

# BOLIG+

Denmark's first  
net-zero energy  
apartment building

Realdania

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Byg



## COLOPHON

BOLIG+ Denmark's first net-zero energy apartment building

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Denmark's first net-zero energy apartment building.

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**BOLIG+**  
Denmark's first  
net-zero energy  
apartment building



**The building's architect, engineer, contractor and owner have achieved what initially looked like a utopian dream: A net-zero energy apartment building.**

## BOLIG+

**Halfway along Søborg Hovedgade (a street in the suburbs of Copenhagen) there is an instantly noticeable break in the row of yellow and red apartment buildings.**

The black-and-white building is the manifestation of a vision which began taking shape in 2005 in connection with EnergyCamp 05. At this event a number of representatives of the building/construction sector debated a new approach to developing energy-efficient homes for the world's growing population.

The thinking behind BOLIG+ arose from a dissatisfaction with the industry's direction and lack of speed. They were conceived by people who dared dream lofty dreams without reference to restrictive conventions about whether certain things were possible. From those invigorating discussions at the energy camp the idea emerged of a net-zero energy building, i.e. a building which would be genuinely energy neutral.

The novel principle was that the building should be capable of producing enough energy

to meet its own consumption needs. Not just for heating, hot water and ventilation but also the building's other needs – including household consumption of electric power.

At the same time, it was a key requirement that it should be possible to erect the building within a normal construction budget.

If BOLIG+ were to be a serious wake-up call to the industry, the building would not have to be an example of expensive technology; on the contrary, it would have to prove itself an equal alternative to ordinary building methods.

BOLIG+ had to demonstrate that energy-neutral building was a question of determination. But the prime requirements of energy production must not be allowed to push aside other important parameters – such as indoor climate and architecture.

To kick off the project the BOLIG+ working group formulated five dogmas on which the building should be founded:



### ■ Energy neutrality

The term energy neutrality is used here to mean that the BOLIG+ building – on its own site – must be capable of producing the same volume of energy as the building and its occupants consume. This means that the energy the building exports (i.e. sells as excess power from its solar panels) must have the same energy value as the energy it imports (i.e. buys from the local district heating network and the power grid). We must be aware that not all energy is equal. There is a difference between the amount of energy raw material required to produce 1 kWh of district heating and 1 kWh of electric power. Heat made available through district heating has an energy factor of 0.6, while electric power has an energy factor of 1.8. In other words, electricity is expensive to use but conversely also a valuable sales commodity, and in this context surplus power production from the building's solar photovoltaic (PV) panels contributes to energy neutrality.

### ■ Indoor climate

One of the essentials in the BOLIG+ project is a good, healthy indoor climate

– with all apartments in the building enjoying pleasant daylight, the right temperature, and good ventilation with the option of natural ventilation in all rooms.

### ■ Flexibility

Flexibility in this context means that rooms in the residential units can be used for a variety of purposes, permitting them to change their function over time without relying heavily on resources for the alteration work.

### ■ Intelligence and user friendliness

BOLIG+ will integrate systems which – by means of monitoring, measuring and demand management – can help towards energy neutrality while at the same time they enhance the usefulness of the dwelling by, for example, providing the option of adjusting systems individually.

### ■ Location and architecture

BOLIG+ must comply with functional and energy requirements while at the same time preserving high architectural quality. And the building must be appropriately in keeping with its surroundings.

### Bordering on the utopian

Since the idea for BOLIG+ was mooted at EnergyCamp 2005 the concept has been carried by a steering group comprising representatives of IDA-BYG (Danish Society of Engineers), Danish Architects' Association, Danish Energy Agency, Technological Institute of Denmark, Danish Building Research Institute and Danish Ecological Council.

The essential point from the outset for BOLIG+ was the ambition to achieve energy neutrality. This parameter was defined for the other four dogmas, and when the consultants' competition for BOLIG+ was held in 2009 it became clear that this was a highly ambitious project. Bordering almost on the utopian.

One of the most absolutely difficult nuts to crack was to solve the problem of how to produce enough on-site energy to enable the building to be energy neutral. With the requirement that the energy had to be produced on the plot of land occupied by the building, this limitation in effect meant only one viable option: solar energy. Initially, 40 consortia took part. These were reduced in the final stages to a field of five, and out of this handful the successful contestant was TEAM+ lead by Arkitema Architects.

The competition was originally for a high-rise building with 74 dwellings,

located on the waterfront in Aalborg. The intention was to sell half of the residential units before work began, ownership of the remaining units being shared between the contractor and Realdania Byg, who had joined the project in 2008 as building owner/client.

But the effect of the economic crisis and the rollercoaster ride that hit the building industry in the late 00s shut down that aspect of the project before it got off the ground. After the attempt in Aalborg, Realdania Byg tried to find a new site for a redefined version of BOLIG+, and in 2013 the location on Søborg Hovedgade came on the market.


The principles behind the Arkitema team's winning proposal still provided a sound foundation for the construction process – so after extensive adaptation of the project to the new location, work on BOLIG+ managed to continue.

This book tells the story of how the building came into being and the thoughts that lay behind it. And of how the architect, engineer, contractors and owner together have delivered what started out in a utopian glow but has since given Denmark its first net-zero energy apartment building.



# The search for zero-energy building

Battling carbon emissions  
We consume more than we think  
Raising the bar



## The search for zero-energy building

The desire to create sustainable homes with a low consumption of energy has been felt throughout the Danish building industry, and there has been no shortage of names: low energy, zero energy, passive buildings, active buildings, etc.

What makes BOLIG+ special, however, is that it goes a step further than other concepts. The crucial difference is the dogma that the building itself should produce its own energy.

Until now, “energy-neutral” has meant producing enough kWh to equal energy consumption for space heating, heating domestic water and powering ventilation systems.

But, of course, that’s only part of the energy a home actually uses. The BOLIG+ way of looking at things is that all the electricity drawn out of our power sockets to keep our refrigerators, TVs, electric kettles and iPads alive is also part of the total picture. So is the energy used to light the stairway, power the front-door intercom, and everything else in shared, communal areas.

The ambition for BOLIG+ is to achieve “zero-energy building” so that a household leaves no carbon footprint when it comes to the energy needed to run the home.

### **Battling carbon emissions**

Aiming for a target of energy neutrality is part of the basic motivation behind the BOLIG+ concept – namely, to reduce carbon emissions from new-build Danish homes. Our homes and the lives we live in them account for such a large share of society’s total carbon emissions that we cannot afford to ignore this, if we are to achieve a general reduction in CO2 emissions. And BOLIG+ principles tell us that our private power consumption is no small factor. For example, in a new apartment in a high-rise building constructed according to current building regulations (in Denmark: Building Regulations

2010 / BR2010) electricity accounts for no less than 56% of a household’s total CO2 emissions.

It is no accident that BOLIG+ focuses sharply on electricity consumption; as a society we have not yet managed to get our consumption under control. Whereas our consumption of water and heating has declined markedly over the past decade, electricity consumption has stubbornly static. True, the electrical appliances and devices at our disposal are more energy efficient – but at the same time we’ve acquired more of them and use them so much that our power consumption remains high.

In the BOLIG+ concept, a household’s annual energy consumption has been set at 1,725 kWh. This is an ambitious target set on behalf of occupants, and it assumes that household appliances used in the building are low-energy rated and that occupants make a conscious effort to limit their electricity consumption.

### **We consume more than we think**

BOLIG+ bases its recommendations on the highest existing standards in Denmark for energy-efficient buildings, i.e. those laid down in the BR2020 regulations (building code). But BOLIG+ doesn’t just add the 1,712 kWh on top of the energy consumption permitted for a building built according to BR2020.

According to BOLIG+ the assumptions on which BR2020 is based are actually over-optimistic. And when the ambition is to be genuinely energy neutral, calculations must be based on realistic figures.

BR2020 assumes in its theoretical model that the “model citizen” lives in an indoor temperature of 20 C, but studies have shown that in the real world this figure is on the low side. The ambient temperature in average Danish living rooms is closer to 22 C.





**In the BOLIG+ concept, a household's annual electricity consumption has been set at the ambitious figure of 1.712 kWh**

A similar pattern applies to household water consumption. Whereas BR2020 is based on consumption of 250 ltr per m<sup>2</sup> annually, studies show that consumption is significantly higher in the case of apartment dwellings – actually 67% higher in apartments of the BOLIG+ building type. In the BOLIG+ project it is reckoned that people need 40 ltr of water per person per day.

At the same time BR2020 operates with a secondary heat source in dwellings from lighting and electrical appliances. In BOLIG+ residents naturally use LED bulbs and energy-efficient appliances in order to minimise their electricity consumption. This produces a minimum of heat; BOLIG+ therefore assumes that a heating supplement is likely to be 41% lower than BR2020.

### **Raising the bar**

These modifications alter the rules of the game. To qualify as energy neutral according to BR2020 standards, a building such as that on Søborg Hovedgade would be required to produce 19.1 (p) kWh/m<sup>2</sup> p.a. Under the BOLIG+ standards the bar has been raised significantly – the figure is now 28.5 (p) kWh/m<sup>2</sup>. To this should be added the 1,712 kWh for each household's annual power consumption and shared consumption in basement and stairwell. Total of 2.2 times the energy consumption of BR2020.

That is the challenge facing the architect and engineer – who must apply their joint skills to designing a building which uses so little energy that enough solar energy can be generated in that building to meet all its energy requirements.



## **An integrated design process**

Workshops drove the project  
Tyranny of the solar panel?  
Adjusting ventilation and windows

**Solar PV panels on the roof of BOLIG+**  
The panels are constructed as mini roofs, with a 12.5° pitch, one surface facing SE, the other NW. The roof of the building is fitted with 182 m<sup>2</sup> of solar panels.



