CARBON TRUST
Making business sense of climate change

Taking control

Lessons learned from installing control systems in low carbon buildings

enter

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> “Controls are an essential element of reducing a building’s energy use and ensuring that buildings designed to be low carbon really perform as low carbon”

Sharing our experience: About this booklet

‘Taking control’ is part of the ‘Sharing our experience’ series. These booklets provide advice and tips to help you to plan, build and manage cost-effective low carbon buildings that really work to save you money and carbon.

The insights are based on real data from 28 case studies from the Department of Energy and Climate Change’s Low Carbon Buildings Programme and our work on refurbishments. The projects cover many sectors including retail, education, offices and mixed use residential buildings..

Further information

To find out how we can help with your low carbon building project, contact us on 0800 085 2005 or visit www.carbontrust.co.uk/buildings

What are controls?

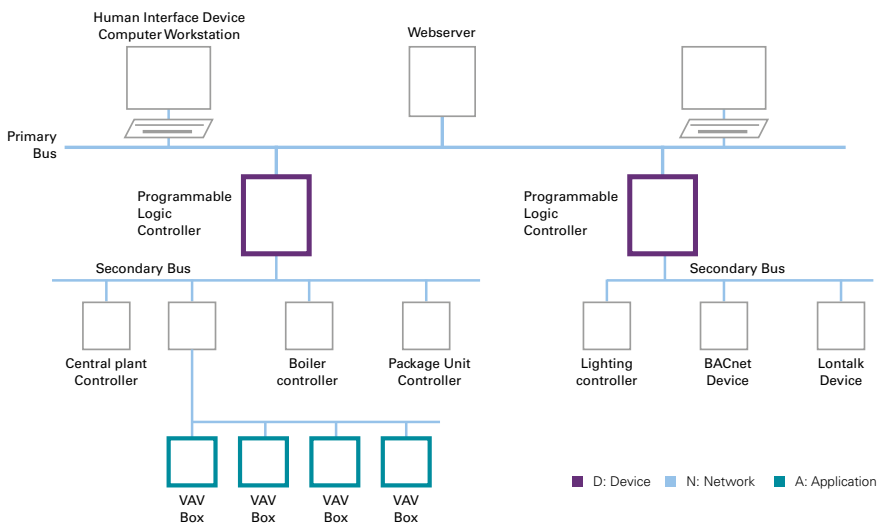
Building controls can be very simple or very sophisticated. They range from simple manual controls, such as light switches, to fully integrated building management systems.

Modern buildings increasingly use sophisticated control systems to manage virtually any element of a building's daily requirements. A full building management system (BMS) can set the temperature and humidity in numerous zones, allow for different time schedules, and control lighting, security systems and low and zero carbon (LZC) technologies. However, most control systems are used primarily to operate building service equipment and maintain comfort levels for the building's inhabitants, rather than being used to their full potential to reduce energy consumption.

Figure 1 shows the 'DNA' of the controls system where:

- D stands for device, the main controller that calculates what each element of the system should be doing,

Figure 1 ***Schematic of a typical building control system***



- N stands for network, the communication systems which each element communicates through to allow the device to get a full understanding of the condition of the building.
- A stands for application, the element that provides the action e.g. the variable air volume (VAV) box.

Figure 2 ***Range of control types in buildings***

	Manual	Discrete	Full building management system
Typical use	• Small buildings, e.g. small shops or community halls • Standalone systems	• Medium-sized buildings, e.g. schools or small offices • Typically heating only and/ or split unit air conditioning • Standalone HVAC 'package' system	• Complex, large buildings, e.g. large offices or supermarkets. • Variety of heating, ventilation and air conditioning systems and occupancy zones • A requirement to integrate low and zero carbon technologies and other 'packages' into control regime • Metering and monitoring of energy performance
Typical Systems	• Lighting • Heating	• Chillers (packaged units), boilers and split units	• Large HVAC systems • Integrated lighting or security
Control/ functionality	• On or off	• Time clocks • Compensated circuits • Optimal start/stop	• On demand control – feedback from room sensors to plant • Optimised control of air conditioning • Ventilation control based on internal air quality • Occupancy and footfall sensing • Integrated control of low or zero carbon operation
Operation/ maintenance	• Manual operation by on-site caretaker or staff	• On-site caretaker or mobile periodic visits by outsourced provider	• On-site or remote building manager • On-site maintenance that requires an overview of building performance.

