Daylight and Well-being

Daylight as a driver for healthy buildings

Case study: Green Solution House

This publication was created as part of the Active House Symposium held in September 2017 at Green Solution House, on the island of Bornholm, Denmark.

Partners: GXN Innovation, Leapcraft, VELUX Modular Skylights.

Image: Green Solution House, a living experiment where light, temperature and air quality are continuously monitored and communicated.

“One experiment is better than a thousand expert views”

Villum Kann Rasmussen, Founder of the VELUX Group

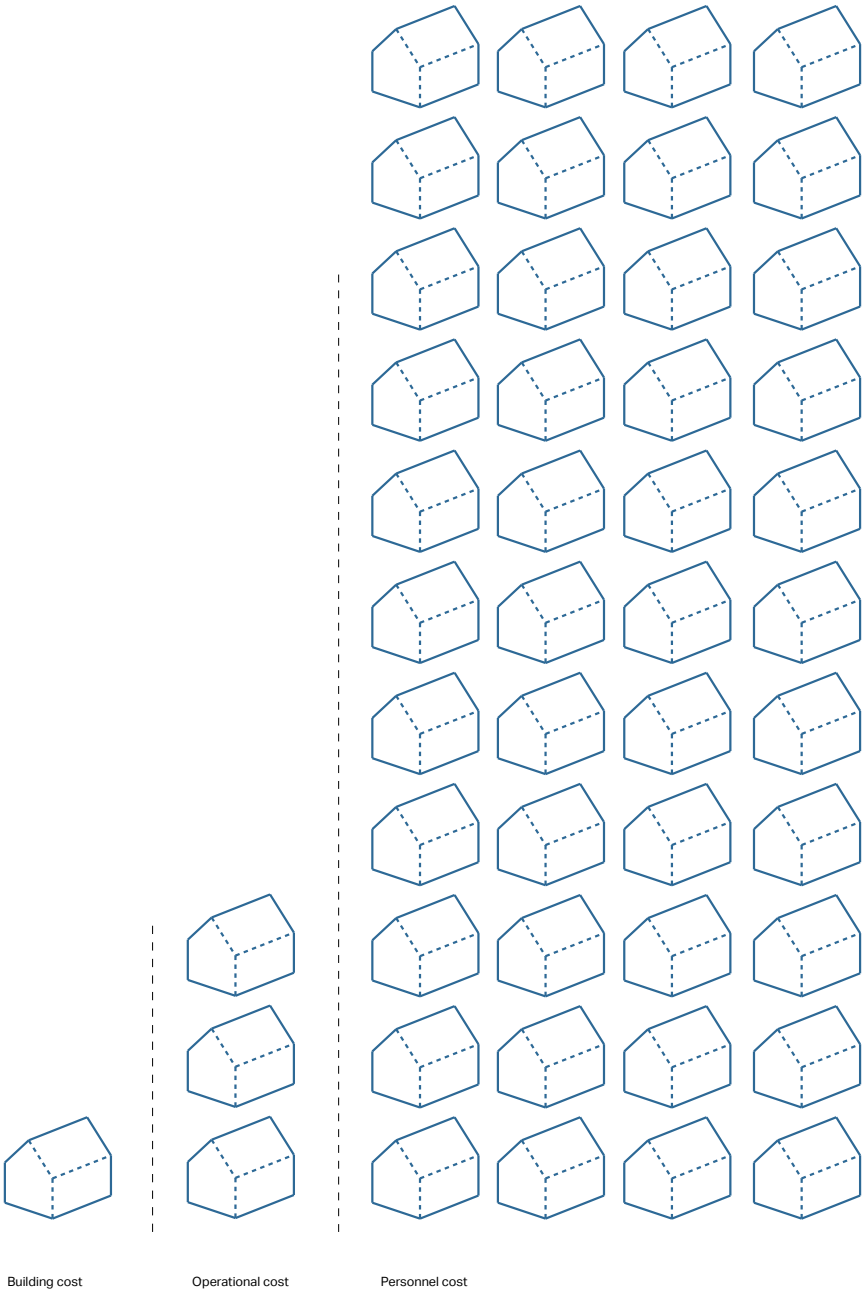
By exploring three different perspectives – Comfort Economy, Healthy Building, and Living Measurements – this booklet explores how comfort in buildings can be defined, integrated, monitored and improved for the benefit of human well-being and environmental sustainability.

We hope that you will find inspiration in this booklet, and in our heartfelt belief in indoor comfort and active, living buildings.

Lotte Kragelund, Marketing Director, VELUX Modular Skylights

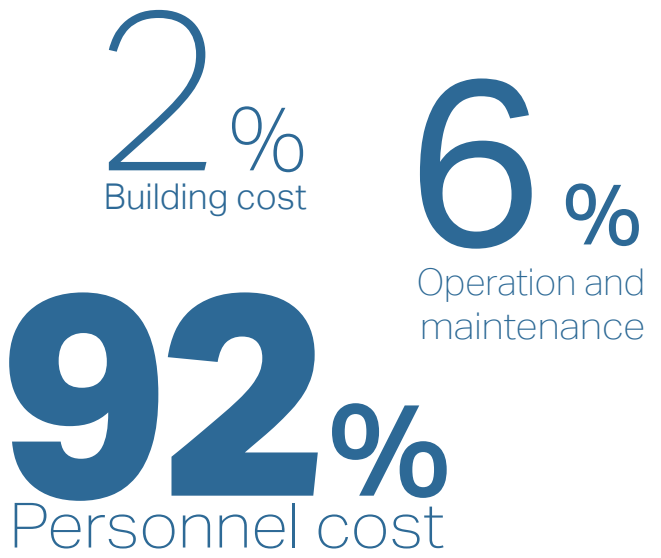
Comfort Economy

The future of building economics will focus on human comfort



Total costs over a 30-year timespan related to building, operations and personnel

From building performance to human well-being



Over a period of 30 years, initial building costs account for 2% of the total costs, operations and maintenance for 6%, and personnel costs account for 92%. Source: Sustainable Building Technical Manual, 1996.