## An integrated design process

**When the competition specifications for BOLIG+ were announced, it was clear to everyone that this was an ambitious project. If the stringent requirements were to be fulfilled, it was equally obvious that it would take all available skills – it was inconceivable that the project would succeed if the architect first produced his proposed design, then invited the engineer to make it work in terms of energy.**

In other words, the BOLIG+ project called for an integrated design process – clearly with the architect and engineer as the central players but also with key contributions from the owner and other stakeholders.

### Workshops drove the project

As already mentioned, TEAM+ won the competition for the original BOLIG+ project in Aalborg.

Most of the integrated design process behind BOLIG+ took place in connection with the Aalborg competition. Structurally, the process was built up around five workshops. Before each workshop, all the parties involved researched their relevant problem areas and submitted the results to the other participants to enable the workshop to proceed as constructively as possible.

*“It was obvious from the outset that it would be very difficult – technically – to achieve complete energy neutrality. When I first heard of the idea, I didn’t really think it could be done.”*

Lars Kvist, project leader, Arkitema

The approach to the task was that each workshop involved preparation (input) which could feed the discussions that were necessary at that stage of the process (agenda), and that these discussions were to result in something specific with which each of the respective skills could continue working (output). This tripartite structure helped to ensure the right rate of progress during the three-month period of debate.

Another key element on the way to a successful project was to make sure the knowledge curve rose steeply – while postponing decisions until the right basis in place.

Although the project in Aalborg was never realised, many of the decisions settling certain principles could be reused in the Søborg project.

### Tyranny of the solar panel?

In the Søborg version of the BOLIG+ project the integrated design process spent serious time examining the issue of how the building’s balconies should be designed in order to produce as much electricity as possible without pushing the other key BOLIG+ dogmas to one side.

Balancing the needs of energy, architecture, economy, privacy for neighbours, and views from the balconies was done carefully based on many different options. At one stage in the process there was some discussion of covering the entire south-facing side of the balconies with photovoltaic panels on the grounds that it would yield the greatest electrical benefit.

Although the kilowatt harvest was tempting, the price was too high. It would reduce the view and thus – to a large extent – the quality of individual dwellings. As Arkitema’s project leader put it: It would be the “tyranny of the solar panel”. The architectural idea of BOLIG+ was that it should be a white building with black squares, not a black building from which the occupants would be lucky if they could peek out from behind solar panels.

### Adjusting ventilation and windows

The ventilation system was something else the integrated design process had to debate before finding an appropriate technical and architectural solution. As will be discussed later in the book, the team opted for a decentralised ventilation system with outlet and intake in the facade, and before agreement was reached on the location of these, the windows were moved to various positions to determine the right distance between the elements.

## **BOLIG+ in Søborg**

Austere facade  
Solar panels behind black panelling  
Balconies turned and twisted  
Sedun on the roof  
Walk in and look out  
Light and spacious  
Finding the balcony balance  
Flexible layout



**In checkerboard fashion the corners of the squares meet precisely, dividing the facade sharply into whites and blacks.**

*“The BOLIG+ building takes its place in the row of high-rise buildings along the street, in many ways reflecting the character of the area – but at the same time pointing to new horizons. It will be a proud landmark.”*

Lars Kvist, project leader, Arkitema

## BOLIG+ in Søborg

**When you drive down Søborg Hovedgade from the north, at one point up ahead a new building seems to have sprouted in the middle of the road. You have found BOLIG+.**

The eye-catching location is admittedly an optical illusion, arising from the fact that the land on which the building stands is high and around a bend in the road – but it is in its own way a suitable setting for a building which in many ways stands out from the neighbouring buildings.

### **Austere facade**

As you come closer you begin to see the building’s dimensions and architecture. Five storeys housing a total of 10 apartments behind a distinctive facade of black and white squares. In checkerboard fashion the corners of the squares meet precisely, dividing the building facade sharply into whites and blacks. Close up, you can see exactly how accurately the corners of the high windows meet.

Mathematical precision was essential – even the width of the window seals was a factor – and the result is an austere simple facade.

The building continues unbroken as a white noise barrier wall snaking along the edge of the plot facing Søborg Hovedgade and turning into Hagavej. The 2.5-m high wall has been built as a noise-abatement device against the traffic on Søborg Hovedgade (the local development plan stipulates a low noise level in the adjacent garden).

### **Solar panels behind black panelling**

The interplay of colours on the facade between the white-painted concrete and the dark panel-

ling is not simply an expression of the architect’s visual preferences: it is the most visible indication that every effort has been made to squeeze as many kWh out of the building as possible.

The large, black panels on the closed balconies along the facade and on the south-facing gable conceal 203 m<sup>2</sup> of PV panelling. Normally, the building owner will choose to install solar PV panels only on the roof, which is both the most effective and the least visible place. The challenge, however, is that as soon as a building is more than two storeys high it becomes difficult to produce enough solar energy on the roof surface to cover the building’s consumption. Which was why it was clear from the beginning that it would be necessary also to place PV panels on the facade.

From the architectural point of view it was a relatively simple exercise to locate solar panels on the SW-facing gable. It was mainly a question here of having solar panels made to dimensions great enough to cover the facade surfaces between the gable windows. Among the black panels a few white rectangles peek out to offer an interplay of colours against the dark surfaces. One small example of how the dogmas – in this case energy requirements and architecture – are constantly challenging each other, needing care and consideration in striking the right balance.



Five storeys housing a total of 10 apartments behind  
**a distinctive facade of  
black and white squares**

**The aim when designing the balconies was to achieve the optimum balance between architecture, economy, energy production, views from within, privacy from the outside, and natural daylight.**

### **Balconies turned and twisted**

Placing solar panels on the west-facing facade skirting Søborg Hovedgade was a much more complex process – because it was on this facade that the building’s balconies had to be located in order to provide an overview of life on the street.

The final design was to create closed, double balconies as distorted rectangles. The shape had by no means suggested itself naturally; it was the result finally of close interaction between architect and engineer, who had calculated many different options on the way.

The simplest solution would have been to place rectangular boxes on the outside of the building – but that did not promise to be the most relevant shape to accommodate the many performance standards, including maximum sq.m. of solar panelling facing south and west. So the shape that finally emerged – at first glance a triangle – is actually a trapezoid (four sides, none of them parallel).

Two of the long sides face south and west because these angles make best use of the sun’s rays. The shortest side faces north-west, and normally solar PV panels would not be installed on a NW-facing facade. It was decided, however, to do this on BOLIG+ for two reasons: Firstly, calculations showed that it would pay because the white building reflects an adequate amount of sunlight, which shines on the NW surface and contributes to energy production. And secondly, because there is an architectural point in having uniform cladding on all visible sides of the balconies.

The number of balconies has also been the subject of debate; the initial intention was to provide a separate-unit balcony for each of the 10 dwellings. Instead it was decided to build five double balconies, and by combining them it was possible at the same time to minimise shadows on the facade-mounted solar panels.



### **Sedum on the roof**

When you enter the driveway access to BOLIG+, you find yourself in a paved courtyard containing 10 parking spaces under a green carport roof. There is a bed of sedum – a mixture of different stonecrops – on the roof of the carport and of the waste-disposal compound.

Sedum also grows on the two balcony roofs that can be seen from the top-storey apartments. There are several reasons for using roof vegetation. It is more interesting for residents to

look down upon the green and red shades of the stonecrop beds than on black roofing felt, and the plant itself offers a number of benefits. As opposed to roofing felt, sedum does not generate heat around the building – which has a positive effect on the indoor climate in the apartments. Sedum absorbs and retains rainwater during heavy showers, offering some relief to the drainage system. It also provides a habitat for insects at the bottom of the food chain.



**There is access to BOLIG+ from both the street and the courtyard – an entrance corridor cuts through the building between the technical-services room and storage room.**

### **Walk in and look out**

When you step inside the BOLIG+ building, you walk across a concrete floor from which a stairway leads to the four storeys upstairs. The ground floor is used only for a technical-services room, general-storage space, drying room, and bicycles.

The stairwell occupies a compact area, and both stairwell and stairs are in raw, grey concrete. There are three apartments on the 1st floor: one two-room (83 m<sup>2</sup>) and two three-



room (89 m<sup>2</sup>). The 2nd floor has the same layout, while the 3rd and 4th floors each hold two large apartments: one three-room (113 m<sup>2</sup>) and one four-room (137 m<sup>2</sup>).

Whichever of the three apartments you enter, the first thing that greets you is an outside view – via either the balcony or an (almost) floor-to-ceiling window. From the windows on the 4th floor you can – on a clear day – see all the way to Sweden.







## Finding the balcony balance

The balconies were one of the elements the team spent most time thinking about. The aim was to achieve the optimum balance between architecture, economy, energy production, views from within, privacy from the outside, and natural daylight.

These considerations have all been taken care of in the balconies' shape and angles – but in addition the balcony design had to create an attractive space, while preventing balconies from causing overheating or cooling of the building.

One of the key requirements was that balconies should be enclosed. This was necessary on account of traffic noise from Søborg Hovedgade – closing the balconies would be the only way to keep them within the dB requirements of the local development plan, and when both windows and the balcony door are closed traffic noise is largely silenced.

Often, enclosed balconies would be viewed as an opportunity to secure an extra insulating element – a heat buffer between the outside and inside. But as BOLIG+ is already so well sealed and insulated, there is little to be gained from having an extra layer of insulation. On the contrary, a sealed balcony would add extra heat, which would upset the indoor climate and increase energy consumption for ventilation and cooling.