Why are good building controls important?

Good building system controls are key to achieving a low carbon building in operation. Their design, installation, commissioning and operation can make or break the low cost, low carbon outcome you want.

Our client case studies showed a range of controls strategies, from fully comprehensive BMS to discrete controls. There is no right or wrong strategy because each of the sites studied was unique and the most appropriate controls depend on the details of the building. However, controls were most successful (comfortable conditions with better than benchmarked energy consumption) where there was someone who understood the controls and was motivated to use them.

Building controls, when used effectively, are an essential element in reducing the energy consumption of a building. This could be:

- not heating or cooling areas that are not occupied
- varying lighting levels depending on available daylight
- changing ventilation rates to match the number of people in a building.

The real power of building controls lies in their ability to provide useful building management information and to carry out complex control routines to ensure energy use is minimised. Our case study projects did not typically take full advantage of this potential. Most control systems are used primarily to operate building service equipment and maintain comfort levels for the building's inhabitants, rather than being used to minimise energy bills.

However, for a building to be genuinely low carbon it not only needs appropriate controls to be specified, designed, procured and installed, but also the correct interaction between the controls and the building's users. If this interaction is missing or inadequate, it will not be possible to achieve a low carbon building.

At one of our case studies the client put in a fully automated, centralised control system with local user interfaces which saved them an estimated 15% of the energy they would have consumed had they gone for purely manual controls.

After completion, an energy audit was undertaken which identified additional energy savings that could be achieved through controls (e.g. staff training on lighting controls and commissioning the presence sensors). If implemented these could have saved a further 17% of the small building's energy use, £2,900 or17.3 tonnes CO_2 per year at a capital cost of £7,250.

A 'good' control set-up – appropriate controls with clear instructions

A 'bad' control setup – numerous unlabelled switches that may all get turned on – and left on – as nobody knows which switch controls what.

Lessons learned

- Choose the appropriate controls for the building.
- Choose the appropriate user interface for the end-users.
- Make sure that the end-users are motivated and know how to use the controls.
- If packaged units are used, make sure they feed back to the main controls.
- Make sure the required control parameters are clear.

Planning and designing good controls

A client's brief for a good control system aims for energy efficiency while maintaining comfort. Designers' specifications need to set out the key energy features so contractors appreciate what the control system needs to do.

Client brief

Low carbon results were best achieved when the client stated an aim to have a low carbon building in operation in the client brief. The design, selection, installation and operation of the resultant control system relates directly to these initial statements. Without such clear directions to the design team, a low carbon building is seldom achieved.

In one refurbishment project the client stated in the first design team meeting that one of their long-term aims was to have an energy efficient building. This shaped the resultant design team discussions and ensured that the energy efficiency features of the control systems were not removed as part of a cost cutting (or value engineering) exercise.

Contractual routes and procurement

The performance of the control system can depend on the contractual routes as much as the specification and design of the system. For the case study projects, where the choice of controls was left to a performance specification or a design and build contractor, the final systems did not contain the energy efficient features to enable the building to reduce its carbon impact and energy cost further over the lifetime of its operation. Had specific obligations been put on the contractor, more attention may have been paid to the control strategy.

"We didn't realise we needed to ask for the control system to make the building energy efficient"

"Clients need to understand what they want the controls to do at the start of the project and then we can deliver to this expectation"

Maintaining controls matters

The preferred maintenance regimes need to be determined at the beginning of the project. The important question to be answered by the client is whether they want:

- an independent installation (independent of the control manufacturer) with a separate maintenance contract that can be moved according to contractual performance
- a manufacturer installation where the only option for maintenance is with the manufacturer.

At Ceredigion County Council, the BMS maintenance contractor was consulted at the start of the build, during the design, and was retained by the council to provide maintenance for the finished building. The on-site maintenance team have a good relationship with the controls sub-contractor, allowing them to use continuous commissioning and rectify faults quickly.

Integrating low or zero carbon technology

To achieve a low carbon building, any low or zero carbon (LZC) technologies should be used at maximum capacity. Modern low carbon buildings, often use a combination of different LZC technologies. The way these are integrated into the control system has a fundamental effect on the energy efficiency of the building.

