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ENERGY AUDIT IN IRT OF MOISTURE AND DAMPNESS DETECTION AND DIAGNOSIS IN BUILDINGS

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Informações do Artigo

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Abstract:

A study of moisture and dampness detection and diagnosis (MDDD) in building envelopes in relation to indoor energy conservation is necessary because it is crucial to pinpoint energy inefficiencies, lower energy inputs, and identify potential solutions to improve energy utilisation. Thermographic and real-world images of moisture presence in building envelopes were captured to demonstrate significant thermal differences caused by moisture and dampness, known to influence energy conservation management of HVAC operations and performance in buildings. Using a qualitative analysis known as gravity, urgency, and tendency (GUT) analysis, a preliminary assessment was conducted to detect and diagnose the presence of moisture in certain areas of surveyed university building walls. Moisture presence was displayed as a thermogram side by side with the actual photos of the identified defective wall regions. There was a significant presence of moisture in the wall, which could significantly influence the building energy audit. The study also entertained discussion on infrared thermography in qualitative and quantitative detection of moisture presence in walls and the need for effective energy audit and conservation of buildings with cognisance to moisture in walls of buildings and other building defects inimical to energy conservation and use.

1. Introduction

Non-Destructive Testing (NDT) is used in conjunction with building energy audits to help with understanding intricate fluid dynamics phenomena, characterising materials and structures, managing manufacturing processes, and refining product design and fabrication [1]. Infrared thermography (IRT) in particular offers highly helpful information to rapidly identify the thermal anomalies associated with structural characteristics, building materials, and energy issues [1] [2]. This non-contact testing technique makes use of an infrared (IR) imaging system that has been calibrated to measure the distribution of emissive power on surfaces across a range of temperatures. A series of two-dimensional, readable infrared images, or thermographs, are created by the infrared camera. Different temperatures are indicated by different colours and tones [3].

Active and passive, or static, thermography are the two methods used in the building energy audit. In order to identify the precise location of energy-related issues, passive IRT scans the whole building fabric for unidentified defects [4] [2]. Active thermography, on the other hand, focusses on scrutinising building defects in depth [4]. Consequently, passive approaches are regarded as the standard methods for conducting an energy audit [4] [2] . Under standard thermal settings, such as the presence of solar radiation, passive thermography monitors temperature changes [4]. The components of this strategy are as follows: (1) aerial; (2) automated fly-past; (3) street pass-by (or drive-in); (4) perimeter walk-around; (5) walk-through; (6) repeat; (7) time-lapse; and (8) mock target survey strategy.

The foundation of aerial surveying is the installation of an infrared camera on an aircraft or a helicopter. Although it allows for the observation of issues on large structures, its utility for energy evaluations is typically limited due to picture blurring limits, the influence of meteorological conditions, and thermal emissivity [4] [5]. Applications for detecting moisture or energy loss from roof surfaces are sporadic [5]. Utilising an infrared camera installed on UAVs or drones is the basis of automated fly-past surveys. Potential uses include detecting heat loss through windows [6]. Street pass-by thermography automatically takes high-resolution pictures of homes from streets or public roads using infrared cameras mounted on vehicles [4] [7]. The "Kinetic Super Resolution Process" is the foundation of this technology, which combines low vehicle speeds, many infrared cameras, and image improvement algorithms created by Essess and MIT to retain high spatial resolution while enhancing temporal resolution (sensor refresh rate) [2]. Currently, this method is employed to expedite the evaluation of thermal performance, particularly in the context of the building stock study [4]. It is four to five times less expensive than traditional approaches (such as walk-around and walk-through IRT) and allows for the minimisation of variations in results caused by surveying numerous buildings under various climatic circumstances.

For the energy audit, walk-around and walk-through thermography are the most used passive methods [8]. These are methodical surface scans of the building’s envelopes and roofs [8]. The first takes street-level observations of each external building elevation, while the second imaging system captures images from the inside and outside [4]. Compared to the indoor survey, which offers a far more regulated climate, the external survey is more vulnerable to erratic environmental conditions [4]. Conversely, it necessitates direct access to the structures since some elements (such as closets, photographs, and bookcases) affect the thermal performance [4]. By applying comparable concepts and techniques, walk-around and walk-through IRT can supplement the walk-through energy audit. The former takes less time than the latter, which can be laborious in large or multi-room buildings [9]. Their application relates to the electrical system, HVAC, and building envelopes [9].[10]. Furthermore, walk-through thermography can facilitate both normal and simulated audits, allowing for a more thorough examination [11].

