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Thermal Imaging for Improving Energy Conservation Behaviors: An Infrared Thermography Survey for Residential Buildings

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Abstract

There is an immediate need to tackle climate change and shift toward a low-carbon, sustainable city in Erbil City. There is a potential to cut greenhouse gas emissions to at least 40% below 2015 levels by 2030, The ambitious targets to help mitigate carbon, build renewable energy technologies, and respond to the effects of climate change, based on a long-term view of the city's future, are followed by a reduction in GHGs for the residential sector. One of the planned steps to accomplish energy retrofits for current buildings is to test the efficacy of thermal imaging at the community level to locate poorly insulated homes and to facilitate energy retrofits. The goal of this research was to investigate the ability of thermal imaging to promote energy-efficient changes in single-family homes. The tool being used for this survey is the FLIR Infrared Camera. The objective is to investigate the scope for testing the thermal performance of the existing house and its envelope using thermography. Thermography was used to look at different rooms and the outside of existing houses in new housing projects in Erbil, Kurdistan. Early identification of performance issues in existing typical houses is advantageous so that remedial work can be carried out in a timely and appropriate way.

Disciplinary: Architectural Technology, Architectural Environment.

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1 Introduction

Heat transfers through the objects in three main mechanisms conduction, radiation, and convection. Radiation the heat will be transferred via the electromagnetic radiation emitted by the objects. The radiation emitted by the objects includes infrared radiation that can be detected by an infrared camera [1]. Monitoring the temperature of structures using infrared thermography is considered a difficult process. Without knowing all factors that influence the infrared radiation measured by the infrared camera, it is significantly difficult to obtain calibrated temperatures. Thermography is used especially in the construction sector to analyze the thermal losses of buildings. It allows identifying the energy loss (heat loss) of each building through a color chart associated with a temperature scale generated by this technique. Aerial thermographic vision is very relevant because the majority of heat loss from a building concerns the order of importance of the roof, walls, and windows [2].

In most nations, buildings consume a substantial amount of energy, with space heating and air conditioning accounting for the majority of this consumption. Estimating energy savings after improving a building's insulation remains a critical topic of research to determine cost savings and payback periods [3]. As a result, it is important to concentrate on creating ways to minimize energy use in buildings, particularly in existing structures [4].

This research examines the thermal performance of an existing conventional house with improved insulation using infrared thermography and temperature sensors. The energy savings of the renovated building are then calculated. This paper provides guidelines on the use of infrared thermography in housing applications. It offers an overview of survey theories as well as specific data, demonstrating how these can be used in a variety of contexts.

Despite possible technological limitations, thermal imaging offers an appealing opportunity to explore and address building exterior problems and encourage energy efficiency solutions. While building occupants may feel hot or cold, they cannot see heat depart or cold enter their houses immediately. They also have trouble identifying issue areas in their house or determining how to fix them. Such problems create a frequent gap between individual homeowners, the energy they use to heat their homes, and the programs in place to help them reduce it [5]. This is when thermal imaging plays a great role. People have a propensity to ignore the very practical, household-specific abilities or "know-how" that they require to minimize their energy use. Viewing thermal pictures can help with the development of energy "know-how," because homeowners and other household members are frequently able to link their actions and behaviors to heat loss [5,6,7]. As a result, thermal imaging can be a strong tool in persuading homeowners to take action.

2 Using Thermal Imaging for Building Investigations

Various testing techniques may be used to investigate building fabric performance. The techniques most often used are described.

2.1 Air Leakage Test

The amount of air leakage through the building envelope (or air permeability) may be measured using the fan pressurization method [8]. This test involves the temporary installation of variable flow portable fans in a suitable aperture in the building envelope and the measurement of the airflow required to maintain a pressure difference between the inside and outside of the building. Smoke generators may be used to identify significant areas of leakage in the building or a portable smoke "pencil" can identify leakage in specific locations. Leakage generates thermal abnormalities with more irregular shapes than insulation inadequacies and with considerable temperature variations, frequently generating distinctive streaks or rays patterns. In Figure 1, the air leakage above the balcony door cools the surface of the surrounding wall and ceiling.