The sealed nature of the balconies has therefore been deliberately “manipulated”. The windows are single glazed, and ventilation openings have been designed so that they cannot be closed.

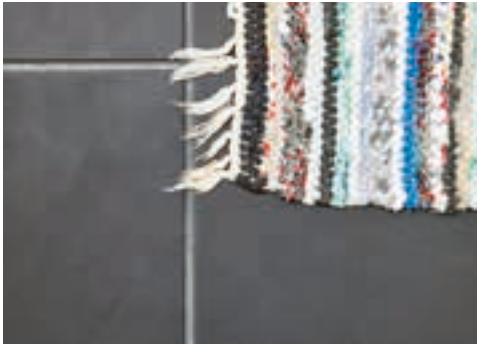
In addition to reducing any tendency for the apartment to overheat, the “leaky” balcony – paradoxically – has another, contrary function: It counteracts heat loss.

It ties up with the fact that it is important that residents don't feel tempted to expand the living room by a few extra sq.m. by letting the balcony door remain chronically open. If they do, the thermal loss from the apartment will be excessive – requiring too much energy to be used for heating. It has therefore been necessary to strike a balance between a balcony which on the one hand is seen as an asset but on the other is not such an attraction that it is included as part of the living room.

To establish a clear differentiation between the living room and the balcony, the latter has been floored with larchwood boards, and its general construction is more primitive, with fibre-cement sheeting on the sides and woodwool on the ceiling. At the same time the door opens to the narrow side of the balcony. A discreet nudging element which makes it less likely that the balcony will be used as an extension of the living room.

In addition, a window system has been chosen with sliding windows, offering flexibility as to how much to open and in which direction. As a result, it will almost always be possible to sit sheltered, enjoying sunshine and fresh air on the balcony.

The balconies have a drainage system ensuring that any rain entering through open windows is conducted to the down-pipe. Another feature: All balconies are higher than street level, enabling residents safely to leave their sliding balcony windows open – also at night or when they leave the apartment.



### Light and spacious

Daylight passing through the balconies and high windows helps to create a sense of spaciousness, emphasising the experience of the light and large rooms encountered elsewhere in the apartment.

One of the factors creating spaciousness is a ceiling height of 2.64 m. One becomes extra conscious of ceiling height in the kitchen area, where the ceiling has been lowered to provide space for the ventilation system. The difference between the two ceiling heights frames and delineates the kitchen despite the fact that it shares an open plan with the living room, and the two levels contribute to the dynamic nature of the two rooms.

The open kitchen/utility room is the heart of each apartment, flooded with daylight from both the balcony and the full-height windows. The apartments have ashwood parquet flooring, and the walls are skim-coated. Instead of putting up a plastered ceiling, it was decided simply to paint the concrete surface; with its v-joints it offers a simpler appearance than a smooth plasterboard ceiling would have done. However, an interesting contrast emerges between the gently

raw concrete deck and the finer, lowered plaster ceiling above the kitchens and entranceways. At the same time, the decision not to have a plasterboard ceiling has created a few extra centimetres of ceiling height.

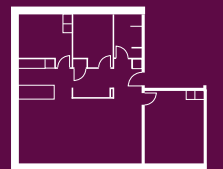
The white kitchen is equipped with energy-efficient appliances to keep electricity consumption to a minimum, and the bathroom simply has square black klinker tiles on the floor and rectangular white tiles on the walls. The bathroom is illuminated by LED spotlights in the ceiling – controlled by a motion sensor – and there are water-saving taps in the shower compartment.

### Flexible layout

One of the BOLIG+ guiding dogmas is that the building should be flexible in use over a period of time. To satisfy this dogma, the architect and engineer have made only the external walls loadbearing, none of the internal wall – permitting a complete change in layout if the need arises. At the same time, a structural panel in the concrete wall between the apartments on the 3rd and 4th floors respectively can be removed and transformed into a door – creating a single apartment occupying the entire 3rd or 4th floors.

# BOLIG+

## Come in and have a look

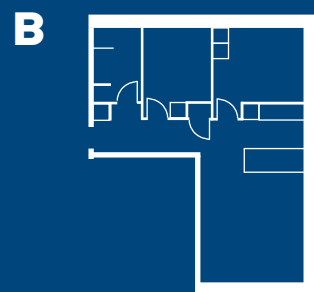
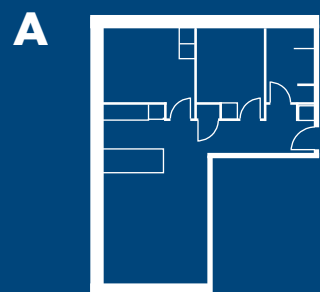


## 1st and 2nd floors

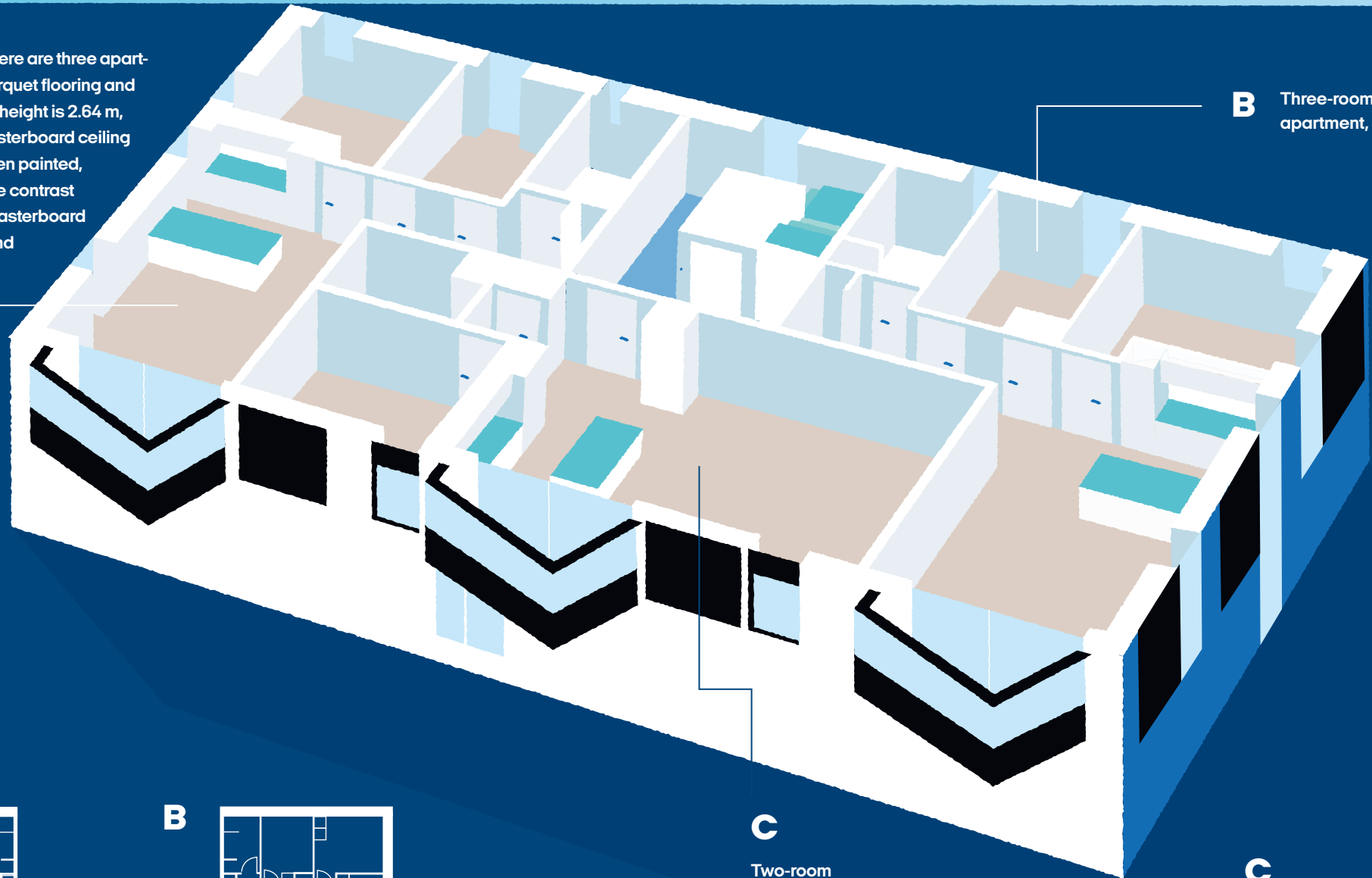
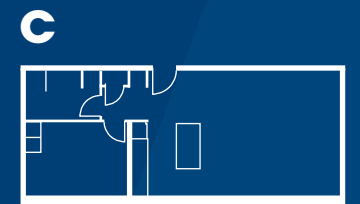
On the 1st and 2nd floors there are three apartments, all with ashwood parquet flooring and skimmed walls. The ceiling height is 2.64 m, and instead of having a plasterboard ceiling the concrete has simply been painted, which provides an attractive contrast with the finer, suspended plasterboard ceiling above the kitchen and entrance hall.