Sustainability is firmly on the agenda when it comes to the built environment. For a number of years, reducing consumption of resources has been the main focus when discussing sustainability. Today we see a shift towards a more holistic approach where the focus is widened - from purely technical building solutions, to solutions that also increase human well-being within buildings.

A typical building owner will expend 6% of the building's overall cost on maintenance over a 30-year usage period. As a result, cost-reduction by minimising consumption of energy and water, for example, is often prioritised. While such reduction is important in achieving buildings that are both environmentally and economically sustainable, there is often even more potential to be found in costs that can be attributed to the actual users of a building – employees, students, residents, etc.

Take, for example, the typical cost distribution in a building housing skilled workers: 2% of costs are accounted for by initial building costs, 6% by maintenance, and up to 92% by the personnel costs (salaries, etc.). This number will obviously vary from building to building, but generally the costs – and the potential gains – associated with the people in buildings greatly exceed those of the building itself.

This means that commercially attractive buildings are buildings in which people are comfortable. If people are comfortable, they work better, learn more, have less sick days and have better levels of productivity.

Studies show that buildings can improve productivity and performance by as much as 12.5%, or reduce them by as much as 17%. That constitutes a 30% swing between the best and worst buildings.

This is why we believe that sustainable buildings of the future should not be just good for the environment – they should also be buildings that enhance the well-being of people.

Buildings can improve productivity and performance by as much as 12.5% or reduce them by as much as 17%. That is a 30% performance swing between the best and worst buildings.

Source: Carnegie Mellon BIDS High Performing

Children playing outdoors around the seasonal lakes at Green Solution House. Photo by SLA

Daylight, air and mother nature

1 kg food

3 litres water

15 kg air

Air quality is a neglected factor. The weight of the air that we breathe in daily is 15 times greater than that of the food we eat.
Source: Cradle to Cradle Building Manual, 2012

Green Solution House is more than just a building. It is a neighbourhood, a community, and represents an island coming together to explore and demonstrate circular sustainability. It is a conference centre and hotel on the island of Bornholm which is engaged in developing innovative green solutions. It is regenerative architecture which aspires to eliminate the concept of waste.

The vision for Green Solution House is to be a showcase for circular sustainability with three goals: 1) to demonstrate green solutions; 2) to promote continuous improvement; and 3) to enable knowledge sharing. The design of the building itself is based on several parameters to show a holistic approach to sustainability. The building has been certified to DGNB (German Sustainable Building Council) standards, documented as an Active House and accepted in the Cradle to Cradle registry.

The renovated hotel rooms and new conference building reach out into the surrounding nature park, where seasonal lakes ensure that all water is handled onsite, while creating a habitat for local biotopes and red-listed species. Indoor comfort is the central experience at Green Solution House. This experience comes from the ever-present natural environment, the clean sea air, and the abundance of daylight throughout the building.

As part of the design, a set of criteria was developed to select materials, prioritising certifications and environmental labels, recyclability, social responsibility, use of resources, safety of compounds, and energy consumed in production, to name but a few.

Active materials, including carpets, plasterboard and a roof membrane, help clean the air, while plenty of windows, skylights and light channels ensure abundant natural light reaches guests and staff throughout the facility. Local biotopes have been introduced into the landscape, strengthening the native biodiversity, and the restaurant serves local produce.

In short, Green Solution House is a building that enhances the experience of its guests by providing plentiful daylight, clean air and abundant access to nature.

Green Solution House revenue increased by 20% in the first year after the re-opening

Source: Architecture Creates Value, by Danish Association of Architectural Firms, 2017

Interview

Trine Richter, Director of Green Solution House

What role does human comfort play at Green Solution House?

Green Solution House is not an ordinary hotel and conference centre. We wanted to make a special building that invites people to come here and experience how sustainability impacts them directly. We wanted to do something extraordinary to attract people to the island of Bornholm.
The building, and the way we operate it, should be unique selling points and in themselves reasons to visit. We developed a holistic sustainability strategy combining the Active House principles and a cradle-to-cradle-inspired approach to sustainability, and the building was DGNB (German Sustainable Building Council) certified.

Why did you choose to follow the Active House principles?

I like the Active House approach to sustainability. Compared to other certification schemes, Active House emphasizes comfort much more coherently. This made it easier to work with the architect and engineers, thinking about how people were actually going to experience the building.
And this in turn lead to conversations about enjoyment and well-being and how these concepts interface with sustainability.

How does daylight play into this?

At Green Solution House, daylight is one of our unique selling points. We embrace daylight in the building and in its design, and we can see that people who use the conference centre are less tired after a full day of meetings. This means that the return on investment on a conference is a lot higher here. We knew from the beginning that we wanted a glass construction in the roof, since we wanted to have both daylight and integrated solar cells.

You have recently begun real-time monitoring of building performance. Why?

Working with our partners Leapcraft, GXN Innovation and VELUX, we monitor daylight, CO_2 levels and other parameters in real time to evaluate performance and understand comfort. We want to monitor how the building actually works and compare this to our intentions during the design phase. Green Solution House should be a showcase for sustainable solutions and therefore we should also be able to monitor how the solutions actually work for people. We believe that if we share our experiences widely, we can help develop new and better ideas.

"Having a bright, daylit conference centre is our best selling point"

Trine Richter, Director, Green Solution House

Healthy Buildings

Buildings that promote the well-being of people

The Active House

The notion of human comfort and well-being in buildings is a complex one that entails many parameters. The Active House standard is a set of industrial guidelines that makes it possible to quantify and measure the comfort and sustainability of a building through an easy-to-use framework. This framework is used as a tool to assist designers in creating buildings that are both comfortable and sustainable.

An Active House is a building that combines energy efficiency with specific attention to user health and comfort, indoor climate and the environment. Thus, Active House is a vision of buildings that create healthier and more comfortable lives for their occupants while minimising the buildings' impact on the environment – thereby moving us towards a cleaner, healthier and safer world.

Main Principles
The Active House focuses on three main principles: comfort, energy and environment.

