed and the complications with the building services mentioned above, no representative results have yet been obtained. The residents responded positively to the questions about the quality of living, the layout of the apartments and the connection to the outside.





## 12 LIVING PLANET CENTRE

Extensive carbon profiling studies were undertaken in the planning phase to minimise embodied carbon in the building construction. These also resulted in some unconventional measures, such as the choice of double rather than triple glazing in the main west and east facades.

Place	Woking, UK
Year	2013
Client	World Wildlife Fund
Architects	Hopkins Architects
Consultants and engineers	Expedition Engineering, Atelier Ten, Grant Associates, Speirs +Major, Willmott Dixon, WWF Facilities Team
Evaluation methods	BREEAM, project-specific monitoring concept
Duration of monitoring	One year

### Results

Together with the contractor Willmott Dixon, WWF's building management team conducted a monitoring and user enquiries with questionnaires during the first year of operation. The contractor also undertook smoke tests to verify the ventilation rates in the meeting rooms.

Although the building performed considerably better than the industry benchmarks, the first year's energy consumption was roughly 50% higher than anticipated. This may be due partly to the fact that the public areas of the building, as well as the conference and educational facilities, have proved very popular and, as a result, the operating hours are longer than anticipated.

Adjustments were made to the ventilation system in particular, in

cluding the night-purge routine that 'flushes' the building with cool air during summer nights to maintain comfortable temperatures. Extra vents were added to the meeting rooms to increase the extraction rates. The four roof cowls, the operation of which had originally been intended to depend only on wind and buoyancy, were equipped with additional manual controls.

### Design approach

The new headquarters of WWF-UK houses 340 employees on two storeys in an open-plan environment, together with conference and educational facilities, as well as an exhibition space. The building, which is rated BREEAM Outstanding, was erected over an existing car park on the banks of the Basingstoke Canal. Great care was taken to ensure natural ventilation and good daylighting across the deep plan, with an average daylight factor of 3.1% on the ground floor and 5.1% at the mezzanine level. The Living Planet Centre can run for about two-thirds of the year on natural ventilation. This is supported by four characteristic cowls on the roof that use buoyancy

and local winds to 'suck' stale air out of the building. Green and red lights distributed across the work areas show whether the building is in natural or mechanical ventilation mode.



PHOTOGRAPHY: MORLEY VON STEINBERG

### Further information

[www.wwf.org.uk/get-involved/living-planet-centre](http://www.wwf.org.uk/get-involved/living-planet-centre)  
[www.hopkins.co.uk/projects/1/151](http://www.hopkins.co.uk/projects/1/151)

Richard Partington, Simon Bradbury: Better Buildings. Learning from Buildings in Use. RIBA Publishing, 2017

John Gerrard et al: The Living Planet Centre, Woking, UK: delivering sustainable design. Engineering Sustainability, Vol. 168, Issue ES2, pp. 82-92



PHOTOGRAPHY: ANNE ARREY





PHOTOGRAPHY: FRED HATT

## 13 SWISS LIVING CHALLENGE/ NEIGHBORHUB

Place	Denver, US/Fribourg, CH
Year	2017
Client	U. S. Department of Energy/Solar Decathlon 2017
Design	Swiss Team, composed of students of the École Polytechnique Fédérale de Lausanne, School of Engineering and Architecture Fribourg, Geneva University of Art and Design, and the University of Fribourg
Project Leader	Prof. Dr. Marilynne Andersen, EPFL, Lausanne
Consultants	150 instructors, professionals and supervisors from academia and industry (project partners)
Evaluation methods	Solar Decathlon Rules + project-specific monitoring concept
Duration of monitoring	8 days in 2017 + continuous monitoring from autumn 2018 onwards

### Design approach

This experimental plus-energy building was the overall winner at the 2017 U.S. Solar Decathlon in Denver. Beyond being useable as a private home, the NeighborHub was conceived as a 'house for neighbourhood living'. The student team chose seven themes, such as energy, waste management, biodiversity, mobility and food, that guided the entire project.

From May 2018 onwards, the building will find a permanent location in Fribourg, Switzerland, on a former brewery site that is now used as an innovation district and research centre. Here the NeighborHub will serve as a place for discussion as well as a demonstrator of future technologies.

The climate concept of the house differentiates between a thermally controlled core and an 'extended skin' along the perimeter, which is neither actively heated nor cooled and where indoor temperatures thus fluctuate. The latter is shielded against the outside world by translucent polycarbonate and transparent acrylic panels for passive solar gain and natural light, as well as opaque facade modules for active solar technology, both thermal

and photovoltaic. The majority of the facade can be folded upwards so that the NeighborHub opens out entirely to its environment. Even when it is closed, the transparent panels provide views outside, and four fully glazed sliding doors also allow daylight to penetrate into the building's core.