**A**  
Three-room  
apartment, 89 m<sup>2</sup>

**B**  
Three-room  
apartment, 89 m<sup>2</sup>



**C**  
Two-room  
apartment, 83 m<sup>2</sup>

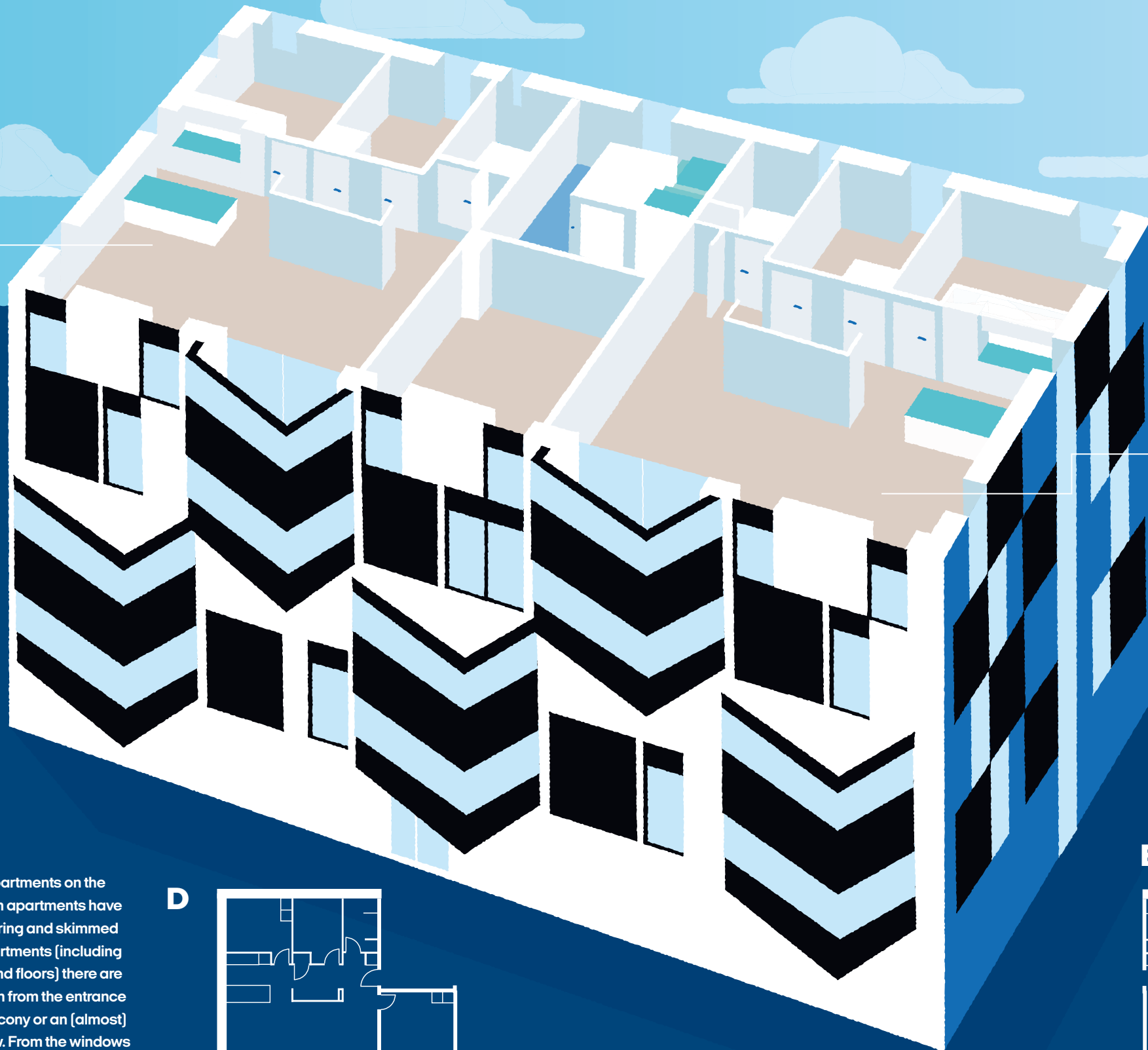
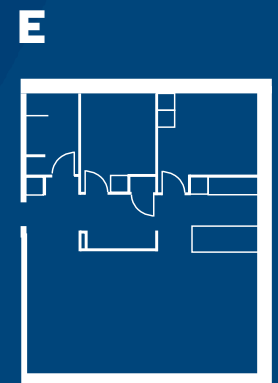


## 3rd and 4th floors

**D** Four-room apartment, 137 m<sup>2</sup>

**E** Three-room apartment, 113 m<sup>2</sup>

There are two large apartments on the 3rd and 4th floors. Both apartments have ashwood parquet flooring and skimmed walls, and from all apartments (including those on the 1st and 2nd floors) there are fine outside views even from the entrance hall – via either the balcony or an (almost) floor-to-ceiling window. From the windows on the 4th floor there is – on a clear day – a view all the way to Sweden.







## Technology behind the facade

- A tight building envelope
- Ventilation for individual needs
- Recovering heat from the shower
- Good old-fashioned radiators
- Take the lift
- No heating on the ground floor



# Technology behind the facade

There are two basic phases in creating an energy-neutral building: First, you plan the building and design it to use as little energy as possible, then you set up an energy production to meet what energy the building will actually need.

The very first step is to choose a dwelling type. Instead of building 10 single-family houses, BOLIG+ gathers the 10 dwelling units into a set of apartments in a high-rise property. This enables the homes to share a building envelope, reducing the surface through which heat can be lost. This solution halves heat consumption.

BOLIG+ has been built in accordance with Danish BR2020 standards – which stipulate, for example, an energy framework in which energy consumption does not exceed 20 kWh/sq.m./p.a. And that includes energy for heating, hot water, ventilation and any necessary cooling.

By adopting BR2020 standards instead of the current BR2010 standards, it is possible to reduce energy consumption by 60%.

The lower energy consumption is achieved by measures such as:

- Improving the tightness of the building's thermal envelope
- Demand-controlled ventilation with a mechanical solution to recover heat
- Heat recovery on the hot-water system.

## A tight building envelope

Having a tight building envelope is a decisive factor in energy consumption. Nothing moves heat faster than air which is allowed to move. The full effect of optimum insulation of a building will not be obtained until leakages are eliminated through which heat can escape.

Airtightness is achieved by combining a simple construction with good components and careful execution.

The simple construction is a building executed with concrete panels in walls and floors in which the concrete construction – assuming tight joints and seals – is in practice airtight. The biggest challenge is to obtain fully airtight joints between the concrete inner leaf of the cavity wall and window frames; for this purpose BOLIG+ used vapour-barrier foil with taped joints. The next key step is to ensure the effective sealing of all pipe and cable sleeves.

An ambitious tightness standard brings with it not only reduced heat loss (ventilation loss) but also higher quality of on-site execution.

The measure of a building's tightness is defined by BR2020 as 0.5 l/s per m<sup>2</sup> in a pressure test of

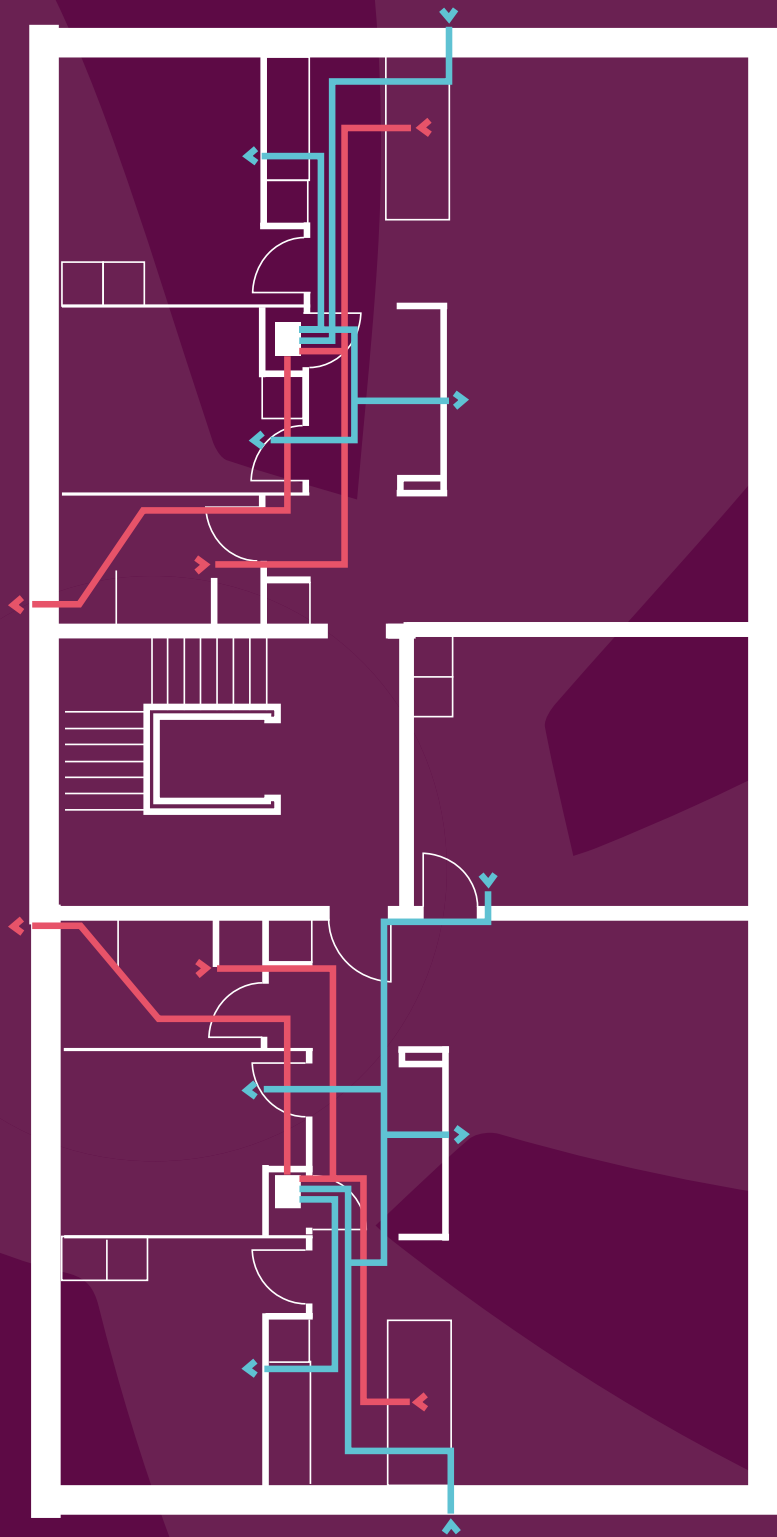
50 Pa. In BOLIG+ a blower-door test showed 0.4 l/s per m<sup>2</sup>.