Comfort – creates a healthier and more comfortable life. An Active House creates healthier and more comfortable indoor conditions for its occupants, ensuring a generous supply of daylight and fresh air. Materials used have a positive impact on comfort and indoor climate.

Founded in **2009** as a **vision** for building sustainable

Active House Alliance is a **global network**

Evolved in **2016** to a **verification** system for sustainable buildings

Active House measuring comfort, energy and daylight.

Energy – makes a positive contribution to energy balance. An Active House is energy efficient. All energy needed for Green Solution House is supplied by renewable energy sources integrated in the building or from the nearby collective energy system and electricity grid.

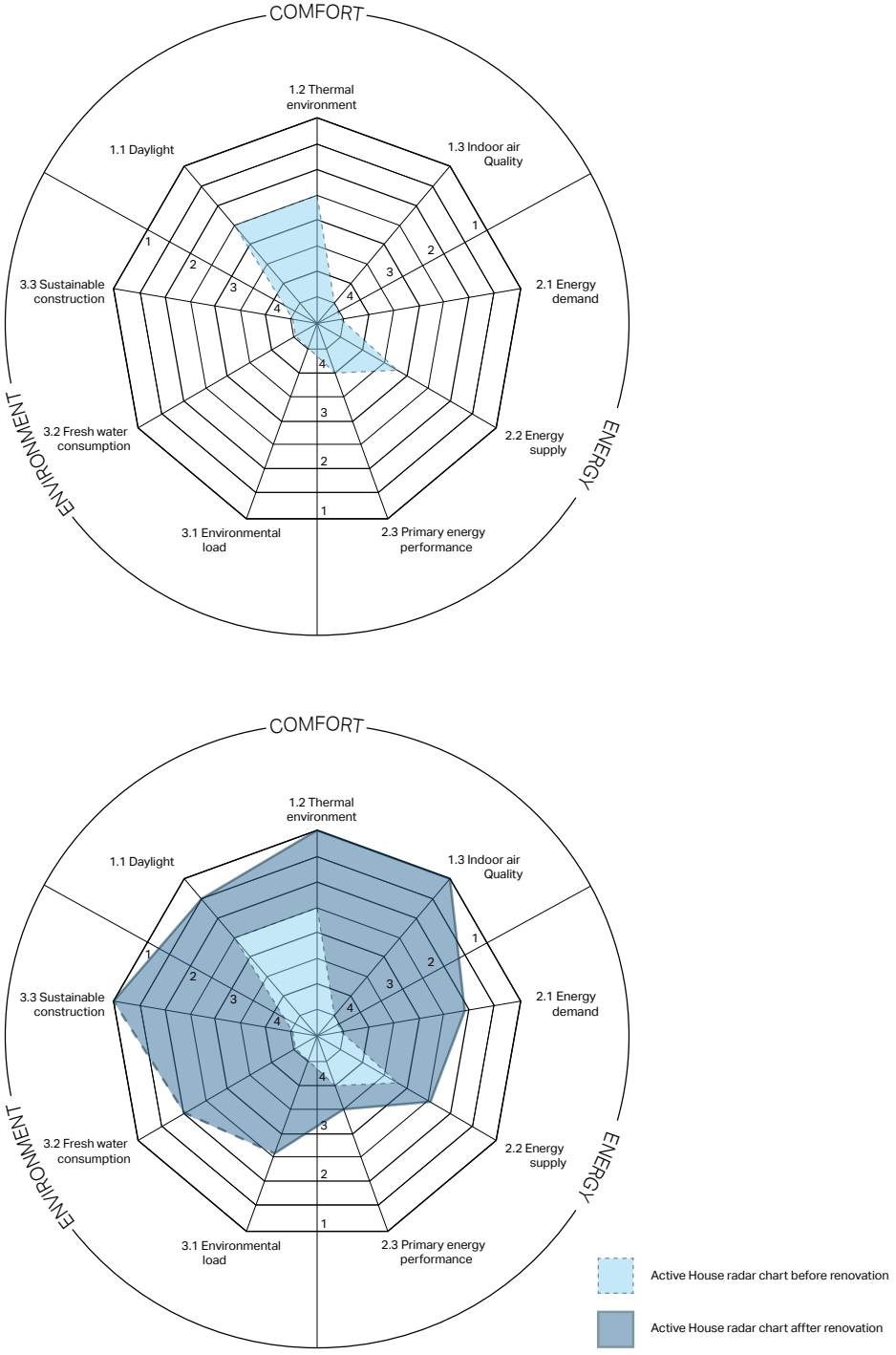
Environment – has a positive impact on the environment. An Active House interacts positively with the environment through an optimised relationship with the local surroundings, focused use of resources, and its overall environmental impact throughout its life cycle.

Comfort Criterias
The specific focus on comfort takes three main parameters into account: daylight, thermal environment and indoor air quality.

Buildings that give more than they take

Active House is a vision of buildings that create healthier and more comfortable lives for their occupants while minimising impact on the environment – thereby moving us towards a cleaner, healthier and safer world.

Source: The Active House specifications, 2017



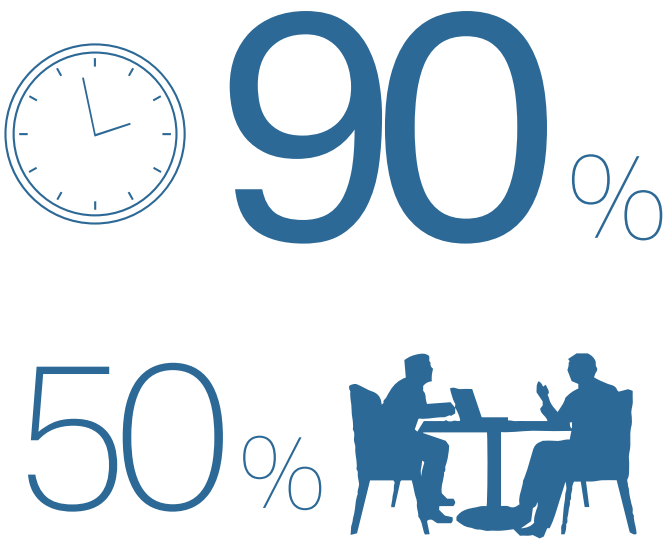
Active House radar, showing criterias and results used to evaluate the Green Solution House

Daylight: an Active House should allow for optimal indoor daylight conditions and attractive views to the outside. Daylight has a direct influence on people's well-being, and electric lighting during daytime should rarely be necessary. This should also make it possible to reduce overall energy consumption for lighting.