Three modular skylights with semi-automated shading – two for the core and one row of modules for the perimeter area – provide the indoor spaces with additional daylight and support the natural ventilation. The electric light is dimmable and equipped with variable colour control in order to help the users maintain a natural sleep/wake cycle.

### Further information

[www.swiss-living-challenge.ch](http://www.swiss-living-challenge.ch)  
[www.solardecathlon.gov/2017/competition-team-switzerland.html](http://www.solardecathlon.gov/2017/competition-team-switzerland.html)

Designing and building the NeighborHub was a huge collaborative effort. More than 250 students from a broad spectrum of disciplines and 150 supervisors from various sectors were involved in the project, devoting over 7,500 working hours. The entire project had a budget of roughly \$4.2 million and ran over three years.

### Evaluation concept

All entries to the Solar Decathlon are evaluated in ten categories, six of which rely on qualitative and four on quantitative criteria. To earn full points on the 'Health and Comfort' category, teams must maintain temperatures between 20°C and 23.3°C, relative humidity between 35% and 60%, indoor CO<sub>2</sub> levels below 1,000 ppm, and provide the building with an airtight envelope.

The NeighborHub is equipped with wireless sensors that keep track

of the indoor climate. A weather station also monitors the outdoor climate and provides forecasts of solar irradiation, wind and rain.

Once the building is operational in Fribourg, the monitoring will resume, with the results being used to refine the control algorithms for the ventilation, heating, cooling and solar shading.

### Results

Alongside the overall Solar Decathlon competition, the NeighborHub also won first prize in six of the ten categories. Of particular interest were the full (100/100) points in both the engineering and the architecture contest. Another first place was achieved in the Health and Comfort category, with 97.165 out of 100 points. Temperatures and CO<sub>2</sub> levels only rose above the maximum permissible limits in a few rare instances. Results were somewhat more mixed in terms of humidity, with values below 20% reached on two of the eight days of the evaluation.

Although the control systems in the house prioritise passive strategies over active heating and cooling, the tight constraints of the competition rules in terms of indoor temperatures meant that a cooling unit had to be installed in the house. When the building enters into permanent operation in Fribourg, the thermal requirements will be less strict. The student team thus hopes that there will be less need for active cooling and the passive design of the perimeter area can be used to a greater degree to ensure a stable indoor climate.



DENNIS SCHROEDER/U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON



Atika was initially conceived as a rooftop extension to be used for residential purposes. The fact that the building now stands on the ground, and is used as an office and laboratory space, proves the versatility of the initial design.

Place	Milan, IT
Year	2007 (original building), 2012 (refurbishment)
Client	VELUX A/S (original building), VELUX Italia, Politecnico di Milano (refurbishment)
Architects	ACXT/IDOM (original building), Atelier 2 – Arch. Valentina Gallotti, Politecnico di Milano – Prof Marco Imperadori (refurbishment)
Consultants and engineers	Experts from different departments of Politecnico di Milano
Evaluation methods	Active House + project-specific monitoring concept
Duration of monitoring	On-going

**Design approach**

Under the name of Atika, this building was originally conceived by the VELUX Group as a model home for the Mediterranean Climate. The company eventually decided to donate it to Politecnico di Milano, as a laboratory for experimentation with new materials and energy technologies. VELUXLab is the first nearly zero energy building on an Italian university campus.

The light-weight steel structure and overall layout of the building were preserved in the refurbishment but the build-up of the walls and roof were modified to better match the climate of Milan. VELUXLab is built around a south-facing patio that is accessible from all the rooms. The pitched roofs are designed to maximise shade in summer and solar gains in winter and to enhance natural ventilation.

**Evaluation concept**

In a first step, 14 temperature sensors were placed inside the walls and roof, and on their surfaces, to monitor the thermal behaviour of the construction. A further six temperature sensors and two electricity meters monitor the energy flows in the mechanical system. All of these are connected to a wireless node network, with the results

In spring and autumn, the roof windows are operated to ventilate used air out of the building. In summer and winter, VELUXLab relies on mechanical ventilation with heat recovery and a reversible air-to-water heat pump to maintain comfortable temperatures. Three solar panels on the roof supply all the hot water needed in the building. Furthermore, 2 kWp of PV panels have been installed on the roof.