Figure 1: The air leakage defects

2.2 Thermography

An infrared (IR) camera may be used to assess the temperature distribution across the interior or exterior surfaces of a building envelope. This technique is referred to as thermal imaging or thermography. If a stable temperature difference is established between the inside and outside of a building then localized reductions in the thermal conductivity of the building envelope (caused by defects in the insulation layer or thermal bridges) will result in surface temperature variations. Under suitable environmental conditions, these surface temperature variations can be detected using an IR camera.

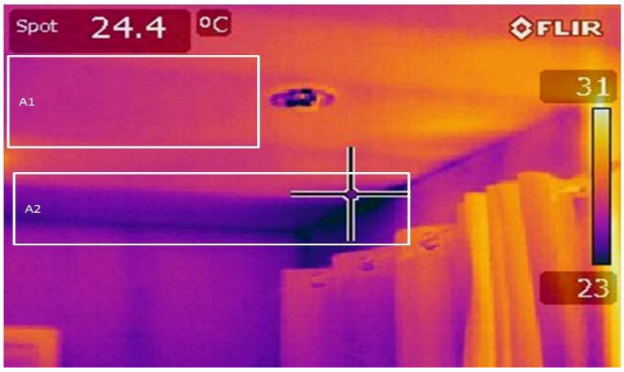

Figure 2: Missing insulation defects

A concise introduction to the scientific principles on which thermography is based is provided [9] and [10]. In addition to identifying insulation defects and thermal bridges, thermography can also be used to locate air leakage paths in the building envelope. Air leakage can be observed internally when the building is depressurized (e.g. during an air leakage test) provided there is a difference between internal and external air temperatures. Fig. 2 shows the appearance of some typical insulation defects. Other applications of thermography include: identifying delamination of external wall finishes [11]; assessing the effectiveness of external wall insulation [12]; and maintenance of electrical and mechanical services [13].

2.3 Heat Flux Measurement

Heat transfer through a building element may be measured using heat flux sensors. By monitoring the heat flows through a building element over an extended period (typically between 7 and 14 days) it is possible to derive an in-situ U-value for the building element. In addition to the above techniques, a visual inspection of the building (including an endoscope examination) can be carried out.

2.4 Conduction Heat Loss

While all building components experience some degree of heat loss, it is the amount of heat loss over time that indicates the thermal conductivity of a material. Using known measures of conduction, areas of missing or damaged insulation, as well as areas of "thermal bridging" can be detected. This "bridging" effect occurs in instances where structural components provide a more conductive path between the interior and exterior of a building, creating a pathway for heat to escape more easily. The identification of unwanted areas of high conductivity in a building can help to minimize condensation and mold growth, which are more likely to occur in these areas.

2.5 Ventilation Heat Loss

Often experienced as drafts, ventilation heat loss tends to occur around gaps and cracks in a building's envelope. Junctions between components such as doors and windows are a common source of unwanted air leakage. Infiltration losses can account for over half of a building's total energy use, and they can reduce building occupants' thermal comfort and create problems of condensation and mold.

2.6 Moisture-related Defects

As noted above, condensation can be a by-product of other building envelope defects; however, other forms of moisture-related issues can also present problems. Moisture ingress occurs when water penetrates the building fabric from the outside, either through capillary action or gradual sorption, or penetration. The amount of moisture in building materials impacts a building's thermal performance as it can increase thermal conductivity and evaporative cooling.

2.7 Structural Defects

Thermography can also be used to detect cracks and/or thermal expansion in building materials, structural failures, and material "delamination", in which materials made up of several layers begin to separate. However, some studies have shown that while delamination can be detectable using thermography, it should be further inspected using other forms of analysis.

2.8 Limitations to Building Thermography

According to the study [14], it is important to note that building thermography is influenced by several factors that can limit the accuracy of thermal image interpretation. Key limitations that should be carefully considered during all inspections include emissivity variances, climatic conditions, and operator expertise. The status of the heating system is also an important influence on the final images as is occupant behavior. In general, three major limitations are:

1. Emissivity Variances: Surface finish, geometry, angle of measurement, temperature and wavelength can all dictate a material's emissivity, and can cause variations in readings that might not be expected [15]. While understanding and setting the emissivity value within the thermal camera is essential for quantitative analysis, some have recommended the need to understand the impact of variances in surface emissivity for qualitative analysis as the effects from reflections can impact pattern recognition [16].