On many projects we found that the overall building controls strategy had not considered how the LZC technologies would be integrated and controlled, which often led to higher carbon emissions than expected. In one building with a ground source heat pump (GSHP), poor control meant the heating energy use was higher than the comparable benchmark. Our investigation found that the controls allowed the gas boiler to operate at the same time as the GSHP, rather the boiler just topping up when required. With both units operating together, neither at full capacity, the result was increased carbon emissions.

Another building had a complex heat pump arrangement combined with a large solar hot water system. During design there had been limited consideration of how these systems would be controlled together. This has resulted in the heat pumps having to be switched off manually on sunny days to benefit from the solar hot water system. The heat pumps then have to be turned back on at night.

"We consider the ground source to be a unit of plant. It is no different, from a controls view, to a packaged chiller or boiler"

Tony Parkinson, London School of Hygiene and Tropical Medicine

User interface design

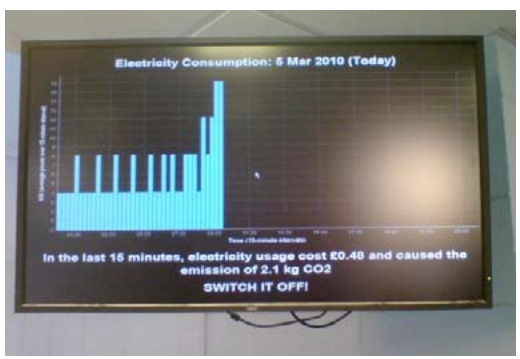
On almost all the projects, the person operating the building was not provided with an adequate user interface to allow them to review the overall performance of their building. Without this they were unable to understand how the building was performing and so were unable to alter conditions (e.g. reduce setpoints or decrease fresh air inputs) in order to save energy as the outcomes of these actions could not be readily observed.

The buildings with a successful control strategy were typically those with a carefully considered brief which stated that the operators of the building should be consulted at the beginning of the project. A good example of this is the North Wales Police building. The design of the user interface was determined by the facilities manager from the start. His experience of the building in its existing form gave a useful insight into what information he needed to run the new building to the required level.

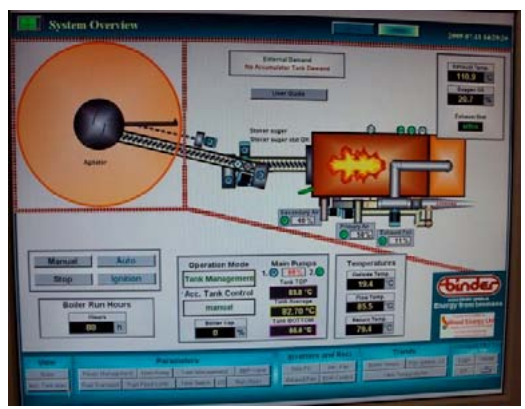
Ask for controls that minimise energy use

Many case study projects relied on the controls installers to develop the plant control method. As a result, systems were often operated using a set time schedule to turn main plant on in the morning and off in the evening. This resulted in boilers and chillers being turned on when they were not needed. This would have been prevented if an optimiser had been used. Most control installers will aim to achieve comfortable occupant conditions in a building, but will not consider more sophisticated control routines to save energy unless the designer specifies it.

One case study building had three separate controls systems: the heating/ventilation, the cooling in cellular offices and the automated metering and targeting package (aM&T). As the heating controls are not able to communicate with the cooling controls they frequently operate at the same time, fighting each other, which causes the energy consumption of the entire building to increase with no improvements in comfort levels. Had a fully integrated control system with an appropriate controller been selected at the start of the project, this could have been prevented.



At Pembrokeshire College, displays in the foyer show the proportion of the building's energy provided by renewables



New England College BMS screen shot with bespoke graphics to match the requirements of building operators and maintenance staff

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End-user interaction

How the end-user interacts with the control system is an important factor in its effective operation and will strongly affect the energy performance of the building. Clients and designers need to think about who will operate the controls and what information they need to make the building work to desired conditions while minimising energy consumption.

Those likely to use the building controls are general staff and the building manager/site engineer, who needs an overall view of the building and system. Local users may want to be involved and 'do their bit' for decreased energy consumption through adjusting local controls, such as a +/- 2°C thermostat.