BOLIG+ is an example of how much can be achieved by using the finest materials and methods for insulation and tightness.

## Ventilation for individual needs

The ventilation system in BOLIG+ is special in several respects – both strictly technically and in the manner in which it has been installed. To keep energy consumption to a minimum BOLIG+ opted for a local, demand-controlled ventilation system.





**The ventilation system** used in BOLIG+ is under individual control: each of the 10 apartments has its own ventilation system. Air is taken in at the gable (blue piping) and expelled towards the garden (red piping). By placing the air outlet adjacent to bathrooms, close to the stairwell – instead of close to living-room or bedroom windows – the nuisance of cooking smells experienced in the other apartments is minimised. The air intakes receiving incoming air are located on the gable behind solar panels, thus harnessing the heat from the panels.

In winter the system is controlled by the moisture level; the manual use of the kitchen extractor fan also contributes to ventilation. However, the system is permanently switched on, producing min. 0.3 l/s per m<sup>2</sup>. Natural ventilation is used in summer, when the basic setting is off – but switches on in response to a PIR sensor in the bathroom and on manual use of the kitchen extractor. The system switches automatically between winter and summer operation depending on the outdoor temperature.

The alternative to demand-controlled ventilation (DCV) would be a ventilation system which operates continuously – which for one thing would consume vastly more energy and for another would not function optimally in relation to the indoor climate. The problem with systems which have continuous, permanent ventilation is that they usually generate too much or too little ventilation.

When there is no need for ventilation, the system runs anyway – and when the need does arise, it seldom provides enough ventilation for the job.

*“We’ve tried to minimise the need for mechanical ventilation by offering useful options for natural ventilation. All rooms have one or more windows which open – but they can also be locked, allowing them to be left slightly open even when the occupants aren’t at home.”*

Simon Kamper, engineer, MOE

For these reasons, a demand-controlled system is advantageous to both the indoor climate and energy consumption. The ventilation system used in BOLIG+ is under individual control: each of the 10 apartments has its own ventilation system. One of the deciding factors in choosing this solution was that it is necessary to keep the roof clear of service installations. They would both throw their shadow on the rooftop solar panels and occupy valuable space which could be used for additional panels.

A large, central system would have its air outlet through the building roof or at ground level –

but with individualised systems both air intake and air outlet can be placed on the facade.

An individualised system also offers significant energy benefits, having shorter ventilation ducts and being easier to control the volume of air in each of the apartments. It means less pressure loss and thereby more efficient ventilation.

The benefits of the individualised system, however, are not without their challenge – because Danish Standard specifies that ventilation discharge should be above roof level. This is partly because of the indoor climate: the need to avoid the stale air and cooking fumes being drawn back into the dwelling or into the adjacent apartments.

To handle this problem the project engineer has done two things. First, the extractor hood has been provided with a carbon filter, which cleans the outgoing air. Second, the intake and outlet have been placed on opposite sides of the building, with care taken to locate windows at a distance from the nearest outlet. In this way, there is plenty of distance from the nearest openable window.

### Recovering heat from the shower

One of the elements with a huge beneficial effect on energy costs in the BOLIG+ project is heat recovery from the domestic hot-water supply. This technology is not in very widespread use in Denmark – but it is extremely effective.

Normally, the hot water from residents’ showers runs off directly into the sewer – but in BOLIG+ it is used to preheat the cold water from the public water-supply system. This is done through a pipe-in-pipe system – one inner, one outer – with the warm shower water exiting to the sewer via the thin-walled inner pipe, and fresh, cold water entering the apartment in the outer. The cold water and warm water are separated only by a thin pipe wall. The heat therefore transfers readily from the outgoing warm water to the incoming cold.

The heat-recovery system makes it possible to preheat the incoming cold water by about 20 C,



sharply reducing the energy needed to heat water. It has actually been calculated that recovering heat from outgoing domestic hot water reduces the household's hot-water energy bill by 20%.

#### Good old-fashioned radiators

The apartments in BOLIG+ are heated by radiators in preference to underfloor heating. This is because underfloor heating is a relatively sluggish form of heating and may therefore use more energy than radiators. At the same time, experience shows that users quickly become accustomed to the floor being constantly and pleasantly warm – and tend to increase their energy consumption with underfloor heating.

Users find it more natural to regulate a thermostat on a radiator than a thermostat controlling floor heating, and radiators adjust more quickly and precisely, producing a good thermal indoor climate.

#### Take the lift

The BOLIG+ project group decided to install a low-speed lift instead of an elevator – for two reasons. First, such a lift does not require as much headroom as an elevator – making a shaft and its machine room on the roof unnecessary. This is an important factor as space on the roof is a costly item for BOLIG+. The roof is where the building creates most of its production of solar energy – so it needs all available space and no shadows.

Second, this type of lift moves more slowly than an elevator and uses less power when it is

in operation. It will not be operating as often as an elevator would – because on account of its low speed residents will be more likely to take the stairs. The lift is yet another example of the subtle, nudging elements incorporated in the building to encourage residents to make more energy-efficient – and in this case also healthier – choices in their everyday lives.

#### No heating on the ground floor

No one lives on the ground floor of BOLIG+. It is used primarily as a drying facility and storage rooms serving the individual apartments. To save energy, the ground floor is unheated. At the same time, the PV panel system's inverters – which convert DC to AC (to match grid power) – have been installed in the drying facility.

Normally they would be located on the roof together with the panels but as they function most efficiently at low temperatures, they have been placed in the ground-floor drying room. The inverter system emits a little heat – which can be used for drying clothes.

The unheated ground floor has presented a few challenges in the form of cold bridging (the loadbearing walls surrounding the lift shaft pass through the apartment above). It has not been possible to eliminate these cold bridges but the overall energy situation has been so favourable that there has been room in the heating account to balance a little wastage.

## Identifying the energy guzzlers

The goal of the BOLIG+ project has been to achieve energy neutrality – but simply finding exactly what the building's energy consumption is has in itself been a challenge.

Many energy-consuming building components – for example, door entry phones, meters and fire dampers – are not subject to statutory requirements governing **energy consumption**; this applies both to component standards and total-energy requirements laid down in building regulations.

Consequently, no one has focused on minimising the consumption of such devices – in spite of the fact that it can by no means be described as negligible. One example which emerged during work on the original BOLIG+ in Aalborg concerned fire dampers. After the BOLIG+ competition a new fire standard was issued which required that fire dampers should be electric powered: they had to snap shut when they lost power. This was formerly accomplished by a retaining cord burning through.

Fire dampers could at that time – during the planning of the BOLIG+ Aalborg project – have a constant power consumption of as much as 16 W each. It may not sound excessive but it was a **standby consumption** – ticking away continuously. With two fire dampers in each apartment – which was the arrangement in BOLIG+ – this would have meant an annual standby consumption of 2.7 (p) kWh/m<sup>2</sup> of floor area.

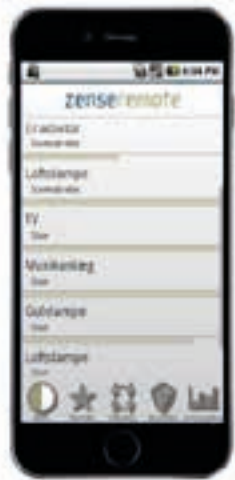
No one appears previously to have questioned this consumption but in light of the BOLIG+ dogma on energy neutrality, the consequences suddenly became very clear. It would have required 170 m<sup>2</sup> of extra solar panelling just to meet the energy consumption of the fire dampers' in the original BOLIG+ in Aalborg and 25 m<sup>2</sup> extra on the building in Søborg.

For that reason, several members of the BOLIG+ steering group submitted responses to the Danish Energy Agency – and in the meantime the electrical industry has developed types of dampers which now use about 2-3 W.

Fire dampers are just one small example of how focusing on the energy consumption of buildings can help to drive developments in a more energy-friendly direction.

The greater the demand for **energy-efficient** products, the greater will be the **willingness** of manufacturers to develop such products.

The BOLIG+ project in Søborg has managed to eliminate the need for fire dampers in almost all apartments – by opting for individual ventilation systems and air outlets/intakes in the facade. Fire dampers are only required where there is an open passage from one fire section – typically an apartment – to another. BOLIG+ avoids this. In the uppermost of the two mid-floor apartments, however, there was no suitable location for the intake. A fire damper therefore proved necessary to avoid the entry of smoke from the apartment below in the event of fire.



*"The more you know, the easier it is to take appropriate action. By giving residents a continuous flow of feedback, we hope and believe they will be motivated to act on the basis of it and actively adjust their pattern of consumption – managing to stay within the energy production that in effect is part of the building."*

- Jørgen Søndermark, project leader, architect, Realdania Byg

Saving

## Saving power becomes a game

BOLIG+ should be an **attractive** place to live, not just for its architecture, indoor climate and electricity bill but also with its comfort and convenience. To enhance its comfort and at the same time encourage residents to economise on power, an intelligent system has been installed to control and monitor electricity consumption in each apartment.

