

# Targeting building energy efficiency using thermal infrared earth observation telescopes

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**Abstract.** Upgrading the energy performance of the UK's entire building stock is the central pillar of any credible and cost-effective strategy to meeting net zero. This research aims to open up the revenue of using thermal infrared data from satellites to assist in processes on building energy performance improvement. High-resolution thermal infrared data output from space offers the potential for fast and effective monitoring provision that can cover large areas and targeted buildings or sites. We have interviewed a set of stakeholders from government, industry and community groups to build the specific use cases and find out detailed user requirements.

## 1. Introduction

Building energy retrofit possesses great potential for CO<sub>2</sub> emissions reduction to meet the UK's Net-Zero goal. However, despite decades of effort trying to improve building energy efficiency, the lion's share of our building stock is still energy inefficient [1]. A better approach is thus needed to assess and retrofit existing buildings more efficiently and at a faster pace. This current research proposes an innovative solution for targeted retrofit on buildings that have a relatively high level of energy use and heat loss. It employs satellite thermal infrared (TIR) imaging to detect building fabric heat loss, serving as a rapid tool to identify and target retrofit potential. This innovative approach of using high-resolution satellite TIR imagery (which enables a factor of 10 improvement over currently achievable resolution) will significantly increase the efficiency and decrease the cost of monitoring buildings' thermal energy performance. It utilises the self-alignment of unfolding, low mass telescopes [2], and is in the development stage where the satellite is likely to be operational in 2023 at the earliest. The output temperature resolution can achieve 1/3 of a degree. Once it becomes available, it will enable the UK government to keep better track of progress against the country's emissions reductions targets, as well as help industry and community groups to deliver a targeted retrofit service and advice. This paper explores detailed use cases, user needs and requirements from these various stakeholder groups.

An enhanced monitoring system to detect any poor practice and keep track of retrofit progress will be key to unlocking the remaining retrofit potential to achieve net-zero. With large variations in how people operate their buildings, there is a crucial need for better targeting buildings for retrofits. The existing databases of Energy Performance Certificates (EPC) or Display Energy Certificates (DEC) contain only a limited set of information on part of the building stock, where standardised behaviour is assumed in simplified modelling calculations using Standard Assessment Procedure (SAP). Certain assumptions are made where it is impractical to inspect parts of the building, such as loft, cavity wall or under-floor insulation. Meanwhile, each EPC is valid for 10 years, during which time changes can occur



to the property, and therefore may not reflect how the building actually performs. In addition, smart meters only show a building's actual energy consumption, without indicating whether or where it is inefficient. For example, if a building uses a relatively high amount of energy, it might be due to the occupants choosing a relatively high indoor temperature for prolonged periods of time, rather than the building itself being inefficient physically. Further monitoring using aerial (or satellite) TIR techniques will provide better information on building fabric heat loss and combined with other available information, give a more complete picture of how a building is performing and its carbon footprint.

Infrared thermography is recognised as a non-intrusive methodology to detect a building's thermal performance [3]. Used in combination with existing monitoring datasets, it can more accurately show how a building-in-use is performing and identify its retrofit potential. For example, it can show up not only high consuming properties, but also poorly insulated buildings. Combined with other data (such as EPCs), one can confirm (probabilistically) whether the building is well insulated or not, and thereby infer the household type [4] (in case of domestic buildings). In particular, appropriate retrofit options can be recommended to stakeholders based on household archetypes [5].

The most recent developments in high-resolution TIR satellite imagery using the unfolding telescope technology, with the capability to identify individual buildings, offer competitive advantages to conventional thermal monitoring. It can quickly provide customised monitoring at a building or street level, as well as collect building heat loss information on a city or national scale. Such information can include not only the roofs of buildings, but also their facades and walls. The resolution level is most suitable for initial identification and large-scale targeting, rather than offering detailed insight into components of buildings that are leaky or inefficient. Therefore, satellite imagery complements other more granular thermal imaging techniques (e.g., drones), which can carry out a more detailed inspection of thermal performance of a specific building or site.