At the outset of a project, it is important to design a user interface with the building manager or site engineer in mind. The interface needs to be simple enough to control the building easily while making it obvious if the building is under-performing in terms of energy efficiency. User interface screens could link into half hourly metering and exception reports and use intuitive graphs and 'traffic lights', to show high consumption. Although the interface should be easy to understand, it should also enable deeper interaction for people who need to fully understand the reasons behind unusual events.

If it is possible to identify the people who will eventually operate and maintain the building at the start of the project, they should be consulted about what information they need regarding the operation and performance measurements required throughout design.

"Having a good plan at the design stage will make sure nothing gets missed during full commissioning months or even years later"

Case study

Pembrokeshire College
User interfaces

At Pembrokeshire College, the installation began with a thorough specification of the control system with quality requirements of the user interface. This interface included a display in public areas to show the 'real time' energy consumption of the building and how users could reduce it. This attention to detail at the start of the project, along with good handover processes, has ensured that users are now using the system and adjusting time schedules to meet evolving occupancy requirements.

Preparing a commissioning plan

The case study projects with the best outcomes where those who prepared a commissioning plan during the design stage and identified suitably qualified controls engineers to witness the commissioning of the controls system.

On one refurbishment project, the decision was made to contract an independent commissioning agent who had to sign off each plant element and its controls, on behalf of the client, before it would be accepted. This challenged the contractor to provide adequate commissioning information and plan suitable times for the witnessing of systems at all stages of installation, as they knew they would be unable to move on to the next stage without this sign-off. There were initially fears during design team meetings that this additional step could slow down the build process, but this didn't happen because the co-ordination of both teams was excellent and plant was fitted correctly the first time, saving time and money.

Lessons learned

- Know what you want your control system to do, and communicate this clearly to the design team.
- Ensure that the designer specifies, in detail, the methods and functions of low carbon controls.
- Talk to the users to help design interfaces that enable them to monitor performance and optimise the controls.
- Tell controls contractors what the controls are for, always focusing upon the idea that the controls are the method of making and keeping the building low carbon.
- Clearly specify your choice of controls to the contractor, even for procurement based on a Performance Specification or design and build contract.
- Ensure that all LZC technologies are fully integrated into the control of the overall building so they operate at maximum efficiency.
- Understand the control interface requirements of all the potential building users and operators of the building.
- However you contract for maintenance of the controls, a strong, collaborative relationship is key.
- Consider how the control system will be commissioned while designing the plant and its control routines.

Installation and commissioning

A badly installed or commissioned control system can make a potential low carbon building consume more energy than it should.

Many case study projects experienced poor commissioning result in additional consultant time, and other associated costs, to correct the issues after handover. While the onus is on the client to set up the correct contractual routes and on the design engineers to produce adequate, detailed specifications, a successful installation also relies on competent installers and commissioning engineers.

Ensure monitoring of installation

A representative from the controls design team should check that the system being installed is the one that was specified.

In a number of instances controllers did not provide the full functionality (such as feedback control) or sensors were installed but not positioned correctly.

The Carbon Trust's team considered that a third of the control systems in the case study buildings were poorly installed. In the best cases these issues were overcome by employing a specialist controls commissioning engineer. In the worst cases the buildings did not perform to their potential from day one.

Value engineering

'Value engineering' of the controls resulted in reduced functionality and increases in energy consumption during operation. This was particularly true when the team responsible for the development costs were not responsible for ongoing operation and maintenance costs.

Defend against this by highlighting the importance of controls in the brief, and holding on to their value in keeping down running costs.

Commissioning control systems

Only half of the building controls in our case study were considered to be adequately commissioned. The projects showed that it was essential the control systems are commissioned once the metering and monitoring systems were installed and the HVAC systems were installed and operational. This was especially true of energy metering systems, which were often left until last and seldom completely functional when the system was handed over. Without the metering working it is not possible to test the user interfaces which report on the building's energy performance.

On one of the case study projects the independent commissioning agent had final say on all plant equipment and would only sign-off an installation once he had witnessed complete

commissioning. However, his budget did not extend to the commissioning of the BMS. This cut resulted in plant equipment working perfectly in isolation, but when working with all the other services it was out of control.