The **Zensehome installation** enables residents to “design” and control their own lighting schemes – for example, on returning home they can opt by pressing a single switch to turn on lights in the corridor and kitchen. Or via **one button**, switch off all relevant power sockets when they leave home. Leaving on holiday, you can have the system repeat the lighting pattern of the past 24 hours to give the apartment an “at home” appearance. And if you’ve forgotten to switch off the iron before going to work, an **app** on your **smartphone** will do that for you.

The system lets **you decide** how to switch lighting and appliances on/off to suit your requirements, and also gives you information on consumption right down to individual socket level.

The philosophy is simple: The more you know, the easier it is to take appropriate action. By letting residents know what they are using electricity on (and how much), BOLIG+ will encourage them to make an effort to **reduce** their consumption below the 1,712 kWh supplied by the building courtesy of the solar-panel system.

At the same time Zensehome introduces an element of “**gamification**” because it is possible for residents to compare their electricity consumption with their own historical figures or those of neighbours/friends – and compete in an effort to be even more **economical**.

Resident also have the opportunity to follow how much power the building’s solar panels are generating. An **app, SolarEdge**, shows how much electricity the total system is producing and how much an individual module contributes. It can show production in real time and over a period of days/months/years.



## **An extraordinary solar-power plant**

Uniting output and aesthetics

Invisible solar panels

Innovative technology

Small solar-panel on the roof

Bypass diodes built into the panel

Optimisers reduce the problem of shade

Mission accomplished



The first phase in the job of creating an energy-neutral building was to pull out all the stops in reducing the building's energy consumption. But a certain minimum level of energy is needed to power the building's electrical installations and to balance the energy used in the district heating supply.

The annual consumption required by BOLIG+ for space heating, domestic water heating and operating the ventilation system corresponds to 28.5 (p) kWh/m<sup>2</sup> per annum. To this must be added 10 times 1,712 kWh for the 10 apartments' annual power consumption and 7.1 (p) kWh/m<sup>2</sup> p.a. for the building's shared areas.

The building's overall consumption totals 65 (p) kWh/m<sup>2</sup>, which is the figure the PV system is required to generate if BOLIG+ is to be a zero-energy building.

The solar-power plant must, in other words, produce 40,000 kWh p.a. An ambitious production target. So ambitious that it is beyond the capability of a standard plant.

### Uniting output and aesthetics

To handle the challenge the PV panels on the BOLIG+ facades are far from standard. In addition to being able to meet an ambitious target, the power plant must also live up to the architect's aesthetic demands.

- The panels had to be large – each up to 2 x 3 m in area.
- They were not permitted to protrude markedly from the building.
- They were not to be mounted in visible aluminium frames.
- The panels were not to be reflective, and the actual PV cells had to be invisible. Viewed from the roadway, the panels had to appear to be an integral part of the building's architecture.

Normally, a photovoltaic (PV) panel consists of a glass plate, a strong aluminium frame around the glass, and a box mounted at the rear containing large bypass diodes to prevent hotspots.

In the design of the BOLIG+ PV panels it has been possible to mould the installation fittings directly into the panel – avoiding the need for both the aluminium frame and the rear-mounted box. The

absence of any box at the rear also means that the cables can emerge at any suitable point. Thus large modules can be adapted to the architecture instead of vice versa.

This production method also means that the panel is significantly slimmer and easier to install. It simply hooks onto a rail on the facade. This technique was a key factor in being able to manufacture PV panels to suit the requirements of the BOLIG+ project.

### Invisible solar panels

The panels were required to be non-reflective, black and without the characteristic blue-violet surface sheen. Broadly speaking, the panels had to be invisible.

For this reason, special black silicone cells were developed for the interior of the module, behind a black background foil. At the same time thin, black strips were specially developed for placing on top of the three metal strips that are otherwise visible in each PV panel. Both of these adaptations were compromises made in the name of aesthetics – which has very slightly reduced the photovoltaic effect.

### Innovative technology

To alleviate this and to optimise panel efficiency, the panel design employed PERC (Passivated Emitter Rear Cell) technology, which involves applying an extra layer of aluminium to the back of the solar panel. This “pacifies” the electrons that interrupt the electric flow; it also reflects the light, reducing the amount of light “lost” to the rear of the panel. Normally, 18% of the light is utilised by a PV panel but in BOLIG+ panels the efficiency figure has been increased to 21%.

This is the case, however, only with the rooftop panels, which are the ones that lend themselves best to optimisation. The facade-mounted panels – in spite of aesthetic compromises – manage an efficiency of 19%.

### Small solar-panel roofs ... on the roof

It has been clear from the start of the BOLIG+ project that the roof surface would have to be fitted with solar panels. In this connection the architect and the engineer have worked intensively on the issue of how to position the panels in order to make best use of the available sunlight.

Normally, solar panels are erected in rows facing south-west and at an angle of approx. 40 degrees. This is the most efficient angle and direction – but the problem is that the first row casts a shadow across the second, which casts its shadow upon the third, etc. The problem can be solved only by moving the panels further apart – but that means not enough space for the necessary number of panels. In both scenarios efficiency in using the rooftop surface drops dramatically. Early in the process – as early as the Aalborg stage – an entirely different solution was suggested: building the solar panels up as miniature roofs. The roof of the building is fitted with 182 m<sup>2</sup> of solar panels.

The calculation had actually been made that the most efficient way would be to lay the panels flat on the roof, if efficiency was the only parameter. But it is not. Because if panels are not positioned at an angle, water, dirt, bird droppings, etc., will not be washed off – and sufficient light cannot reach the photovoltaic system.

It was therefore calculated that the panels should be constructed as mini roofs, with a 12.5° pitch, one surface facing SE, the other NW. A NW-facing surface would not normally be considered particularly efficient – but the BOLIG+ project shows a different situation.

The explanation is to be found in the Danish climate. There are relatively few cloudless days with full sunshine, and the presence of clouds means that about half of the sunlight that reaches buildings is diffuse light, i.e. light from several directions. And these rays can be caught as well by a NW-facing surface as by a SE-facing.

### Bypass diodes built into the panel

A common issue with solar panels is that if a cell, which is an active component in a photovoltaic module or solar panel, is blocked by a leaf or bird dropping, it changes from being an active producing unit to being a unit which absorbs electricity. Indeed it can become such a serious situation that “hot-spots” can develop in the cells – causing the glass face to overheat and fracture. To avoid this happening, panel designers place protective bypass diodes in a box on the back of the panel to conduct the power around the blocked cell. The problem with this arrangement, however, is that cells are connected

in groups – and at least 20 cells have to be taken out of production every time one cell becomes blocked.

This reduces productivity. Instead, many small diodes are grouped together so that it becomes necessary to take only 3-4 cells out of production if one cell is cut off from the light.

### Optimisers reduce the problem of shades

As an extra device for improving efficiency, the panels were provided with a so-called “optimiser”. When a current is transmitted from a series of solar-cell modules to the shared inverter that converts current from DC to AC, a problem can occur if one of the modules is in the shade: it degrades the efficiency of the other modules in the series.

This problem is likely to occur in a building like BOLIG+, in which one could imagine, for example, that a resident might hang a towel out of the balcony window to dry. That could knock out a whole series of solar-cell modules – but if each module has its own optimiser, it is capable of adjusting the current to the next module in the series. Admittedly output is lost from the module covered by the towel but it does not knock out the other modules in the series. The same applies when partial shade is created by buildings on the other side of the street. Calculations indicate that – thanks to increased production – the investment in optimisers pays for itself within 2-3 years.

### Mission accomplished

The solar-power plant mounted on the walls of BOLIG+ has thus been optimised in every possible way – and the benefits are clear. The system’s design dimensions can deliver approx. 40 MW p.a., which is about one-third more than a standard system is capable of producing. The mission has therefore been accomplished of establishing sufficient energy production to balance out total energy consumption.

*“BOLIG+ has been a rather special project because we had to co-ordinate a number of demanding factors and at the same time adopt certain groundbreaking solutions – for example, making sure the actual solar cells could not be seen in the PV panels mounted on the facade. Preferably, they had to be invisible!”*

- Solar Panel Supplier Yakov Safir,  
CEO, Racell Sapphire

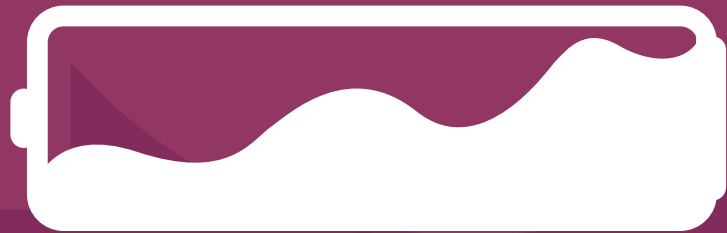


## Great strength in specially design fittings

To ensure stable and safe installation of the large panels without unsightly aluminium frames, the architect and solar panel supplier developed a **new type** of installation fitting. The easiest solution would have been to find an existing aluminium profile which would do the job – but aluminium could not meet the official Danish fire-safety standards.

The panel supplier therefore had to **design** a new **bracket** which – together with the rest of the panel assembly – underwent extensive tests at the hands of experts from the **Technical University of Denmark**. Initial testing identified a weakness in the bracket assembly in crosswind conditions. This led to the brackets being **reinforced** and embedded more fully in the solar panel

The panels must be able to withstand a pull of 200 kg/m<sup>2</sup>, and that has been more than achieved now. In fact, tests show that the strength profile is closer to 1,000 kg/m<sup>2</sup>. In addition, a method of installation has been developed which – once the installation rails have been precisely positioned on the facade – enable the large modules to be fitted and removed easily and quickly.