2. Climatic Conditions: All building thermography inspections will be influenced in some way by the climatic conditions (i.e. weather) at the time of image recording. Again, while some internal climatic conditions can impact thermal imaging, external thermography is particularly susceptible to such variations. Thermographers should therefore adhere to certain standards of practice and should avoid the following: (temperature difference across a construction, solar loading, night sky radiant cooling, the effects of moisture, and finally windy conditions). With the absence of steady-state conditions, attention to the effects that transient weather conditions can have on image interpretation is essential for qualitative analysis and makes accurate quantitative analysis using external thermography impractical [16].

3. Image Interpretation: Image interpretation was the most challenging aspect of thermal imaging [17]; Results from thermographic inspections should be followed up with other inspection methods before major retrofits are undertaken. To improve operator interpretation, all thermographers must be suitably qualified. Building thermographers should also have a deep understanding of building construction, defects, and thermal physics. However, short-term training and thermal imaging under the supervision of a qualified thermographer might be suitable in certain contexts.

3 Literature Review

The subject of the application of the thermographic technique in the building sector for diagnostic purposes has prompted several research studies to verify not only the potential but also the critical aspects of this interesting technique. Studies have often addressed issues such as the calculation of the emissivity or transmittance, but under stationary conditions and often through laboratory tests. This study aims to carry out a quantitative analysis and not a qualitative one, starting from the reading of the IR thermographic images.

Fokaides and Kalogirou [18] calculate the overall heat transfer coefficient (U-value) in building envelopes starting from infrared thermography (IR). The U-values obtained are validated using measurements performed with the use of a thermo-hygrometer for two seasons (summer and winter), and finally with the use of heat flux meters. The percentage absolute deviation between the notional and the measured U-values for IR thermography is found to be at an acceptable level, being in the range of 10–20%. According to the analysis, finally one can observe that the sensitivity analysis is a great advantage of using an IR system. The analysis was conducted from inside the building, so it was possible to simplify some of the parameters required for the calculation of the U-value.

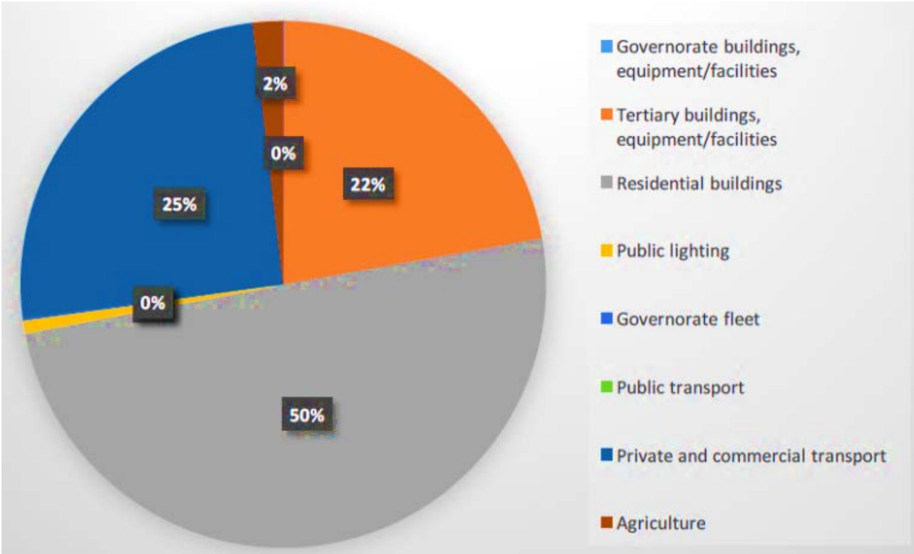

Figure 3: Greenhouse gas emission per sector [22]

