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Time-lapse thermography for building defect detection

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ABSTRACT

Building thermography traditionally captures the thermal condition of building fabric at one single point in time, rather than changes in state over a sustained period. Buildings, materials and the environment are, however, rarely in a thermal equilibrium, which therefore risks the misinterpretation of building defects by employing this standard methodology. This paper tests the premise that time-lapse thermography can better capture building defects and dynamic thermal behaviour. Results investigating the temporal resolution required for time-lapse thermography over two case study houses found that under typical conditions small temperature differences (approximately 0.2 K) between thermal areas could be expected for 30-min image intervals. Results also demonstrate that thermal patterns vary significantly from day-to-day, with a 2.0 K surface temperature difference experienced from one day to the next. Temporal resolutions needed adjusting for different types of construction. Time-lapse experiments raised practical limitations for the methodology that included problems with the distance to target and foreground obstructions. At the same time, these experiments show that time-lapse thermography could greatly improve our understanding of building transient behaviour and possible building defects. Time-lapse thermography also enables enhanced differentiation between environmental conditions (such as clear sky reflections), actual behaviour and construction defects, thereby mitigating the risk of misinterpretation.

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1. Introduction

According to the United Nations Environment Programme, buildings account for over 40% of the world's energy use [1]. Within the European context, building energy use is rising, with EU dwellings responsible for approximately 70% of all energy use in buildings [2]. Of the 22.4 million dwellings in England, almost 90% were built prior to 1991 [3], a pattern which mirrors the housing trend throughout Europe [2]. Since new build construction in England for 2013 only totalled 109,370 units [4], the aim of the UK government to meet carbon reduction targets of 80% on 1990 levels by 2050 [5] appears unachievable unless widespread action is taken to thermally improve existing dwellings. In addition, increased energy costs are leading to increased levels of fuel poverty [6]. The risk of fuel poverty is typically larger amongst occupants of rural buildings [7] due to a lower uptake of gas central heating and less energy efficient construction. It is therefore important to improve existing dwellings that are energy inefficient thermally and to minimise the energy demand required for heating buildings.

The ability to identify thermally inefficient areas successfully, such as specific thermal defects, is fundamental to the subsequent success of thermally improving existing buildings [8]. Thermography is an analysis technique which is increasingly being used by construction professionals as a non-destructive tool suited for this task [9]. Thermography, also named thermal imaging, uses a special type of camera to detect infrared radiation, which is emitted from surfaces [10] such as the building fabric. Since the infrared radiation relates to temperature, this in turn depends on heat transfer through the building envelope. Providing there is sufficient temperature difference across a construction, thermography can be used as a tool to identify quickly potential building defects, such as moisture ingress, without the need to undertake costly and damaging physical exploratory investigations. However, image interpretation is a key limitation since thermographers need to be particularly mindful of the external conditions and parameters which can inhibit defect detection, such as emissivity, distance, level, span. [11].

At present, building thermographers tend to capture a series of thermal images during a visit to a building but do not undertake

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any longitudinal studies [12]. Such images have the potential for misinterpretation due to transient effects, such as that provided by thermal mass dampening temperature change over time, which are not always recognised in images taken at a single point in time [13]. Furthermore, internal and external conditions have an impact on the temperature of a construction; the specific effects will vary depending on the ability of the particular fabric to store heat energy. For example, solid masonry walls have a greater capacity to store energy through thermal mass when compared with lighter-weight timber-frame walls. Depending on the internal room temperature and that of the inner wall surface, energy stored in thermal mass might reverse the heat flow direction [14] from that which might be initially expected. Alternatively, some constructions might contain insulation or cavities, which present less thermal conductivity when compared with solid wall constructions such as stone or cob. This will have an impact on heat flow through a wall. As such, low-conductive materials will present a barrier to the flow of heat in either direction and could have an impact on thermal image results.

However, some recent thermal cameras now have the ability to record sequences of images thus creating a time-lapse series and thereby presenting new opportunities for longitudinal building thermography [15] to observe the transient flow of heat through construction over a much longer period. To date, this approach has not been used for thermal studies of whole buildings.

This paper aims to develop and investigate the use of a time-lapse thermography methodology for the inspection of buildings. It seeks to better understand transient thermal changes of the fabric and how these interrelate with the identification of building defects through thermography.