## BOLIG+ and its batteries

Solar-power technology is maturing, and government subsidies across Europe are being phased out. This means that the economics of solar-power installations are changing.

A scheme was introduced in Denmark about five years ago – the Net Metering Scheme – which meant that the national grid acted as a free storage facility for any unused solar power. The scheme was marketed under the slogan that “The meter can run backwards”, and the sales and purchase prices for power were equal.

The scheme has since been changed to an “hour-by-hour” arrangement. Power produced on a solar-powered system must be used within a given hour, and any power not used immediately must be sold to the national grid at a reduced price, currently about DKK 0.60 per kWh. When the sun has gone down, and the consumer needs electricity, it can be bought back off the grid – this time at the normal rate, current-

ly DKK 2.20 per kWh. Thus it will be seen that the saving achieved from a solar-power plant is no longer as attractive as it used to be – but perhaps it could be if it were possible to put some electricity aside for the dark hours to avoid first selling the power then buying it back.

### **A battery can store electricity**

The answer is batteries. A battery can store solar power locally when the sun shines, making the power available when the heavy need for power arises around meal-time. In other words, the power does not need first to be transferred to the national grid – and the consumer avoids first having to sell the power cheap then buying it back at a premium.

The BOLIG+ building has been designed from the outset to employ a battery solution, and a technical room on the ground floor has been earmarked to house one or more batteries.

But for a long time batteries have been much too expensive compared with the saving they provide, and the BOLIG+ project group has therefore been obliged to wait and watch market developments.

But just before BOLIG+ reached its current stage of completion, a new type of battery came on the scene: the “flow battery”, forecast to become the successor to lithium-ion batteries (the power unit in Tesla electric vehicles). The principle in a flow battery is that the power is stored in a tank of liquid instead of in the actual power-dispensing part of the battery.

### **Batteries in BOLIG+**

In the battery used in BOLIG+ the liquid is based on the metal, vanadium, in a solution of acid. The principle is cheaper than in traditional battery designs, and in view of its great development potential it is likely to improve still further the economics of battery installations.

The liquid-based battery also has a very long service life because it can tolerate being charged and discharged up to 10,000 times – compared with the li-ion battery used in private solar-power plants, which usually can manage 3-4,000 recharge cycles.

In this respect the liquid-filled battery has a working life similar to that of the solar-power plant and does not need replacement during that period. At the same time, the flow battery has the advantage of not representing a fire risk. If the battery short-circuits, nothing dangerous happens – whereas in the li-ion battery there is likely to be a much greater discharge of energy, which can result in a fire. Another difference is that in a flow battery it is possible to scale and tailor the output and capacity

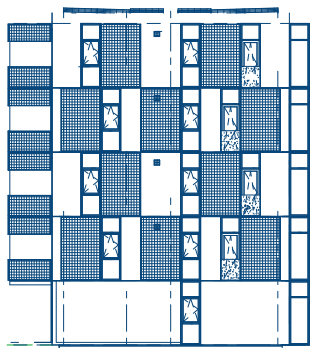
independently of each other – whereas a li-ion battery is purchased as a complete, ready-made package. If circumstances require greater energy output, this necessitates more capacity – and thus the trouble and expense of a larger battery unit.

### **Output and capacity**

Batteries are defined by their output and capacity. Output is the flow of power that can be obtained from the battery at any given moment, while capacity is the total volume of power the battery can hold.

The ideal setup would be a battery which could store all the electricity it could generate – and which at any time could deliver all the electricity needed. But in this scenario, of course, one has to take the economics into account. A very large battery is correspondingly very expensive – so in the BOLIG+ process it has been vital to strike a balance between on the one hand a battery that is not too expensive and on the other a saving which is great enough to justify the investment – in relation to the battery’s useful life.

The battery installed in BOLIG+ has an output of 1 kW and a capacity of 40 kWh. With this size of unit the proportion of electric power that the building’s residents can use directly from the solar-power plant can be doubled from approx. 25% to nearly 50%. This in turn means that on an annual basis approx. 7,200 kWh no longer needs to be sold and bought via the grid, and for each kWh there is a saving of the differential between purchase and sales price, currently about DKK 1.50. There are signs that in the long term the authorities will increase the purchase/sales differential still further. If so, the economics will favour the battery solution even more clearly.



*"My work is no different from what it usually is. Maybe the insulation thicknesses are not what we're used to but the building processes are the same – and it's been just as quick and easy to build a BOLIG+ building as an ordinary apartment block."*

- Jakob Ploug, project leader, Dansk Boligbyg

## An unusual building built in the usual way

BOLIG+ is a unique building – but that doesn't mean it has been a unique task to build it. The process, according to the building contractor, didn't differ much from a standard building project. The passage of time favoured many of the solutions used in BOLIG+. In 2009 many of the elements being considered for an energy-efficient building were not in such common use as they are today.

Technical solutions are more integrated in the actual building than one often sees – but that does not affect the actual building process.

Where the BOLIG+ project has stood out – from the contractor's point of view – has been the close dialogue it has encouraged between architect, engineer and owner. Because project economy has been a defining factor, the building has been planned and executed with one eye on a spreadsheet, and there has been an ongoing dialogue on which solutions were possible within the budget.

## BOLIG+ became an argument for bringing BR2020 forward

Long before the first turf had been cut for **BOLIG+**, the project had played a part in shaping the political agenda. The winning proposal in the 2009 competition demonstrated that it was possible to construct a building within a normal building budget and amply keep within the **energy standards** laid down in **BR2020**.

Armed with this information, a Danish politician Anne Grete Holmsgaard – at a meeting with Economy Minister Brian Mikkelsen in 2011 – used **BOLIG+** as an argument for bringing forward the approval of **energy efficiency class 2020**, which would **lower energy consumption** by a further 25% in relation to BR2015.

The argument **succeeded**, and the BR2020 guidelines were approved **four years earlier** than originally planned.



# Energy neutrality need not cost more



Economics has been the 6th dogma of the BOLIG+ project. Achieving the five basic dogmas becomes really interesting only in the context of a real-world building economy.

And any owner wishing to repeat the project has the assurance that it is possible for a low-energy building project to succeed within an ordinary market price per square metre.

The BOLIG+ project has succeeded thanks to many decisions and choices made on the journey. One of the most important of these was the decision not to build a basement. Going underground is expensive. The BOLIG+ option was therefore to locate on the ground floor those facilities which would otherwise typically have belonged in a basement. For example, technical room, drying room, storage rooms, etc.

# The power picture

In an energy sense, the BOLIG+ project has managed to achieve “zero-energy building”. In other words, the value of the energy that the building and its residents use is balanced by the value of the total energy produced by the building’s solar-power plant.

Consumption and production are calculated hourly, and the accompanying diagram illustrates three different scenarios showing how consumption and production fluctuate during the course of an ordinary day.

Around midday, when most of the residents are at work, the building uses almost no power – but the solar-power plant is generating maximum electric power, most of which is sold to the grid.

Around 18:00 consumption again rises because most of the residents have returned home and many are busy cooking. On the other hand, the sun is low (except in summer) so this is usually again when energy has to be “imported”.

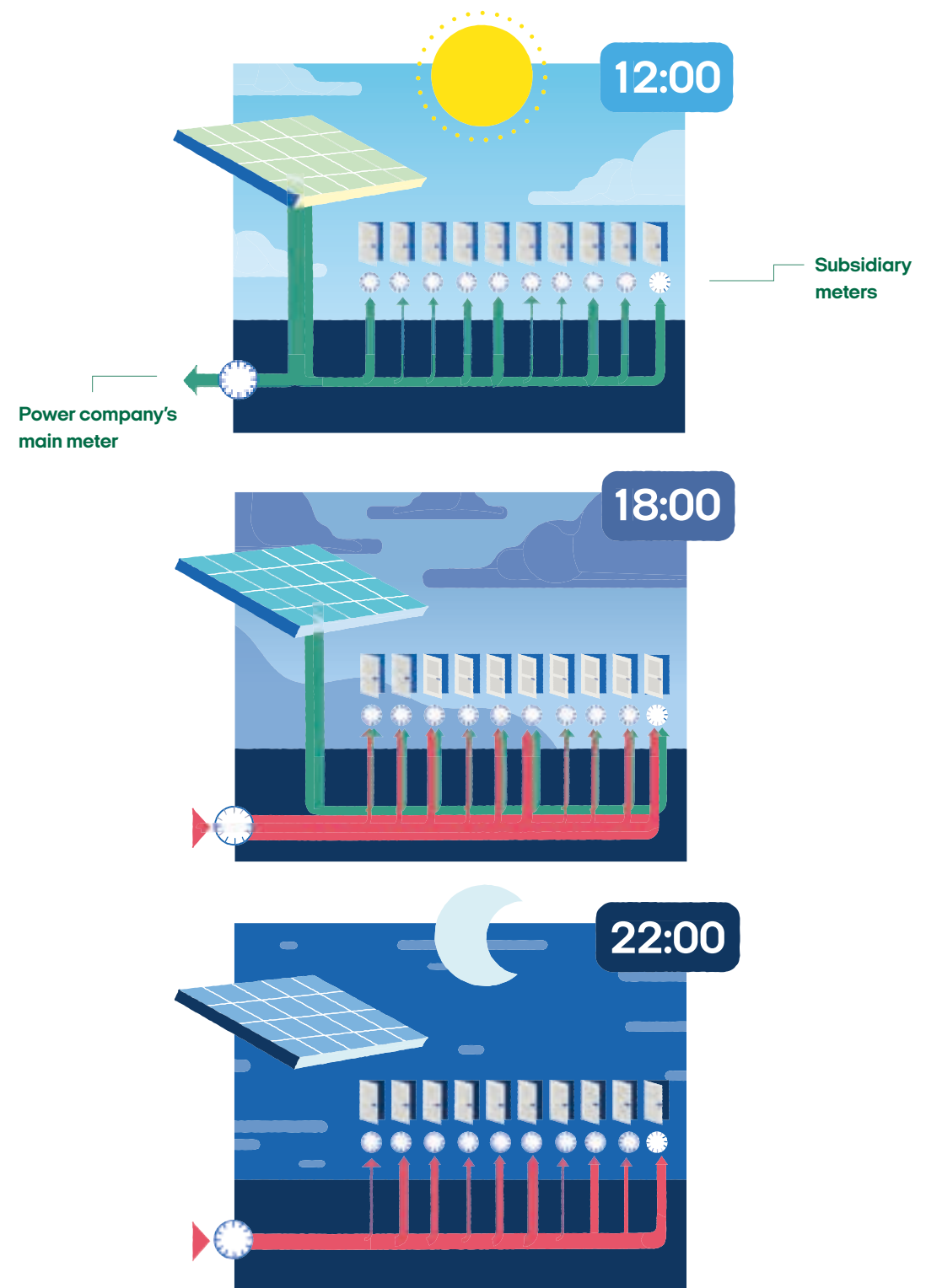
The fact that energy transactions balance is thanks to the energy factor used to translate different forms of energy to figures which are comparable in relation to the energy footprint created.