Thermal comfort: A pleasant thermal environment is essential for a comfortable building. Thermal comfort, both in summer and winter, enhances mood, increases performance and, in some cases, can prevent and alleviate illness. Active Houses should minimise overheating in summer and optimise indoor temperatures in winter without unnecessary energy use. Where possible, simple, energy-efficient and easily-maintained solutions should be used.

Indoor air quality: Good indoor air quality has an important impact on the health of a building's occupants. Good indoor air quality can prevent problems such as mucous membrane irritation, asthma and allergies, along with contributing to the prevention of some cardiovascular diseases. In addition, it helps to avoid bad odours, which can effect overall well-being. Active Houses should provide good air quality for occupants while minimising energy use (for ventilation) as far as possible. This means that, wherever possible, natural ventilation or hybrid systems (combining natural and mechanical ventilation) should be used, as these offer the best energy performance.

The Active House Radar
This is a graphic tool used when a building is assessed for Active House labelling. It shows performance levels



'We spend 90% of our time indoors, and 50% of our time awake working'.
Source: Healthy Homes Barometer, 2017.

for each of the three main principles. The radar can be used when designing an Active House, but also to show the actual performance of the completed building.

It shows the level of ambition for each of the three main principles – comfort, energy and environment – and can also show how "active" the building's real-life performance is. For Active House assessment, the level of ambition is measured in four levels where 1 is the highest and 4 is the lowest.

Located opposite are two Active House radars, visualising the performance of the Green Solution House before and after its renovation. The radar clearly shows major improvements when looking at sustainable performance. Both environmental and energy criteria have improved significantly, while the comfort parameter shows impressive daylight levels, as well as ideal levels for thermal environment and Indoor air quality.

Interview

Kasper Guldager, architect of Green Solution House

Tell us about the design of Green Solution House

The client wanted a clear vision and strategy for Green Solution House, which made the design both challenging and rewarding. Challenging, because we had to really push the envelope in terms of sustainable architecture, in order to come up with a number of previously unseen solutions. Rewarding, because the completed building really is something special. I am very happy with the fact that sustainability is no longer an abstract or technical problem at Green Solution House, but rather something that you can actually go and experience first-hand for yourself.

How did you ensure this during the design phases?

Right from the start we worked hard to redefine the meaning and experience of sustainable architecture. We created new strategies for interactive indoor climate, intelligent materials and circular sustainability. This included evaluation of materials and, wherever possible, use of locally-sourced and upcycled materials, but also the use of the Active House principles as parameters for design. This enabled us to combine high performance on comfort and energy efficiency with a low impact on the environment.

What role does comfort play in sustainable architecture?

Green Solution House takes a human-centric approach to sustainability. Daylight is a case in point. Daylight conditions in the conference facilities, rooms and hallways make a big difference in how people experience the building. We sought to open up the building. We installed skylights in rooms and corridors and replaced balustrades of concrete with glazing. We wanted to increase transparency so that natural light changes throughout the day and the different seasons, becoming an integral part of the experience of the building.

How do you see data impacting sustainable architecture?

Data changes our relationship with buildings and allows us to deepen our collaboration with clients. We can learn from buildings together – not only as we build but also while they are in use – and update our design and strategies accordingly. Real-time monitoring directly links building performance to human comfort. Data can make value visible, to the benefit of both building owners and occupants. Improving this knowledge is one of the core goals of Green Solution House, and is something we are proud to be working on today.

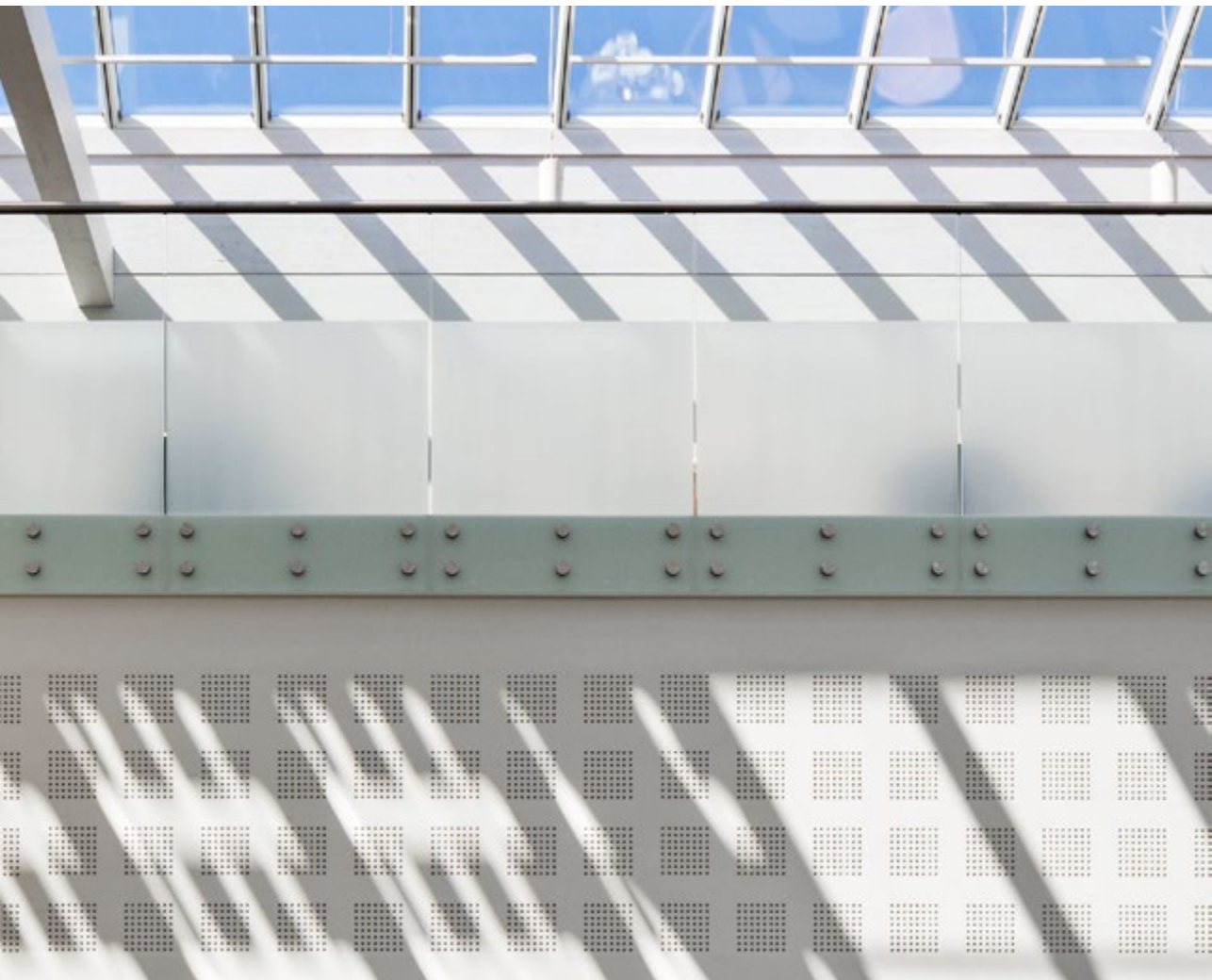
"Green Solution House is designed to stimulate the senses and increase the comfort of guests and employees"