The electric lighting in VELUXLab is equipped with sensors and dimmers to that it can be automatically regulated, depending on available daylight levels. The indoor ceilings are finished with perforated acoustic panels made of plasterboard with added zeolite that are capable of cleaning the indoor air of pollutants.

broadcast in real time on the University intranet. In a second step, the VELUX Lab is now being equipped with Leapcraft sensors (see also the article on Green Solution House) that allow for a continuous monitoring of CO<sub>2</sub>, humidity, particulate matter, VOCs and daylight levels.

**Further information**

- www.activehouse.info/cases/veluxlab/
- www.atelier2.it/opere/veluxlab/
- bit.ly/veluxlab1
- bit.ly/veluxlab2
- bit.ly/veluxlab3
- bit.ly/veluxlab4
- bit.ly/veluxlab5

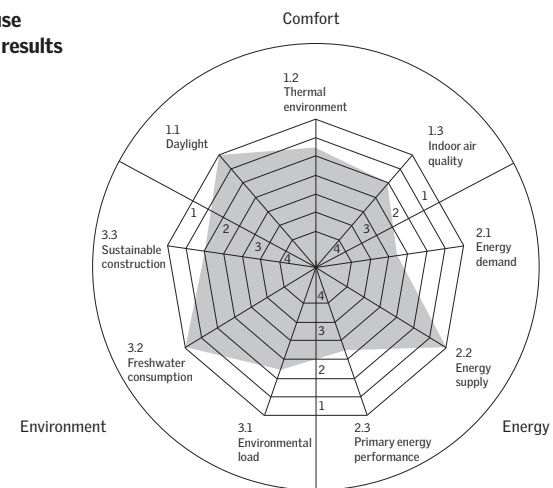
**Results**

In 2011, the building was left empty, and monitored to validate the design strategies after completion of the refurbishment. Since 2012, the researchers' team of Politecnico di Milano has occupied the spaces; several people work there every day, thus influencing the thermal behaviour and indoor comfort of the building.

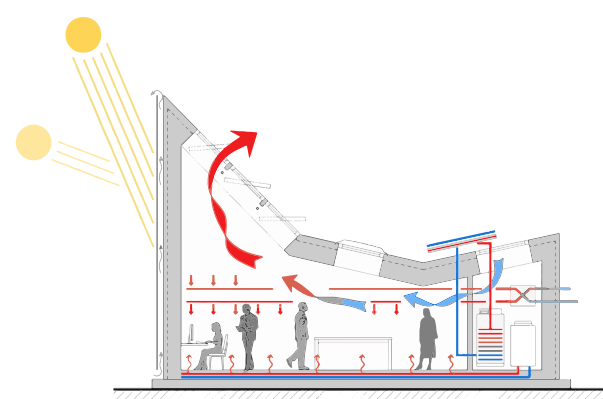
The temperature sensors have delivered huge amounts of data about the thermal behaviour of the building and the thermal comfort inside

it. Once the Leapcraft sensors are installed, the research team hopes to get an even more comprehensive overview of the indoor comfort. The daylight-dependent lighting controls have helped to reduce electricity demand for lighting by almost 80% compared to a standard solution. The sensors deployed in the mechanical system show that up to 35% of the monthly electricity consumption in VELUXLab is met by the rooftop PV panels in summer.

**Active House evaluation results**



**Climate and ventilation concept**



PHOTOGRAPHY: VELUX GROUP, 2012





# 15 SUNDE BOLIGER

Place	Holstebro, DK
Year	2017
Client	Realdania By & Byg
Architects	Pluskontoret Architects, Lendager Group
Consultants and engineers	MOE, Prof Torben Sigsgaard (Aarhus University)
Evaluation method	Indeklimahjulet (Indoor Climate Wheel)
Duration of monitoring	Two years

## Design approach

These three single-family homes, called YES-tech, NO-tech and NOW-tech, explore the effects of different design strategies on indoor comfort and indoor air quality.