## 2. Methodology

Development of the Climate Change End-User Cases for the TIR spaces telescopes was underpinned by an in-depth stakeholder engagement analysis. This was the first exploration of how potential stakeholders might use and benefit from such high-resolution satellite TIR data provision. To better understand detailed use cases, we approached a wide range of professionals from government, industry and civil society groups to discuss about their ideas on how they would envisage using such data once it is made available. The interviews followed detailed procedures which have been described below.

### 2.1. Stakeholder Interviews

*2.1.1. Interview procedures.* The interviewees were drawn initially from existing professional networks of the researchers involved, and through other outreaching activities. The pool of stakeholders was then gradually expanded to also include those who were introduced to the project via existing connections, and through other organisations' websites. An open call for interested parties to participate in the interviews was also published on the associated institute's website and newsletter.

The initial climate change use case application of interest was the energy efficiency of buildings, so the stakeholders targeted so far were mainly from sectors where building retrofit and built environment decarbonisation activities are likely to be highly relevant, such as government departments and/or local authorities, construction and/or building consultancy companies, property companies who manage large estates, and community action groups.

The interviews carried out focussed on the following questions as a starting point for the discussion: 1) Who is the expected user(s) for this particular use case? 2) How would the TIR data be used in this application? 3) What are the user needs and requirements? 4) Mentions or concerns relating to financial aspects of access to the TIR data? 5) Any other useful information relating to this use case?

We used example thermal infrared imagery generated from the NASA MASTER airborne dataset [6] to communicate with stakeholders who would like to see what an exemplary output will look like. However, this dataset was collected by airplane, which may result in a much shallower angle than that

from a satellite. In addition, the resolution from this dataset might not necessarily coincide with that from our proposed satellite. Nevertheless, they are sufficient to communicate the idea in order to provide the potential stakeholders an overarching picture of what approximately can be anticipated [7].

*2.1.2. A selection of interview case profiles.* Based on 26 stakeholder interviews conducted so far, we have selected the strongest use cases and developed 14 Climate Change End-User Cases for the TIR space telescopes, with a primary focus on the energy efficiency of buildings. Each use case focuses on a particular distinct application of the TIR earth observation data by a particular user (or set of users), within the remit of improving the energy efficiency of buildings. The use cases are profiled in Table 1. To ensure stakeholder confidentiality we have anonymised the stakeholder(s) interviewed, and only give an indication of their role and the type of organisation.

Table.1 A list of 14 Climate Change End-User Cases and stakeholder interviews profile

Interview	Role	Organisation type
A	Data Manager – Home Analytics; Data Insight Analyst	Social enterprise
B	Head of Corporate Strategy and the team	Local authority
C	Senior manager	Semiconductor and software design company
D	Director, Climate Positive Solutions	Privately-owned international property company
E	Operation manager	Housing association, part of Local authority
F	Associate - Building Sciences BSE; BNI/EUNA Practice Leader for Building Sciences	Global engineering, management and development consultancy
G	Strategic Planning Manager; Consultant; Energy Projects Manager	Local Government; a collaboration of eleven Local Enterprise Partnerships
H	Partner	Multi-disciplined firm of property and agribusiness consultants
I	Consultant / Chair of the Decarbonisation of Homes in Advisory Group	Multinational professional services firm in the built environment/ national Government
J	Principal Policy Officer	Strategic regional authority
K	Director - Head of Systems	Global real estate company
L	Environmental Consultant	Charity
M	Programme Director; Senior Transformation Advisor	Local authority
N	Research team lead	Not-for-profit, part of energy company

## 2.2. Content analysis

Interview recordings were transcribed and processed using content analysis [8]. Content analysis is an established research method used to identify patterns in recorded communication. In this work, qualitative ways of interpreting and understanding were used to categorise or “code” words, themes, and concepts within the transcripts and then analyse the results.

## 3. Results

The stakeholder engagement interviews were used to develop a detailed understanding of each stakeholder’s interest in the proposed TIR space telescopes, and how the TIR data provided may help to further their aims and data analysis needs. As such, the interviews focussed on an exploration of any likely uses and subsequent requirements by the potential stakeholders. For example, these included resolution requirements from the stakeholders’ perspective and understanding, as well as frequency of use, data format preferences, and their willingness and/or any barriers to pay for such data provision.