Repeat surveys are designed to track the development of faults by continuously observing the building's performance [4]. It is typically utilised to support both standard and simulated audits, with a focus on post-occupancy assessment, refurbishment evaluation, and moisture detection [12]. Utilising recorded videos, sequences, and time-lapse photos, time-lapse surveys track variations in the material surface form over time [4] [13]. The practical constraints include safety and security issues, like restricted spatial resolution and field of view, the distance between the infrared camera and the item surface, unwanted objects in the foreground, and difficulties in maintaining the infrared camera's power supply [13]. In this instance, too, it might help the standard audit to find out how different plasters evaporate and dry, or to figure out how well thermal insulation [4] or construction build-up [10] performs thermally. The measurement of appropriate mock targets' surface temperatures in thermal equilibrium with interior air is the foundation for mock target IRT [14], to sum up. It offers multifaceted air temperature readings in indoor environments instantaneously. Its primary use is for evaluating how comfortable people are during conventional and simulated audits.

For the energy assessments, each of these methods produced results that were judged appropriate. Some of them are especially appropriate for the interior energy evaluation, which is the study's main focus, even though some of them will properly dynamically analyse energy from the exterior of the structure, such as the aerial, automated fly past, and street pass by. It has been determined that perimeter walk-around and walk-through procedures are the most popular and suitable for interior building energy audits. When employing outside IRT surveys, inside issues such as moisture intrusion, dampness, condensation, or ventilation losses may go entirely unnoticed.

Each of these approaches resulted appropriately for the energy assessments as deemed fit. While some of them will suitably dynamically assess energy from the external of the building, for example the aerial, automated fly past and the street -pass by, some are particular suitable for the internal energy assessment which is the focus of this study. Perimeter walk-around and walk through has been identified has the most common and appropriate for indoor energy audit of building. Internal defects such as moisture ingress, dampness, condensation or ventilation losses might be completely missed using outside IRT surveys [2].

In order to obtain information with streamlined processes, minimal expenses, and shorter turnaround times, infrared thermography has been widely employed in walk-through and routine audits [15] [2]. One of the many building defects that this qualitative investigation has been able to accurately identify and diagnose is the detection of moisture and dampness defects in structures. Because many defects have an effect on energy behaviour, this is the match between building diagnostics and energy audit [2]. Energy difficulties can affect building defects by increasing the amount of moisture on internal wall surfaces, which can influence pathogenic growth on wall surfaces. Conversely, internal moisture affects energy performance. The impact of moisture on energy audit has been demonstrated in the literature, but little research has been done on the common moisture movement characteristics and defects in building envelopes and roofs, particularly in tropical countries, in the context of energy audit and conservation, which is why this study was conducted. Perhaps common moisture features in the tropical regions of the world can reveal significant information about the amount of energy lost and conserved, through visible and infrared thermography surveillance. Furthermore, the study distinguished between different kinds of moisture presence using the gravity, urgency, and tendency (GUT) scoring system, which is also useful to determine the order of importance for building facade repairs. If a moisture defect remains uncorrected, the presence of moisture can indicate the extent of energy loss or conservation.

The study methodology section includes thermograms and actual photos taken at various locations within a university building, together with the circumstances and protocol of the survey. After that, there was a section on the results and discussion, which went over the different aspects of moisture and dampness in buildings as they were presented in the methodology section. The purpose of this section was to draw attention to the thermal effect, energy losses, moisture and dampness in building defects since maintaining thermal comfort in enclosed spaces requires the use of more than 60–70% of a building's energy supply [16]. The study ends with a section on the study's conclusions, recommendations, and the need for more research.

2. Methodology

A selected preliminary survey of various spots in a six-story university building in Rio de Janeiro built in 1960s was carried out with the intent of capturing real and thermographic images of moisture and dampness detection and defect for a qualitative analysis of various types of moisture identifications in the building. The walk-through passive IRT method, already identified as a viable method in energy audit, was used to identify the various features of moisture presence and classified into subdivisions for a qualitative analysis. The climatic conditions were stable producing clearer infrared images. In terms of good practice, outside inspections are best conducted during the night or in the early morning with heating systems switched on to maximise the thermal contrast [17]. On the contrary, inside inspections are best collected during daytime or early evening periods to reduce the effects of the solar heat loads [17], this timing was observed for this survey.