The work [19] calculated the sensible heat flux from the exterior surface of buildings using time-sequential thermography, based upon an appropriate simplification of the building model. During the survey, both the exterior surface temperature at three points throughout the day and the weather and other related conditions were all monitored. Thus, the surface temperatures in each polygon were measured and averaged to obtain the surface temperature of each zone. Starting from the surface temperature and their area, it is possible to calculate the sensible heat flux but not the U-value, while the local heat conductivity and the air temperature are assumed to be constant for all elements. The study concludes with the remark that, although the convective heat transfer coefficient varies widely at different positions on the surface of a building. Haralambopoulos and Paparsenos [9] determined the level of thermal insulation in old buildings through spot measurements of thermal resistance and planar infrared thermography. Infrared thermography for building diagnostics is the issue [20]. The infrared audit was applied to evaluate the energy performance of the building envelope of existing buildings from the outside, discussed in this paper, which presents many advantages. The latest generation of thermal imagers can return mappings with a high level of definition, and a higher level of accuracy and images can also be processed later. This technique of investigation, therefore, is very suited to performing a thermal mapping of a large number of buildings. It is an “infrared screening” that can provide useful information to local Administrations. The issue of infrared scanning [21] aimed at an extensive application of thermography on 87 public buildings. The scope of the work, however, was to conduct a qualitative assessment of the methodology, highlighting, with a statistical approach, the application fields. The residential sector represents the core element in producing greenhouse gas emissions and is responsible for 50% of the Erbil governorate as shown in Figure 3.

4 Method

Thermography is a method that uses thermal imaging cameras to visually reflect the infrared energy released from the earth. The graphic images created are visually showing the temperature distribution on the surface of the building [23]. These images are used to determine the thermal efficiency of the building by determining the thermal anomaly region that leads to excess heat loss. This could return to many building issues, including structural moisture, condensation risk, structural delamination of air leakage, voids, and buried utilities. An infrared thermographic survey is divided into two parts; firstly: External thermal analysis: indicates anomalies by highlighting the areas where energy is escaping, and the energy that is used for heating or cooling the house. Each image is supported by analysis to explain possible reasons for the anomaly to aid the remedial action required. The second type of internal survey: shows the results of the internal scan, where anomalies are presented with g analysis to identify the projected reasons behind this situation.

The house that will be introduced to the survey is a detached house located in the Altun city – Erbil. The house is on two floors; the ground floor with lounge and kitchen with one bedroom and bath on the first floor.

Figure 4: Aerial view of the house

Figure 5: GF Plan of the house

5 Result and Discussion

5.1 Typical Appearance of Construction Defects Identified Using Thermography to Ceiling and Roof

- ***Entrance extension***

The green highlighted isotherm in the infrared image shows the area where the surface temperature is below the critical surface temperature which is on average 10°C (Figure 6).

Figure 6: Using thermography for the entrance

Area 1 is likely due to the missing /poorly fitted insulation within the pitched roof above the extension.

Area 2 the junction between the walls shows the cold area which is likely due to missing insulation which allows cold air to infiltrate the residence.

Early-stage checks on the installation of insulation; identifying air leakage through the building envelope; assessing insulation continuity and the severity of thermal bridges; and investigating the performance of building services. It is relevant to distinguish between these applications because different criteria apply to when and how tests may be conducted during the construction process.