### 3.1. Use cases

This subsection describes three key use cases in which the TIR satellite data could potentially be used by a variety of stakeholders. Depending on the objectives and line of work involved in the stakeholders’ organisations, these can range from initiating client projects to making investment decisions about upgrading properties, from quality assurance to tracking performance, from energy efficiency advice to communication and persuasion on behavioural change for energy demand reduction.

*3.1.1. Informing investment decisions and identifying opportunities.* Many of the stakeholders interviewed have raised the prospect of using TIR satellite data for properties in their portfolio, to make investment decisions such as helping target long-term interventions so they can see where they need to tackle first. This can also include establishing for every single property how it's performing, in addition to identifying areas that are poor performing, when used in combination with their databases. The data can be used to determine the business case, such as feasibility, and looking at where the investment is going to have the highest yield, or to deliver the quickest return on investment. It can also help to gain funding and identify opportunities, for the works and interventions, and help to reach that target by the target dates, as well as building capacity in predicting future resilience. More often than not, building energy efficiency involves both heating and cooling, as well as reduction of overheating risk. In addition, for government, it's a useful tool to identify fuel poverty and being strategic about the steps to take in supporting retrofits.

*3.1.2. Quality control and verification.* During several interviews, quality control was brought up as an important goal when considering the use of TIR data. This is especially the case when large retrofit installations have been implemented and the quality needs to be monitored to ensure that the anticipated performance is to be achieved. The use can include recording progress of delivering energy efficiency measures. And if any construction errors or performance gaps are found, this can help further narrowing it down to tackle any design or installation issues. In other words, what is designed and anticipated can be verified and tracked.

*"It'd be cool to continue to collect that data to have a before and after with the satellite imagery. We can then see what's actually happening in the home, before and after that intervention, rather than just assuming that 'well, we've put in insulation so we're going to achieve these hypothetical savings'; it'd be cool to see how it's actually playing out on the ground."* (Interview A)

*3.1.3. Advice and communication.* Some stakeholders would look to use the data primarily for their advisory services, to advise a client's whole business plan. One suggested using it to inform policy making and regulatory design. It can also be used to calculate building fabric energy efficiency when both internal temperature and external temperature are available, as well as heat loss through the fabric. When used together with EPCs, it can indicate fuel poverty households or power outage by looking for those expected to have relatively high energy use but appearing with very low temperature. It can also be used as part of social competitions towards sustainability, as well as nudging property-owners towards increased uptake of building retrofit measures and lower energy demand. It serves as evidence to say or show how the building is doing in its performance so as to try communicating with investors in making improvements on the building.

*"That's quite useful for decision makers, for getting voice across to the public."* (Interview G)

It can be combined with existing model work to add on a further layer of accuracy, to improve models which typically run with logistic regression, so as to improve energy efficiency advice capabilities. It can certainly be used as further information on commercial buildings as there's a current lack of available data, and for district heating schemes that the government is looking at, i.e. to identify heating loads that one could build a network around.

### *3.2. User requirements*

When using the satellite data output, it is important to make clear how the output will suit the users' needs and requirements. These include any requests or suggestions on resolution, frequency and format to fit in the work of potential stakeholders. The following subsections describe respective details arising from discussions during the stakeholder interviews.

*3.2.1. Resolution and viewing angle.* It is important for many stakeholders to be able to have angled view to see facades. Almost all interviewees have requested individual building level resolution, down to address level, which equates to 3 – 6m ground sample distance (GSD). Ideally the data can really

identify certain house types if certain stakeholders are working on domestic buildings. They can then be scaled up to Census Output Areas and/or Council areas to be able to benchmark statistics against different areas. For some users, it is also important to differentiate between floors in mixed-use buildings or within multi-tenancy buildings, so that they will be able to see how their leasehold space is performing, whether that is just one or a few floors' space.

*3.2.2. Frequency.* For monitoring projects' quality aspects, the frequency required is once pre-work and once post-work, usually during night-time at winter, and each time coming back to monitor after a retrofit measure is installed. There is also a suggestion of doing a time lapse, such as annual monitoring before and after retrofit, focusing on the same place on the same day every year. Additionally, some users suggested maybe monthly or weekly during winter months, like a snapshot at multiple points regarding monitoring performance. The multiple points could be the morning, midday and end of day, depending on the heating system's on and off patterns.