The subdivisions of the presence of moisture as adapted (IAQ, 2013; Braga et al., 2019) are: 1. accidental moisture (AM); 2. air moisture (AirM); 3. building moisture (BM); 4. percolation moisture (PM); and 5. upward moisture (UM). Each of these moistures were assessed base on the two thermogram and photograph of two places (one internal and one external wall) in the building. GUT was scored to demonstrate the extent of moisture presence, which also suggests the extent of energy losses or that could be conserved if the moisture is retained or removed through prioritised repair in the maintenance of the building. Table 1 was redesigned by authors and adapted for the purpose of assigning qualitative scores for ease of evaluating the extent of moisture presence in the selected building envelopes and walls of the university building. The GUT scores are obtained through the products of the assigned scores for gravity (G), urgency (U), and tendency (T), (G x U x T) of each inspected portion and are shown in photographs and thermograms. Note that the higher the GUT score the higher the severity of the presence of moisture in the building envelopes and roofs.

The definition of the AM, AirM, BM, PM, and UM GUT Qualitative evaluations were based on the following moisture presence definition [1]; [2]. ***Accidental moisture (AM)*** is brought on by piping system flaws that result in infiltrations of rainwater, sewage, and drinking water. Given the possibility of the existence of materials with an extended life cycle, this kind of moisture is especially important for historic buildings moisture presence assessments. ***Air moisture (AirM)*** stems from the high relative humidity in the atmosphere and the presence of surfaces that are colder than the dew point. The phenomena arise from the air's decreased ability to absorb moisture when it cools near the wall interface. ***Building moisture (BM)*** is described as the moisture that was inside the materials during construction and that is externalised as a result of the equilibrium that is created between the material and the environment, as well as construction mistakes that let water in, for instance, poorly done construction or movement joints. ***Percolation moisture (PM)*** is distinguished by moisture seeping through tiny cracks from the outside into the interior spaces, by the materials' high absorption capacity from the air, or even by imperfections in the interface between building parts, like wall plans and doors or windows. It is typically induced by rains, which can exacerbate the infiltration when accompanied with wind. ***Upward moisture (UM)*** is typified by the presence of soil-derived water, which is caused by both seasonal increases in humidity and the ongoing presence of surface water table moisture, which is mostly observed on walls and floors.

3. Results and Discussion of Results

Only two of the four actual and thermographic photos that were obtained of various locations across the building were included in this investigation. The sunshine effect, which was unfavourable for the building's exterior wall thermograms taken from the university building's balconies, is the cause of this. As previously mentioned, the external portion of the structure is best photographed at night when there are no artificial or natural illumination heating impacts. This was a constraint in the preliminary survey that was employed for this study.

The images revealed the existence of two different forms of moisture. The first one, represented in Figure 1, is moisture from rainwater-induced percolation (PM). Figure 1 depicts one of the external walls of the university's laboratory. Despite the fact that the IRT image was captured while the sun was still shining, the thermogram clearly shows a significant amount of moisture. The thermogram's Xcs1 point represents the coldest location, and the wall's average temperature is shown by AV1. A PM GUT aggregate score of 125 is obtained from the qualitative assessment for the presence of moisture (see Table 1, column 4). By multiplying the assigned qualitative scores for gravity (G = 5), urgency (U = 5), and tendency (T = 5), the 125 score was calculated. This suggests that the wall is seriously moist and that there is significant percolation-related movement in the wall. The wall depicted in Figure 1 is situated at the highest point of the six-story building, directly facing the impact of the sun and driving rain.

The second set of images in Figure 2 was taken inside a research office. The water outlet line from the air conditioner (AC) was leaking, which is why there was moisture on and in the wall. As was discovered during this walk-through internal survey examination, this amply illustrates the ability of passive IRT to more clearly identify both surface and internal moisture present in walls under controlled climatic conditions. Take note of the location of the AC pipe leak, which is indicated inside the ellipse in both the thermogram and the actual photo. This area is the moistest (and coldest) of the entire surface area that was photographed. Meanwhile, one issue that can be found when analysing the functional differences of the HVAC system and visualising its performance during the design and installation phases is the detection of water leaks from pipes [3]. When the assigned qualitative scores for gravity (G = 5), urgency (U = 5), and tendency (T = 5) are multiplied, a qualitative assessment of the AM GUT moisture presence score of 125 is obtained. This indicates a very serious moisture presence, but this time it is due to accidental moisture (AM), as defined in the methodology section.

The wall of the university building under inspection is a wet mass, which means that heat is absorbed and retained longer before radiating than it would be from a dry material. This is the most popular method for identifying moisture issues in walls or roofs [3]. Even when the air temperature is at the proper levels, cold and hot surfaces have a direct detrimental effect on a person's ability to remain warm [3]. These show the relationship between the amount of moisture in walls and indoor thermal comfort, as well as the additional energy needed to maintain human thermal comfort even in buildings with damp building envelopes. Because evaporation cools wet surfaces at steady-state conditions, thermography can be used to map the moisture distribution in plaster. A single gramme of evaporating water can absorb up to 2500 joules of energy, making the evaporation process extremely energy-consuming [4]. Where evaporation produces a cooling impact on the surface, it outweighs temperature variations caused by other elements, such as emissivity [4].