In the most successful projects, the operators of the control systems were involved in the commissioning process throughout. This was especially successful where the team who had been contracted to maintain the building attended the commissioning, witnessed sessions and formed a relationship with the controls installers. This enabled issues identified after the project handover to be quickly and effectively dealt with.

Seasonal commissioning

Some building systems and their controls can only be fully commissioned in the season that they are in use (e.g. chillers, motorised windows). This seasonal commissioning should ideally be carried out by the original project team or an independent commissioning engineer within the first year of operation. You will need to set aside a budget for this additional work.

Lessons learned

- Check the contractually specified equipment is actually procured as per the specification and installed correctly, especially with regard to sensor positioning and control functionality.
- Ensure that 'value engineering' exercises have not resulted in a system that cannot perform the functions designed, including the integration of any LZC technologies into the main control strategy.
- Allow budget and time for commissioning, including a full year of fine-tuning during the warranty period.
- Commission the plant and controls system as a whole, rather than individual components. If using manual or discrete controls, ensure detailed instructions on how to operate them are provided.
- Involve the building operators in the commissioning process, as they will understand how the building actually works at an early stage and form relationships with the installation contractors.

Operation

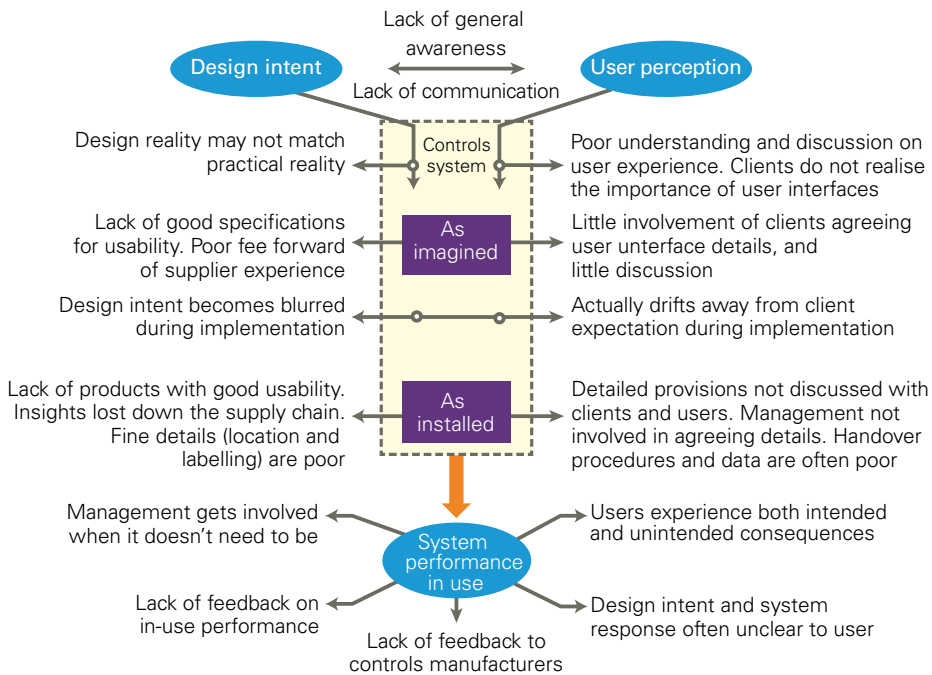
The operators of the controls are as vital as the controls themselves.

There are many examples of sites with potentially excellent control strategies, but as the operators at the site have never been properly trained how to use them, they are overridden or ignored, leaving plant to operate wastefully.

At City Academy, Hackney the building had been operational for 12 months with the heat pumps controlled to be off in winter and on in summer, and with the gas boilers providing all the building's heating. Had the staff been given sufficient training to understand the control strategy properly, this error could have been highlighted and fixed sooner, reducing the waste of fossil fuel energy and increasing the use of renewable heat.

At 60% of the case study buildings, the control system was considered to be ineffectively operated with very few building operators and users well-trained on their systems.

Figure 3: The design of a controls system through to installation and the accompanying issues.



The operation of a control system is the most essential element in achieving a low carbon building because without good control any design intent and commissioning achievements are lost.