The research has the following objectives, to:

(a) Compare and contrast a time-lapse methodology with the more commonly used method of capturing images at one single point in time;
(b) Develop a time-lapse thermography methodology, which explores the key limitations and practicalities involved with conducting on-site internal and external investigations;
(c) Investigate different temporal resolutions required for undertaking time-lapse analysis, in order to better highlight defects and thermal behaviour.

This paper applies a qualitative time-lapse thermography methodology to three case-study buildings to explore the use of apparent surface temperature changes over prolonged periods of time in order to draw conclusions from transient changes. Although building thermography can also be used to observe the behaviour of and defects within HVAC systems, this work primarily focuses on observing the building fabric.

2. State-of-the-art in building thermography

2.1. Traditional building thermography

There are two schemes of analysis by which building thermography can be performed: *active* and *passive*. Active thermography utilises a forced heating or cooling stimulus, which creates an enhanced thermal contrast to locate specific defects such as sub-surface cracks [16]. In contrast, passive thermography observes the natural temperature differences of objects which would normally be at a different temperature to each other [12]. Avdelidis et al. [17] reported that passive thermography is the most common analysis scheme for building inspections, typically combined with qualitative analysis, since the aim is to detect potential defects in buildings without artificial intervention. In this context, the use of heating systems is not considered to be an active/imposed stimulus since these are a regular part of the building.

Currently, the most common form of passive building thermography utilises a *walk-around* or *walk-through* methodology [18]. In this paper, these are collectively referred to as *traditional* passive building thermography. Given the higher speed and minimal disruption to occupants, authors such as Holst [19] advocate the sole use of a walk-around survey which only observes external building surfaces. Yet the presence of climatic conditions, such as precipitation or wind, during external thermography [11] can hinder external defect detection. Hence there may be the need for the addition of an internal walk-through, where the thermographer inspects internal surfaces [13]. Both approaches require the thermographer to scan each surface systematically with a thermal camera as he/she walks around, or through, the building [20], concentrating on any warmer or cooler spots (compared with the ambient temperature) that might suggest irregularities or defects. As stated, in traditional thermography thermal images are recorded at one moment in time, and not longitudinally. This is significant because the condition of the element being observed is only captured at the specific moment the image is taken. Traditional passive building thermography can be subject to a number of different sources of inaccuracy, such as camera thermal resolution [21], emissivity [22], problems with reflected apparent temperatures [19] and climatic weather conditions [13].

Climatic conditions pose particular problems for thermography. Firstly, climatic conditions dictate when thermography should or should not be undertaken; the recommendation [13] is for dry conditions with low wind levels, cloud covered sky and at least a 10.0 K temperature difference between internal and external spaces. However, climatic conditions can also have an impact on the thermal condition of the building fabric. In particular, such changes could alter the apparent properties of materials on a transient basis, particularly when subject to environmental stimulus such as temperature, wind, moisture or solar gain. The impact of varying air movement, for example, is very complex [10] and can vary more quickly than other conditions owing to gusts, which could have an impact on single image results due to forced convection. This can be compounded when coupled with other climatic conditions such as moisture in the material [11].

2.2. Time-lapse building thermography

For the longitudinal application of thermography, the terms ‘transient’ and ‘time-lapse’ are important. ‘Transients’ are found when certain factors such as climatic conditions vary over time. ‘Time-lapse’ is the process of capturing spaced data sets (such as images), which can be presented in a sequence to speed up slow processes such as transient changes.

Accordingly, we define time-lapse thermography as a passive thermal imaging methodology, which aims to better understand transient heat flow within a building’s fabric by recording a sequence of images. Time-lapse image capturing is commonly attributed to photography [23] where typically slow or fast events can be accelerated or slowed by saving image frames at different temporal intervals to that of traditional film speeds (25 frames/s). Given the slow nature of transient changes in building materials, time-lapse image recording appears well suited to thermographic investigations.

To establish the current thinking regarding time-lapse thermography, a review of existing literature was conducted. From this, it was discovered that the most commonly reported use of time-lapse thermography involved active thermography. This is exemplified by Hamzah [26] whose work located structural defects hidden beneath material surfaces using forced heating phases prior to thermographic observation over periods no greater than 22 s.

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