Kasper Guldager, Senior Partner 3XN, Director GXN

Living Measurements

Live information on comfort parameters

Daylight and shadow play at the central foyer space
at Green Solution House



Buildings as lifelong relationships

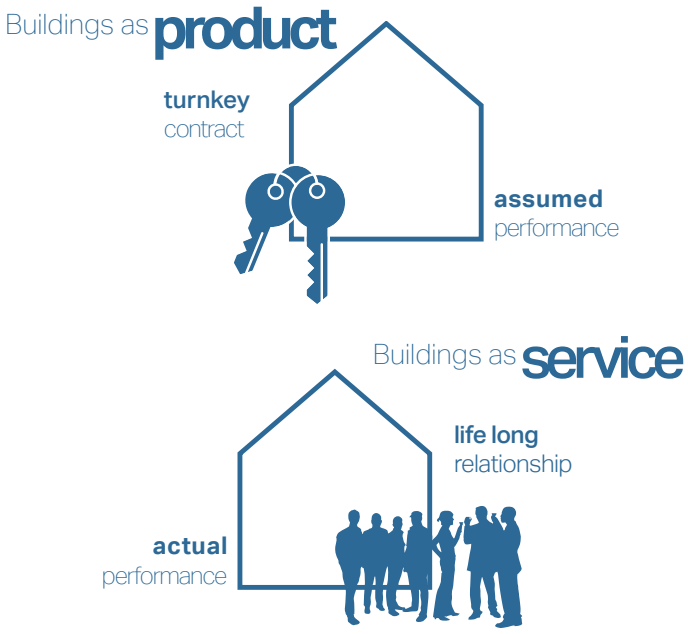
Buildings are dynamic entities, constantly being affected by the behaviour of their users. One thing is how buildings are designed and described before construction; another thing is the actual performance during operations. There is now an increasing demand to register and document the effects of buildings in use, especially in regards to comfort and indoor environment.

Today, the monitoring, tuning and calibration of technical building systems are done through commissioning. Often, this mainly pertains to a building's services, such as energy consumption or water management. The parameters which have physiological or psychological effects on a building's users are often not documented or improved during use.

In commercial buildings, where the performance of employees is a major economic factor, well-being and comfort are becoming a vital part of what architecture should deliver. Thus, there is a tendency towards buildings being perceived as lifelong relationships provided to tenants or building owners, and towards comfort as a service that the architecture needs to deliver.

A living experiment

Green Solution House is a living and continuous experiment. As such, Green Solution House is as much a process as it is a building.



Here, green solutions are tested, demonstrated and continuously revisited. The belief is that this iterative process creates understanding and leads to innovation.

The knowledge created through experimentation is exchanged with the local and global communities to inspire a sustainable future.

As part of that effort, the performance of the Green Solution House is being monitored in order to produce insights for continuous improvement. Thus, dynamic data and digital technology are utilised to inform about the performance of the building on a day-to-day basis.

Tracking comfort in Green Solution House

At selected strategic points, sensors have been installed for live monitoring of different parameters that affect indoor comfort. The

Commissioning is the process of assuring that all systems and components of a building are designed, installed, tested, operated, and maintained according to the specifications and requirements of the building owner.

Source: Whole Building Design Guide, - wbdg.org

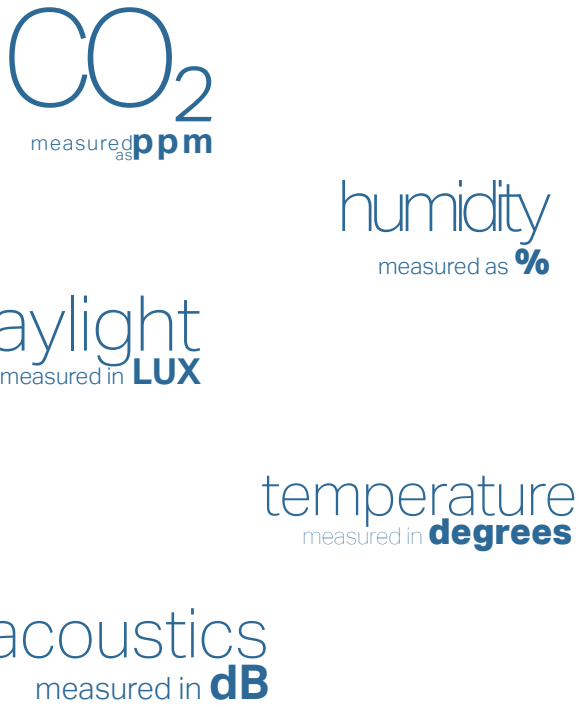
Dashboard showing live data from Green Solution House

sensors provide valuable insight into the quality of the indoor environment by monitoring CO_2, humidity, daylight, thermal comfort and acoustics.