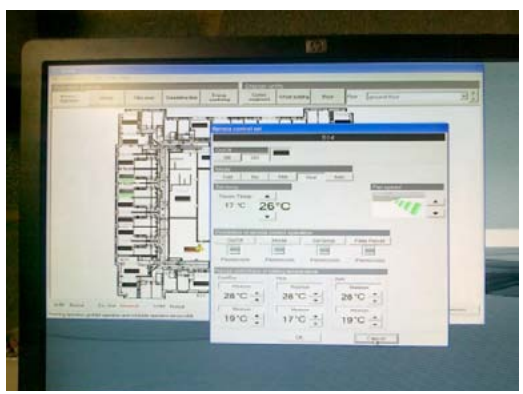
Handover and training

On many projects there was no training of the building users and operators with regard to how to operate their new control systems. On only three projects did the users receive any written information about how their buildings were designed to operate, what control they had over the building conditions and how changing the control parameters would impact on the building's energy consumption.

As well as trying to identify defects and commissioning faults, building operators had to teach themselves how to operate the controls. On only two sites were users provided with a simple operation 'set-up' manual or training.

The most successful projects occurred if a relationship had been established by the maintenance staff and the designers and installation contractors prior to handover and when the end users were involved in the final commissioning of the controls. This relationship should be in addition to formal training and written manuals to be sure that the knowledge does not just rest with one or two individuals.

Complex controls provide detailed information about system performance but require bespoke end-user training.



Complex controls provide detailed information about system performance but require bespoke end-user training

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Optimising performance

There were many aspects to operating a control system which were not considered until the building was near completion or, in some cases, already handed over. These areas are currently not common practice but would help with the operation of the system:

- Maintenance contracts – these were often not considered until a late stage.
- Control performance reviews – most of the sites undertook a maintenance contract for the controls to check that equipment was working and within calibration. However, no sites specified that performance reviews (i.e. measuring the building's energy performance against other buildings within the portfolio or recognised benchmarks) should be carried out as part of the maintenance.
- Updated logbooks – none of the sites produced logbooks that could be regularly updated by the control system users when changes were made and settings adjusted.
- Ongoing optimisation – even the best designed and commissioned control strategy is likely to evolve with the user's and the building's requirements. It is therefore important to maintain records of all changes to the system during the lifetime of the building and ensure that any features designed to minimise energy consumption are not compromised by such changes.

Lessons learned

- Ensure sufficient budget is retained for training key personnel in how the control strategy works and produce appropriate training materials, such as manuals, video training and webinars, for future operators.
- Ensure user interfaces are made available to building operators and that they are commissioned correctly.
- Update building logbooks with all changes to the control functions.
- Update control settings for energy efficiency when changes are made in the building.

Further information

BSRIA

Technical Note TN 6/98. Specifying building management systems by K Pennycook and G Hamilton

A note for clients when briefing consulting engineers on system specifications.

Application Guide AG9/2001. Standard specification for BMS by Kevin Pennycook

Presents a full set of standard specification clauses for building management systems.

BMS Maintenance Guide, plus a model maintenance specification. BSRIA Guidance note by Andrew Martin

Details the issues involved in BMS maintenance and provides specification clauses to assist the procurement of a BMS maintenance service.

The Carbon Trust

Building controls technology overview (CTV032)

This overview explores some of the main types of building controls and demonstrates the best energy saving opportunities available.

Heating control technology guide (CTG002)

Introduces the main energy saving opportunities for existing systems and explains how upgrading controls can cut energy consumption and save money.

How to implement a building energy management system

Information on the building energy management systems and how to specify their installation.

CIBSE

Automatic Controls, CIBSE Commissioning Control Code C

Provide recommendations and guidance on the best practice approach to commissioning controls systems.

The Carbon Trust is a not-for-profit company with the mission to accelerate the move to a low carbon economy. We provide specialist support to business and the public sector to help cut carbon emissions, save energy and commercialise low carbon technologies. By stimulating low carbon action we contribute to key UK goals of lower carbon emissions, the development of low carbon businesses, increased energy security and associated jobs.

We help to cut carbon emissions now by:

- providing specialist advice and finance to help organisations cut carbon
- setting standards for carbon reduction.

We reduce potential future carbon emissions by:

- opening markets for low carbon technologies
- leading industry collaborations to commercialise technologies
- investing in early-stage low carbon companies.

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