- ***Living Room***

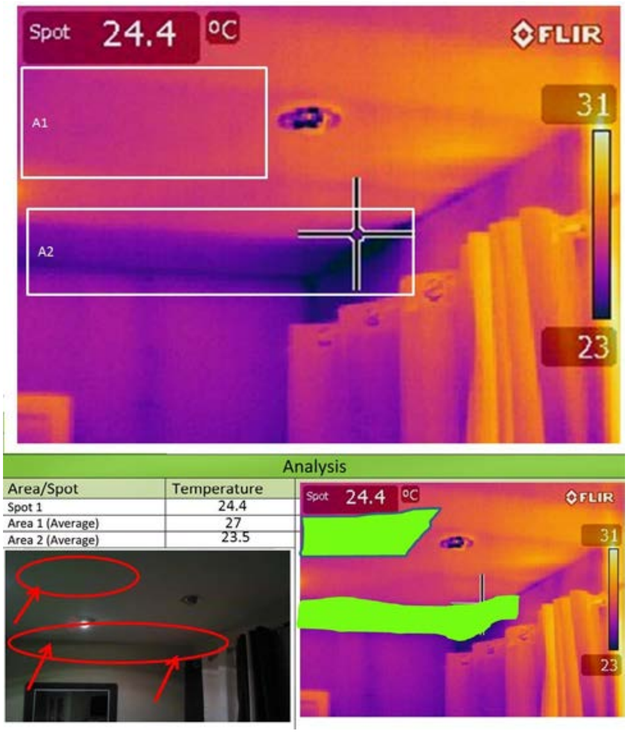

Figure 7: Using thermography for the Living room

The green highlighted isotherm in the infrared image (Figure 7) shows the area where the surface temperature is below the critical surface temperature which is on average 23°C. Both area 1 and 2 shows the cold area which is likely due to missing/poorly insulation within the ceiling. The missing insulation and thermal bridging may be a common defect in the new house in the studied area and can also have a significant effect on the energy efficiency of the building fabric. Visual inspection is unlikely to identify defects within the insulation layer once covered over by surface finishes. Therefore, the performance of insulation, which is sensitive to the quality of installation, may be subject to considerable variation. Heat flux measurement and co-heating tests enable thermal transmission to be measured. However, the cost and time taken to conduct these tests are currently a barrier to their more widespread use, particularly during the construction process.

- ***Kitchen***

The green highlighted isotherm in the infrared image (Figure 8) shows the area where the surface temperature is below the critical surface temperature which is on average 28°C.

- **Area 1:** This image shows a wider area of moisture infection in the ceiling of the kitchen. The big differences in surface temperature that are more than 5°C represent a high degree of water saturation. The dampness in the ceiling is likely due to the water incursion from the leaking pipes that are related to the bathroom on the first floor directly above the kitchen. The concerns of dampness are because it is a source that supports the growth of bacteria, fungi, and insects.
- **Area2:** The highlighted joint between the wall and ceiling seems to be affected by two sources, air leakage from external and water leaking from the bath floor. This is likely due to the missing insulation in the ceiling and poor insulation in the external wall.