During the evening and night, solar panels produce little or no electric power, and extra electricity has to be purchased from the power company.

We have to bear in mind that not all energy is equal. Less energy raw-material is used to produce 1 kWh of heat than 1 kWh of electricity; consequently district heating is calculated at an energy factor of 0.6 while electric power is calculated at an energy factor of 1.8.

In other words: When BOLIG+ can sell 1,000 kWh of electric power from the excess production of its solar-power plant, it counts as 1,800 kWh on the plus side of the energy account.

Conversely, the 1,000 kWh of district heating that BOLIG+ buys counts only as 600 kWh on the minus side.



## The power picture

Production of electricity depends on the time of day. In the middle of the day, when the light is strongest, solar panels are at their most productive. Some of the power is used by the building and apartments; the remainder is sold to the power company. During the evening and night, solar panels produce little or no electric power, and extra electricity has to be purchased from the power company. The consumption of electricity also varies according to the time of day – and also depends on which residents live in the individual apartments.

# Energy neutral doesn't mean free

Although BOLIG+ is a zero-energy building, it does not mean that zero is what will appear on residents' electricity bills. The resident who moves into BOLIG+ can look forward to low running costs – but it is not free.

BOLIG+ is not an island with its own closed energy circuit. It is a residential building interacting fully with surrounding society in all forms of infrastructure. This means, for example, that regular standing charges will be payable to the district-heating provider and the energy company.

BOLIG+ is connected to the district heating network because from a broader CO<sub>2</sub> and social perspective it is a logical choice. It is an existing and efficient infrastructure which – following a political decision – is in the process of moving to a green agenda.

## Electricity calculated hourly

Electricity consumption in BOLIG+ is charged on an “hour-by-hour” basis. In practice, this means that an hourly account is kept of how much electricity the BOLIG+ building on the one hand receives from its own solar-power plant and on the other hand buys from the grid.

For example, if the BOLIG+ building during any given hour has taken 30% of its total electricity consumption from its own solar plant and 70% from the grid, each apartment will be charged for its total consumption during that hour according to the same proportional split.

This means that the 30% costs only the low price that BOLIG+ would get from selling electricity to the grid. The 70% on the other hand costs the full – and almost four times

more expensive – price that BOLIG+ has to pay for buying power from the grid.

## Measuring the success of BOLIG+

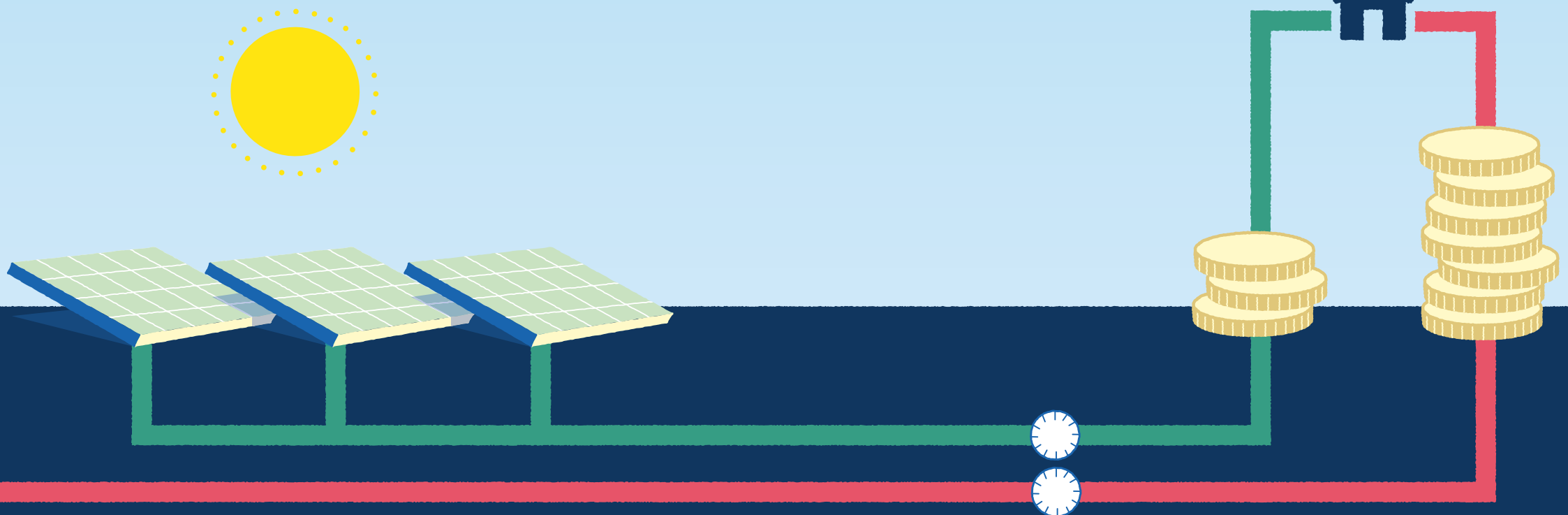
Calculation of BOLIG+ statistics shows that the building is genuinely energy neutral – at least on paper. But when residents move in, the real opportunity arises to measure its success – that's when it becomes possible to conclude whether the calculations measure up in the real world.

The BOLIG+ project steering group – specifically represented by its members, Technological Institute of Denmark and the Danish Building Research Institute (SBI) – will carry out measurements and assessments of all apartments. This analysis project aims to document and evaluate the BOLIG+ dogmas, focusing specifically on

energy neutrality, quality of the indoor climate, and user friendliness.

First, the various energy flows – the building's and residents' consumption on the one hand and the production of the solar-power plant on the other – will be monitored to ascertain whether the building lives up to the dogma of energy neutrality.

And secondly, measurements will be made of daylight, temperature, relative humidity and CO<sub>2</sub> content to assess whether the building complies with the dogma of a good indoor climate. The indoor climate will be analysed and compared with the indoor climate normally found in comparable houses to monitor whether – as is expected – it is better.



# BOLIG+

## - utopian dream that became reality

It took 10 years from the initial formation of the idea of an energy-neutral apartment block to the stage where the idea crystallised into a five-storey building on Søborg Hovedgade, NW of Copenhagen. Back then – 10 years ago – it seemed an impossible idea to build an energy-neutral block of flats for the same price as an “ordinary” housing project – but BOLIG+ has proved that it is possible.

The aim of BOLIG+ has been to introduce a housing concept which could reduce the carbon emissions normally encountered in new buildings. The focus of the project centred mainly on the consumption of electricity because it represents a large part of society’s total energy consumption, and because it has not yet been possible to radically shift the pattern of electricity use.

The groundbreaking aspect of BOLIG+ is a change in views towards day-to-day electricity consumption. It is no longer a private matter but on the contrary something the building industry must become involved in. Both by creating a framework which allows it to be minimised and by compensating for the reduction by having the building generate its own energy.

The building on Søborg Hovedgade is proof that both courses of action are feasible and that it is achievable without compromising the building’s housing and architectural qualities. Energy neutrality has become a genuine and competitive option.



From the initial rough sketches to Denmark’s first net-zero energy apartment building.

*“This adventure has had something about it of Jules Verne and his story of sailing around the world under the sea. At first thought, an impossible dream. But once the idea has been thought and spoken aloud, someone will certainly pick it up and run with it – until it become reality.*”

*The world has to be introduced to something new before progress is made. Someone has to dare to dream and to set new, unimaginable goals. Once expressed, they will eventually be achieved. The Danish building industry harbours the kind of innovative powers that can realise even the most exceptional of objectives.”*

- Jørgen Søndermark, project leader, architect, Realdania Byg

BOLIG+ Denmark's first genuinely energy-neutral apartment building highlights new routes to lower energy consumption, better indoor climate and greater user-friendliness.

Realdania Byg develops innovative new builds – as tangible examples to encourage and inspire the development of modern building. The company also buys and restores buildings that are deemed important representatives of architectural building styles from various time periods and areas in Denmark.

More information at [www.realdaniabyg.dk](http://www.realdaniabyg.dk)

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