The majority of stakeholders prefer yearly estimates of heat loss by property, or even some seasonal data. For some, it's usually once or twice a year; but depends on whether or when other datasets are being released. Some stakeholders requested a quarterly revisit rate or seasonal frequency, depending on the locations and local climate. One suggested daily frequency so as to combine with smart meter data, depending on affordability.

*3.2.3. Format.* The required data formats tend to be grouped into visual and numerical. For some stakeholders, they prefer converting a picture into data, into numbers one can crunch, such as actual values of kWh/m<sup>2</sup>/a of thermal output for particular buildings. In this way, one can find ways of connecting it to existing datasets at the building level, or at least at a small area level. Ideally the data would merge with other data such as EPC at address level, to build the whole picture up. Examples can be integration into maps or statistical models. Numerical data also shows measurability whereas colourful images might not be suited to distinguishing changes easily sometimes. For other stakeholders, they give preference for images which are direct and easy to see where the challenges are and where the prioritisations need to be. There are also stakeholders who hold capacity in data analytics, and ideally want to integrate the analytical imagery processing into their value chain, while developing know-how in the process.

*"I can see this becoming featured because it's current, it's relevant, it's visual, it would be at the forefront of it."* (Interview H)

Some stakeholders ideally want to pick out historical datasets on certain individual buildings quickly, due to their relatively short project lifecycles. Some consider the ideal is to use it as an easy-use evidence base, where they prefer the output to be processed and ready, so they don't potentially have to put a lot of resources into managing the data.

### *3.3. Financial considerations*

Certain concerns were raised by some interviewees over affordability of TIR satellite data. And in the line of most organisations' work, cost is an important factor, where they need to see demonstrated value added to the project. *Interview I* suggested that a commercial test would be held to compare satellite output with ground- or airplane-based systems, or other vehicle-mounted data, in terms of possible accuracy aspect of the output, where detail is needed at the right price. Some stakeholders indicated, based on their budget, that it is about how much they can spend on each building, depending on the size and level of detail level required, for these data points. For some, consideration would be driven by impact, such as whether they can achieve similar impact by using lower grade information that's cheaper. Local authority will get the license to get the best data if they have a duty allocated.

When discussing financial aspects, most interviewees indicated that they would be interested in getting a subscription model for relatively small areas, if there is a specific type of information that is not publicly available which is required for a particular building or model. They wouldn't necessarily do it for the entire country because that might be too expensive, but if they have a particular client that

operates in a particular region, they might look to some subscription services for those geographies. Certain concern was raised on subscription models as to terms and conditions for data sharing, due to restrictions around sharing the data with other users, so this might reduce the utility of it for some stakeholders.

#### 4. Conclusions

This research has revealed the applicability of satellite TIR data in many areas towards monitoring and improving building energy efficiency. The stakeholder engagement interviews have uncovered a range of potential uses for TIR satellite data and improved our understanding in respective requirements and financial considerations. Key use cases include: 1) investment decision making, initiating and identifying projects such as which buildings to target; 2) quality control, tracking and verification; 3) advice and recommendations on building energy performance and retrofit, communication and persuasion in behavioural change towards lower energy use and/or increased uptake of retrofit measures. User requirements focused on revisit rate, data resolution and format. Most stakeholders preferred annual, seasonal or by-annual frequency, with angled view to see facades and a resolution that can identify individual buildings, equating to a range of 3 – 6m GSD, considering domestic properties being the smallest with some terraced houses having a width of around 3m. Furthermore, some stakeholders would prefer visual data output, while others favour both images and value derived products such as U values that can be incorporated into their existing data analytics i.e., modelling. There are some financial considerations but overall, for larger companies, as long as it justifies return of investment (ROI) and demonstrates superiority over other similar market products, or for smaller companies the added value and being within budget, then it should be straightforward for the uptake of such data products by the potential stakeholders. Some licensing models may pose challenge for certain stakeholders who intend to share such data or derived data products with their clients or relevant third parties.

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