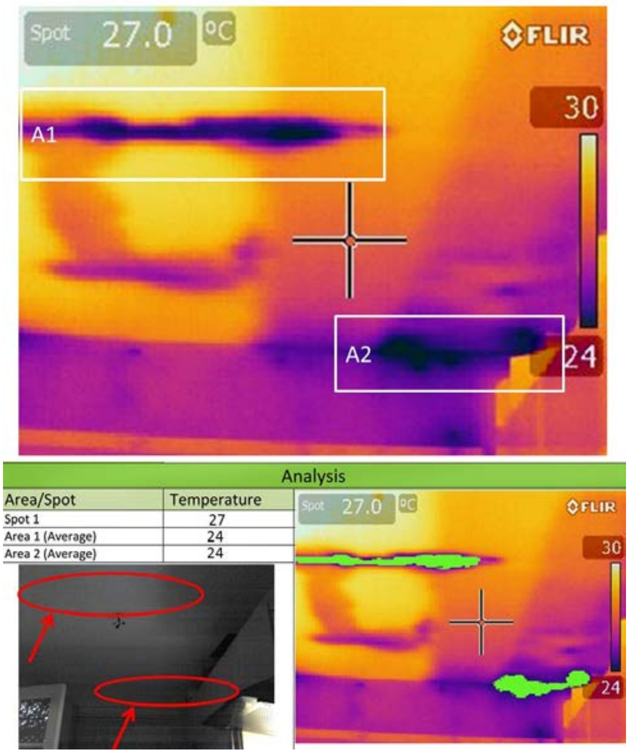

Figure 8: Using thermography for the kitchen

- ***Staircase ceiling***

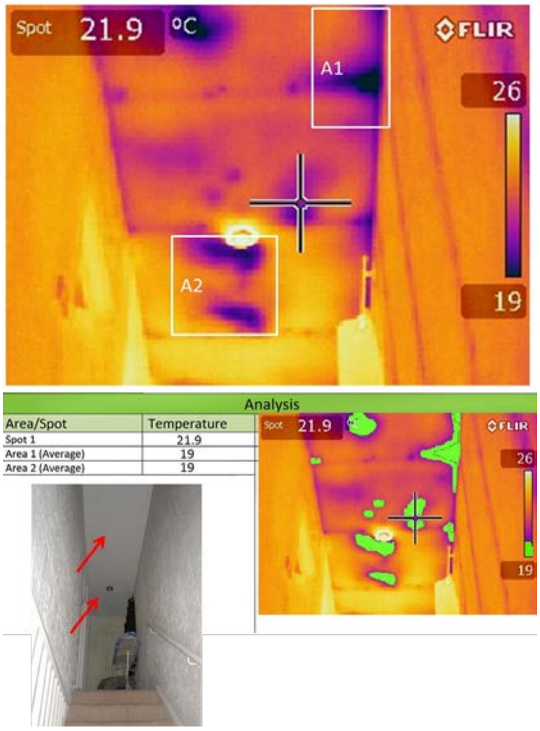

Figure 9: Using thermography for the staircase area

The green highlighted isotherm in the infrared image shows the area where the surface temperature is below the critical surface temperature which is on average 19°C.

These areas illustrate the dampness in the ceiling due to the missing insulation also it shows the cold air infiltration which leads to heat loss and eventually reduces the efficiency of the building.

- ***Bedroom***

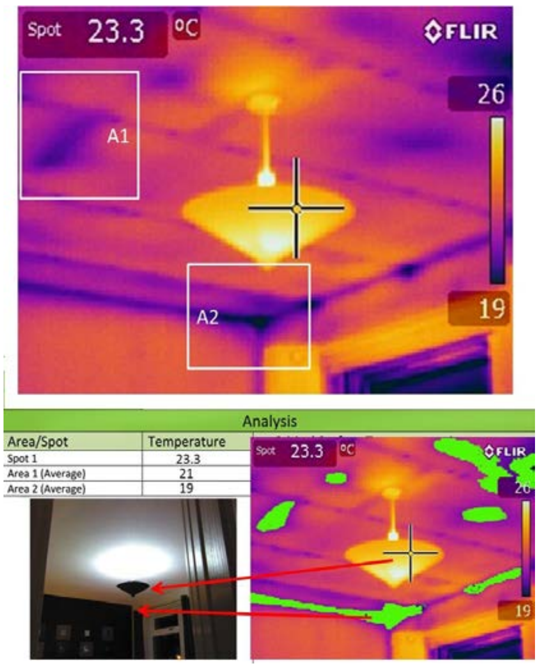

Figure 10: Using thermography for the bedroom

The dark blue areas (Figure 10) in the ceiling represent the area where the temperature of the surface is below the critical surface temperature which is on average 23.3°C

Area1: These wide spots in the ceiling show the missing of the fitted insulation in the loft.

The missing insulation leads to an increase the air infiltration from and into the room, which has an impact on reducing the heating efficiency in the room due to a large amount of air penetrating the ceiling, especially on windy days.

However, area 2 shows the joint poor/missing insulation which causes air leakage.

Figure 11: Wide spot of air infiltration due to missing fitted insulation in the loft

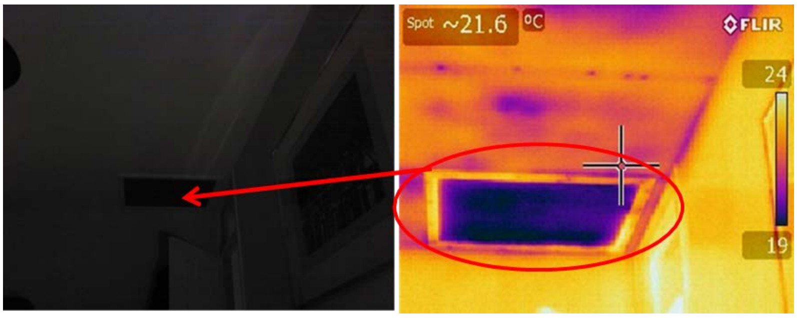

Figure 12: The small opening to the loft level creates a thermal bridge

- ***Walls***

  The major problem with the wall is concentrated in three areas:

- ***The staircase wall:***

Figure 13: the defects on the staircase wall

The green highlighted isotherm in the infrared image (Figure 13) shows the area where the surface temperature is below critical surface temperature which is on average 24°C.