In particular, damp surfaces have a lower temperature than dry ones. The three physical processes that impact the decrease in surface temperature are the "evaporative cooling" of the surface, which results in an endothermic reaction; the increase in the rate of heat transfer under steady-state conditions; and the higher heat storage capacity of moist materials relative to dry materials [5] . Because many materials have reduced thermal conductivity as a result of these processes, the thermal performance of the building elements is impacted. In order to prevent serious degradation, including condensation, efflorescence, biological and mould growth, material performance degradation, and detachment, a number of IRT surveys try to track down water leaks and locate moisture before any obvious markings appear [6] . There are currently many operational processes being developed that use IRT surveys alone or in conjunction with heat flux monitoring, visual testing, and coring to detect moisture-related anomalies in building elements [5] [7] [4]. As seen in Figure 2, under controlled climatic conditions in passive thermography, moisture, water leaks, penetrative damp, and rising damp through the building's elements generate a deep patch thermal pattern on the surfaces that is more glaring. In research on the use of infrared thermography for building diagnostics, Balaras and Argiriou [3] found that, if moisture-saturated insulation is widespread, the pattern on the thermograph will be "mottled" or "patchy."

Both qualitative and quantitative research methods have categorised the application of IRT for the energy evaluation [7] [8] [9]. Without giving the patterns a temperature value, the qualitative analysis seeks to identify the existence of anomalies in temperature on the building surface [7,9]. In order to obtain information with streamlined processes, minimal expenses, and shorter turnaround times, it has been widely utilised in walk-through and standard energy audits [10]. Thermal characterisation of walls, glazing, and windows; detection of thermal bridging and areas of excessive heat loss; thermal insulation examination; air leakage inspection; moisture and water detection; HVAC and electrical system characterisation; indoor temperature measurements; and human comfort assessment are among its areas of action. The building envelope's thermal performances have been measured using the quantitative studies in both standard and simulation audits [8]. The percentage of locations with thermal anomalies, insulation level detection, U-value measurements, dynamic wall characterisation, and moisture content determination are its primary areas of activity. In the meantime, this study's assessment of moisture determination was qualitative.

4. Conclusion and Recommendation

Moisture in a building's walls can have detrimental effects on its structural integrity, occupant comfort, and energy consumption. As a result, it is crucial to recognise and describe this developing defect using the best available technologies, one of which is the IRT. According to an article, "qualitative thermographic building surveys provide sufficient information to identify the following: electrical faults, hidden components like pipes and wall ties, continuity of insulation, occurrences of thermal bridges, sources of air leakage, particularly at critical junctions, moisture, and damp within an element” [11]. For the majority of energy auditors, this method will suffice to reach conclusions. For instance, IRT is widely utilised by energy efficiency specialists in the US as a qualitative instrument to assist with Home Energy Rating System reporting tasks [12]. In the same vein, this study used IRT to qualitatively identify and diagnose moisture and dampness in walls during a preliminary survey on a university building. There was a substantial amount of moisture present in the thermographic and real photos, which can have an impact on how energy-efficient and energy-conscious a building is, particularly the infrastructure of educational institutions. It is possible that the whole-building energy audits will underestimate the peak energy consumption of the buildings if the case and review in this study's discussion are ignored regarding moisture presence in the building envelope. This may cause the HVAC system to be oversized, particularly in arid settings, and the energy usage to be underestimated, mostly in tropical areas [13].

As was previously mentioned, the case examined in this study is an early investigation into the application of IRT in MDDD. The primary focus of the wider study will be on maintenance practices and procedures that are critical to effectively managing the presence of accidental moisture in the university building envelopes investigated. This study recommends creating smart sensors for indoor monitoring, environmental control, and human comfort evaluations in addition to initiating long-term environmental monitoring utilising the mock target IRT. Modern advances in machine learning and numerical analysis can be applied to the matching of thermographic data with building geometry to produce high-quality quantitative results that are more accurate than the overall qualitative results that are typically provided by the use of IRT in energy audit, monitoring, and management.