By integrating live monitoring and smart building technologies, it is possible to gather information on building performance in real-time. For users and facility managers, this offers a chance to improve performance and comfort while the building is being occupied and operated.

Measuring parameters
At Green Solution House, a series of parameters is being monitored:

$C0_2$ is a colourless and odourless gas. It naturally occurs in the atmosphere of the earth, but it is also being made through human activity, when we breathe, or when we burn candles for example.



How comfort is monitored at the Green Solution House.
Source: Leapcraft 2017

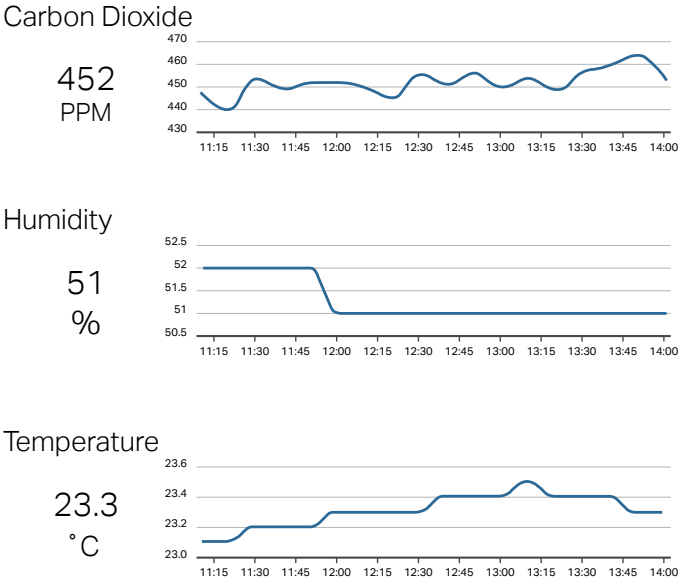
Measurements are taken in ppm (parts per million - the number of CO_2 molecules for every million air molecules).

A normal (outdoor) CO_2 level is about 300-400 ppm, and indoor levels should preferably be under 1,000 ppm. If a lot of people are gathered in a room, the CO_2 levels will rise quickly, which can cause symptoms such as headaches. The solution is to ventilate, either naturally or by mechanical ventilation.

Humidity is measured as a percentage (%) in relative humidity (RH), and describes the amount of water vapour in the air at a certain temperature.

Indoor air can be up to five times more polluted than outdoor air.

Source: The United States Environmental Protection Agency



Live monitoring data graphs from the Green Solution House

The humidity inside a building should preferably be 40-45% in winter and 60-65% in summer. If these levels are higher, people are more likely to get a headache or develop allergies, and the building will be more likely to develop mould or moisture damage, which can be very costly to repair. As with CO_2, humidity can be lowered to healthy levels, either by natural or mechanical ventilation.

Daylight has a very positive impact on well-being. If you get enough daylight, it strengthens your ability to concentrate, you sleep better, and you are less likely to suffer depression. Daylight is measured in LUX (described as number of lumens per m²). On a typical cloudy day, you will have around 1,000 LUX, and in bright daylight the level will be in the region of 10,000-25,000 LUX. Thermal comfort is also of great importance for human well-being. It is measured in degrees, and ideally should be fairly constant, within a range of 20°C-22 °C, without draughts. The challenge can be to avoid overheating in summer, and to avoid getting too cold in the winter.

Acoustic levels are measured in decibels (dB), and appropriate levels are important for the ability to concentrate. The normal level in an office is around 65-70 dB, and if the levels are higher for longer periods of time, it can have a negative effect on your general well-being.

Live monitoring of buildings' indoor environment enables us to evaluate – and subsequently improve – the overall performance of the building, and thereby the comfort and well-being of its occupants.

Daylight is essential for sustainable urban development and is an important factor to consider when designing buildings and shaping our cities, offices and homes. Daylight helps to balance our 24-hour Circadian rhythm, and is vital to our general health and well-being.

Source: VELUX Modular Skylight, 2017

Interview

Vinay Venkatraman, CEO at Leapcraft, and Internet of Things and Data Specialist for Green Solution House.

Tell us about your collaboration with VELUX and Green Solution House

Leapcraft specialises in sensors for the built environment and cloud solutions for data analytics. For Green Solution House, we have deployed a range of sensors that capture data on indoor climate, thermal performance, light levels, energy demand and supply, as well as water consumption and a whole range of other values that we are gathering from the building.

Why is this important?

We have had a very interesting discussion with VELUX about how to anchor building data in a way that can drive positive behavioural change in the built environment. Early on we agreed the need for a holistic balance in evaluating building performance. Green Solution House has sustainability values built into its core DNA, so the question became how to amplify this while enabling different products and services to interact.

Where do you see the value of data for the built environment?

Real-time building data enables a fine-grained approach to building management and performance. It also enables pattern recognition over time. By analysing historical data, we can look for patterns that inform building performance and this can be very effective in driving better solutions for indoor climate and energy efficiency, while improving well-being for the buildings' users.

How will monitoring and data affect the built environment in the future?

This market is going to grow exponentially. Almost every product and service provider will have to embrace data in one way or another in the future. The technology used in building sensors is getting cheaper and more effective, while the technology for storing and processing large data sets is also coming down in cost. This is allowing both large and small actors to access these technologies.

What becomes interesting is scalability. You can go from a prototype to an exponential service very fast and that will change market dynamics. The big question becomes what you do with that data in order to provide meaning and significant value to the users of a building. That is driven by social science, interaction design, technology development and architecture, all coming together in new types of solutions which we have not seen before.