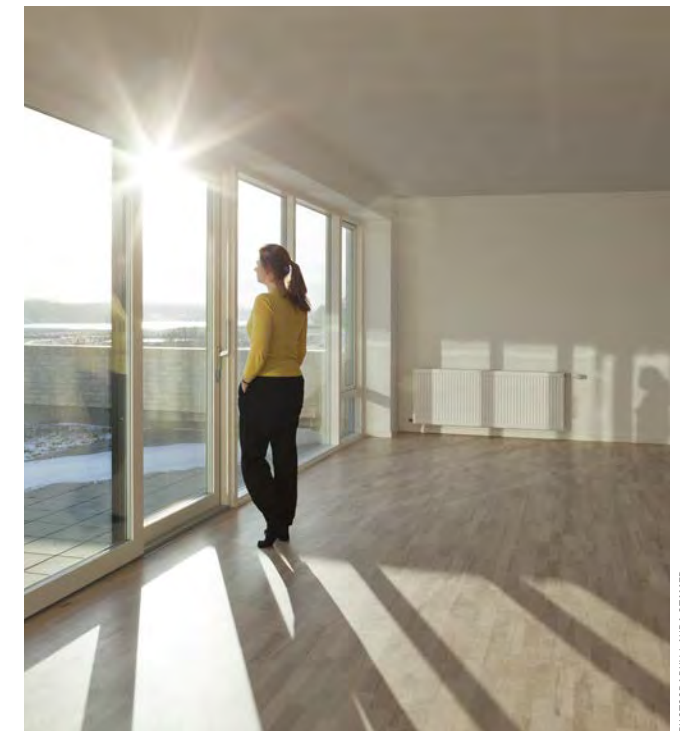
The NOW-tech house was built according to current practice with standard materials and technical solutions. The YES-tech house has a zone-divided, demand-driven ventilation system equipped with CO<sub>2</sub>, particle, moisture and temperature sensors in each room. Fresh air enters the rooms through thousands of little perforations in the ceiling in order to avoid drafts. A powerful extraction hood in the kitchen directly extracts particles at the source.

In the NO-tech house, priority is given to low-emission and moisture absorbing materials to maintain a good air quality. The kitchen is divided from the rest of the house by a glass partition wall. The children have both a bedroom and a separate playroom at their disposal to protect them from any emissions from their toys while they sleep. Instead of a centralised MVHR system, four solar chimneys equipped with roof windows and heavy, clay-brick walls have been placed in different rooms to improve natural ventilation. Small exhaust fans have been placed inside the solar chimneys to get rid of the used air even during cloudy skies.

## Evaluation concept

The Indeklimahjulet (Indoor Climate Wheel) tool was specifically developed for the design of the Sunde Boliger in order to achieve a balance between health and comfort in the indoor climate. A total of 12 aspects are considered, half of which are accessible to our senses (such as daylight, humidity or temperature) while the other half usually escape our perception but significantly impact human health (such as particulate matter and the off-gassing of furniture and building materials). Upon completion of the buildings, the engineers performed numerous air quality measurements to establish a baseline with which the air quality during occupancy can later be compared. Once the homes are

occupied, the monitoring will continue for another two years. This includes the air exchange rates and air velocities in the various spaces, the relative humidity at different ventilation rates, CO<sub>2</sub> levels, the indoor temperatures in all rooms, and the distribution of particles in the indoor air. Furthermore, the monitoring will keep track of VOC and other emissions from furniture and building materials. Alongside the physical measurements, the residents will be interviewed several times, asking them about factors such as the smells they perceive, the indoor temperatures and the noise levels.



PHOTOGRAPHY: LAURA STAMER

## Results

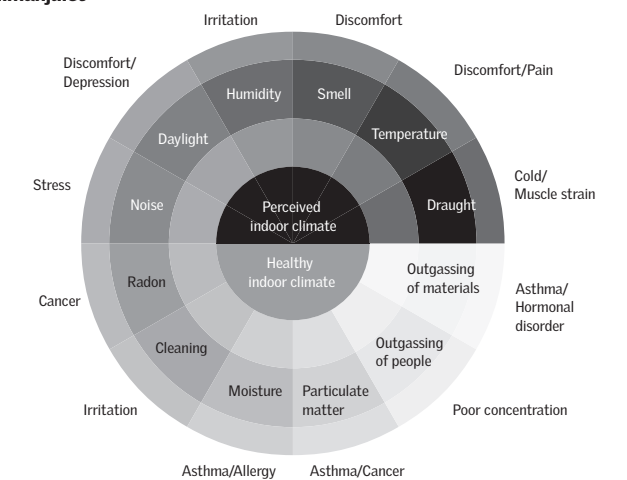
As the residents will not move into their homes until spring 2018, no monitoring results from the occupancy phase are available. However, a first test of the actual air exchange rates after building completion showed similar results both for the NO-tech house (in the case of natural ventilation only) and the YES-tech houses. Both were higher than the values measured in the NOW-tech house, and significantly above the minimum

air exchange stipulated by the Danish Building Regulation.

A second test also proved the effectiveness of the powerful ventilation hood in the YES-tech house when it came to reducing particulate matter in the kitchen. Compared to the NOW-tech house (which has a less effective kitchen hood installed), the particulate matter concentration rose to much lower peak levels during cooking.

In the NO-tech house, the architects decided to promote outdoor living. The house has both an outdoor kitchen and outdoor shower for use during summer, to prevent moisture and particles from accumulating in the house.

## Indeklimahjulet



PHOTOGRAPHY: LAURA STAMER







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