5. References

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APPENDIX A

Table 1: The GUT scoring for each of the moisture presence subdivisions in the building envelopes (Adapted from Kepner & Tregoe, 1981; Barbosa et al., 2021)

AM GUT scores **Gravity** (scores) Result	**Air GUT** scores **Gravity** (scores) Result	**BM GUT** scores **Gravity** (scores) Result	**PM GUT** scores **Gravity** (scores) Result	**UM GUT** scores **Gravity** (scores) Result
Strongly serious (5)	Strongly serious (5)	Strongly serious (5)	Strongly serious (5)	Strongly serious (5)
Very serious (4)	Very serious (4)	Very serious (4)	Very serious (4)	Very serious (4)
Serious (3)	Serious (3)	Serious (3)	Serious (3)	Serious (3)
Little serious (2)	Little serious (2)	Little serious (2)	Little serious (2)	Little serious (2)
Not serious (1)	Not serious (1)	Not serious (1)	Not serious (1)	Not serious (1)
Score =	***Score =***	***Score =***	***Score =***	***Score =***
Urgency (scores)	**Urgency** (scores)	**Urgency** (scores)	**Urgency** (scores)	**Urgency** (scores)
Deadline	Deadline	Deadline	Deadline	Deadline
Strongly urgent (5)	Strongly urgent (5)	Strongly urgent (5)	Strongly urgent (5)	Strongly urgent (5)
Very urgent (4)	Very urgent (4)	Very urgent (4)	Very urgent (4)	Very urgent (4)
Urgent (3)	Urgent (3)	Urgent (3)	Urgent (3)	Urgent (3)
Little urgent (2)	Little urgent (2)	Little urgent (2)	Little urgent (2)	Little urgent (2)
Not urgent (1)	Not urgent (1)	Not urgent (1)	Not urgent (1)	Not urgent (1)
Score =	***Score =***	***Score =***	***Score =***	***Score =***
Tendency (scores)	**Tendency** (scores)	**Tendency** (scores)	**Tendency** (scores)	**Tendency** (scores)
Progress	Progress	Progress	Progress	Progress
Strongly full (5)	Strongly full (5)	Strongly full (5)	Strongly full (5)	Strongly full (5)
Very full (4)	Very full (4)	Very full (4)	Very full (4)	Very full (4)
Full (3)	Full (3)	Full (3)	Full (3)	Full (3)
Little full (2)	Little full (2)	Little full (2)	Little full (2)	Little full (2)
Not full (1)	Not full (1)	Not full (1)	Not full (1)	Not full (1)
Score =	***Score =***	***Score =***	***Score =***	***Score =***
AM GUT aggregate score	**AirM GUT aggregate score**	**BM GUT aggregate score**	**PM GUT aggregate score**	**UM GUT aggregate score**

APPENDIX B

Figure 1: Thermography and real picture of a university building laboratory external wall showing high moisture presence and pattern

Source: Authors own work

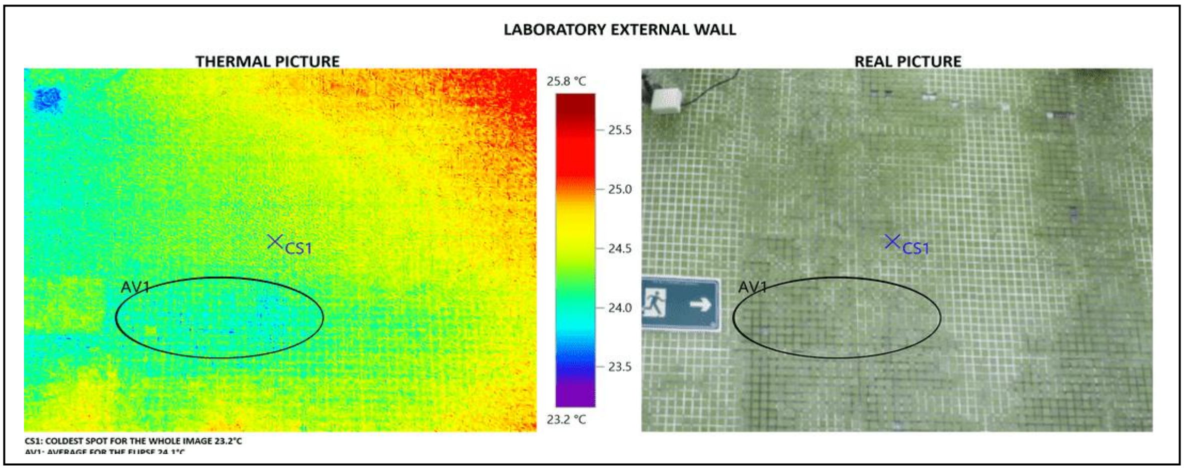

Figure 2: A university building research office internal wall revealing serious moisture presence and movement more visible and elaborate in the thermogram

Source: Authors own work