"Our ambition is to enhance people's well-being by empowering people with data and quantifying the built environment in real time"

Vinay Venkatraman, CEO Leapcraft

Quantifying an Active House

Case Study:
Green Solution House,
Bornholm

4
variables
were measured: CO_2, noise, humidity and temperature.

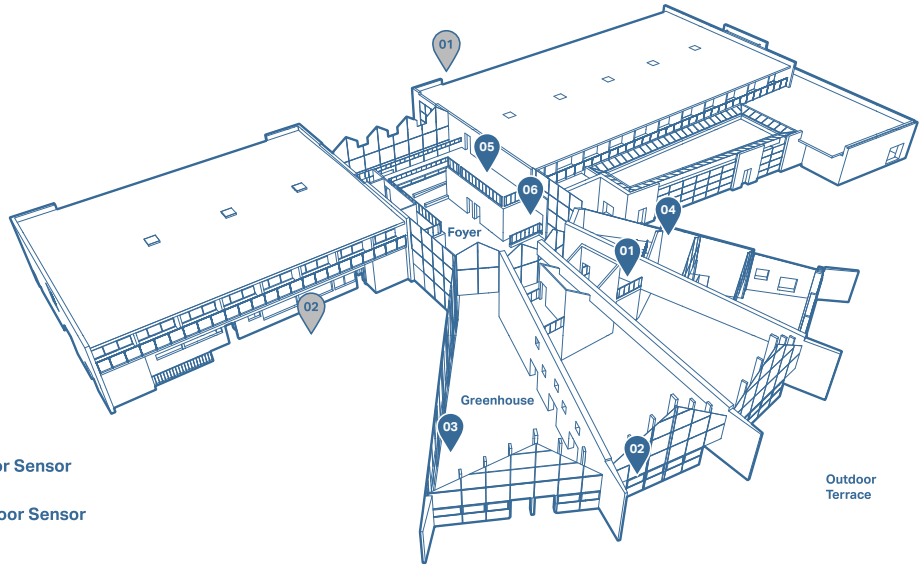
98
percent
of the time, sensors were active (2% due to lost Wi-Fi signal).

2 spaces
had sensors installed; the Foyer and the Conference Hall.

13 **sensors**
were installed in total.

Measuring the performance of an Active House

The Active House framework provides an opportunity – and a methodology – for tracking a building's performance, not only in terms of energy efficiency, but also from an indoor comfort and environmental point of view. Green Solution House was monitored in order to measure a range of parameters, and this data was then split into two parts: building performance, and occupancy detection (event classification).



The experiment required 13 sensors to be installed throughout the Green Solution House.

Foyer

The Foyer at Green Solution House is a well-lit space, and the first point of entry for visitors to both the hotel accommodation and conference centre. Environmental factors were measured in each area in order to monitor its performance against the parameters defined within the Active House framework, and also to provide a basis for measuring occupancy, and thereby establishing a pattern of usage.

Performance
Temperature in the Foyer slowly decreases as autumn gives way to winter and outdoor temperatures fall. Nevertheless, the temperature inside the Foyer stays well within the optimum range (class 4) of values as set out by the Active House principles.

Due to the nature of the space, fluctuating noise levels were expected. Absolute noise levels were low between 1am and 6:30am, but increase rapidly with the start of the working day, rising above the 40dB threshold. High levels of noise are attributed to specific events occurring in the space.

The Foyer is periodically ventilated via façade and roof openings, so fluctuating relative CO_2 levels were expected. Fresh air brought in through the door brings values down closer to outdoor levels of CO_2. The lack of abnormal increases in CO_2 levels suggests that a thorough exchange of air is occurring.

Event classification
High-occupancy events were identified by utilising parameters measured by the sensors, along with pre-existing information about the space. Based on these measurements, occupancy and presence patterns differ during the course of the day.

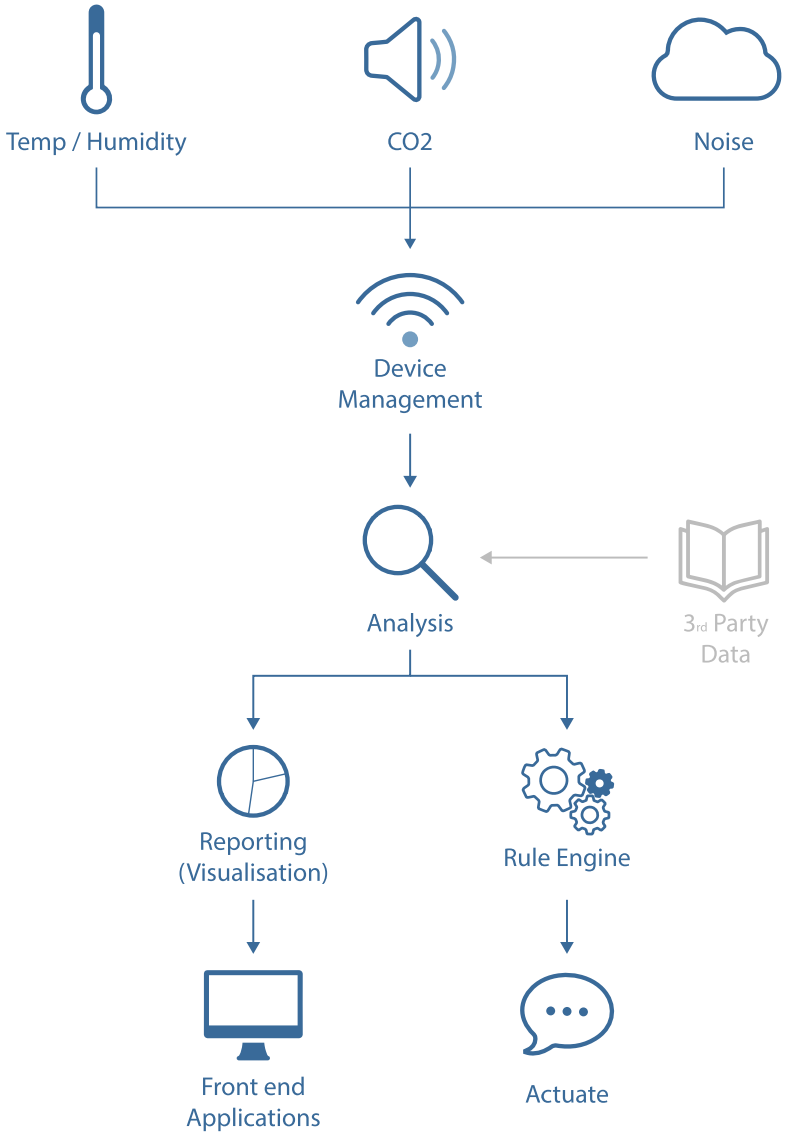
Parameters: noise became the main parameter for determining occupancy. Values frequently passed the prerequisite threshold, meaning that events were classified on a large number of days.

Usage pattern: the Foyer received high levels of traffic throughout the day, in a fairly random pattern. Additionally, the Foyer acts as a hub for other activities.

Outcome: the information collected was valuable in determining when usage was occurring; however, the noise variable needs to become more reliable and refined if the nature of occupancy is also to be determined.

Data variability explained:

"The devices send data only when a change of considerable magnitude is registered by any of the available sensors"
-AmbiNode
Source: Leapcraft, 2017



Data Architecture. Various parameters are harvested from sensors, analysed and visualised through a number of methods in order to make sense of the data.

Conference Hall

The Conference Hall is also predominantly day-lit, but is spatially different from the Foyer. It experiences varied use, mainly for corporate events, and therefore sees periods of heavy use interspersed with periods of little use. Identical factors as those measured in the Foyer were monitored in order to quantify building performance, and to identify occupancy and pattern of usage.

Performance

Due to the Conference Hall not being continuously accessible, the effects of external actions have a less significant impact. Over the measurement period, daytime temperatures were stable at 24°C, but taking into account outdoor values the room performs primarily in class 2 and 3, with occasional dips into class 1 performance.

The Conference Hall is not a standard space in terms of usage. Although visible, it proved difficult to identify continuous patterns. Different days have different variations in noise levels, and this provides additional information that can be used for classifying events.

The Conference Hall exhibits a stable CO_2 concentration throughout the measurement period, likely due to the lower number of air exchanges that take place. There are some instances in which the relative value reaches around 400ppm, which would indicate occupancy of the room.

Event classification

Parameters: the predicted parameter (CO_2) failed to provide enough resolution to be useful. Therefore, noise levels above a baseline of 35dB were taken as a threshold by which to classify an event. A hand-logged data set was also used as a guiding value.

Usage pattern: the Conference Hall experiences occupancy in a block-by-block pattern. Occupancy increases rapidly at the beginning of an event, stagnates with minor changes during the event, and then slowly dissipates toward the end.

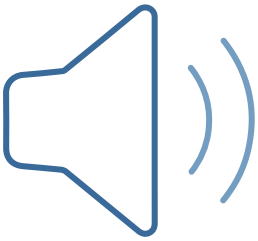
Outcome: despite the risk of false-positive values, noise values – along with a hand-logged data set provided by the establishment – provide sufficient information for classification of an event. A labelled dataset would certainly provide a more comprehensive categorisation of events in the Conference Hall, but a lack thereof does not hinder the overall identification process.

Why measure occupancy?

The ability to classify events occuring within the Conference Hall provides valuable information regarding usage of the space.

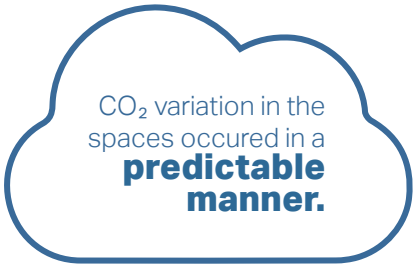
Source: Leapcraft, 2017

Preliminary predictors of operational mechanical ventilation systems were visualised, with **limited correlations** to actual ventilation operation.

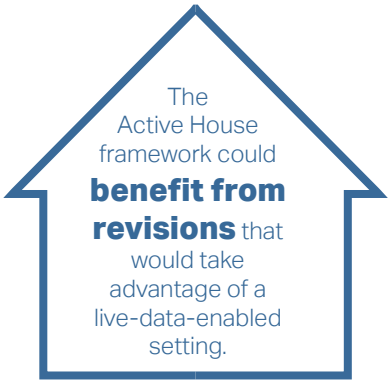


Noise data collected acted as a **strong indicator** of occupancy.

The key findings provide a **strong foundation** from which to perform more thorough analysis based on the dataset.



CO_2 variation in the spaces occured in a **predictable manner.**



The Active House framework could **benefit from revisions** that would take advantage of a live-data-enabled setting.

Changes in temperature and humidity proved to be **in line** with the Active House principles.

The experiment produced the above key findings.

Conclusion

Controlled monitoring of ambient environmental parameters at Green Solution House over a period of time displayed a close relationship between the performance of the built space and its underlying principles. This longitudinal data was vital in seeing performance across the different seasons – especially winter, when building performance comes under stress.

Nevertheless, the parameters measured would require higher resolution and more clarity in order to identify detailed trends within the study. Some of the issues encountered were due to artefacts created by the hardware that required processing after the study was complete. Yet, in spite of the resolution issue, the parameters of CO_2 and noise are good – if not perfect – indicators of occupancy.

Further data generation across the different seasons would provide more insight, as changes in human behaviour and outdoor weather conditions subsequently impact the indoor climate.

Overall, this experiment provided a good baseline and the necessary insights from which to develop a stronger test-case in the future. It also provides reasonable empirical data to support the case for the Active House framework. This is an exciting juncture, in which different stakeholders have the chance to subscribe to the Active House framework and stay committed to its goals over time.

For more in depth analysis of the experiment, please refer to **'Active House Live: Quantifying an Active House'**
(Leapcraft, January 2018)