- ***Bedroom wall***

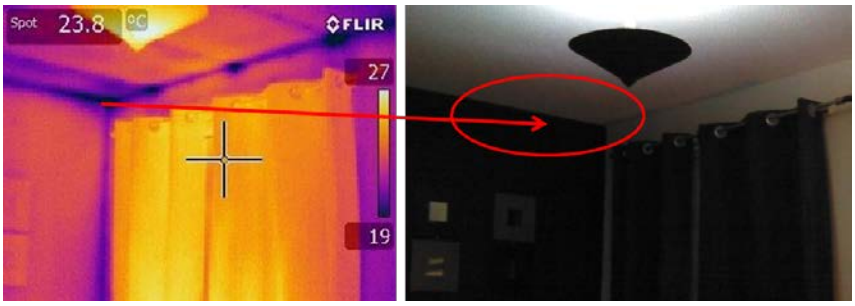

Figure 14: Investigations in the bedroom wall

The dark blue area in the wall (Figure 14) is due to cold air infiltration from the ceiling joint and this is due to poor/missing insulation.

- ***Kitchen wall***

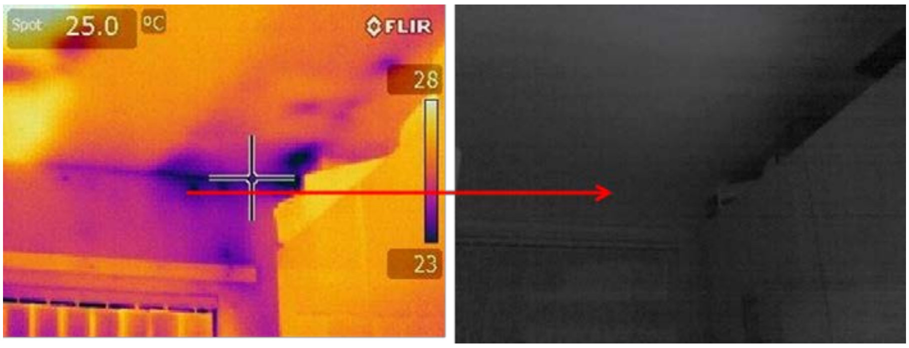

Figure 15: Kitchen wall under thermography

Water leakage and also air infiltration lead to heat loss through the cold area shown in the image due to poor/missing insulation.

- ***Bathroom***

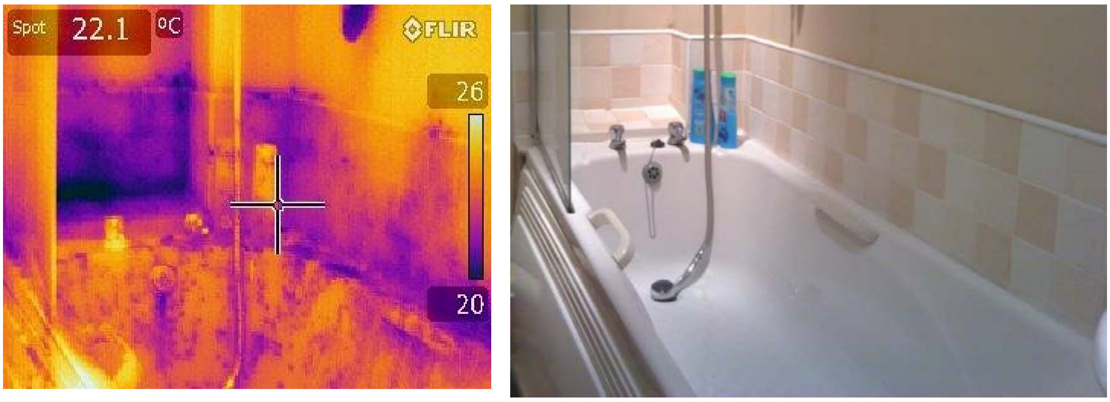

Figure 16: leakage of the water in the side of the bathroom

The image (Figure 16) illustrates the leakage of water into the side of the bathroom. This is due to poor insulation being used for the bath.

- ***Floors***
- ***Living room floor***

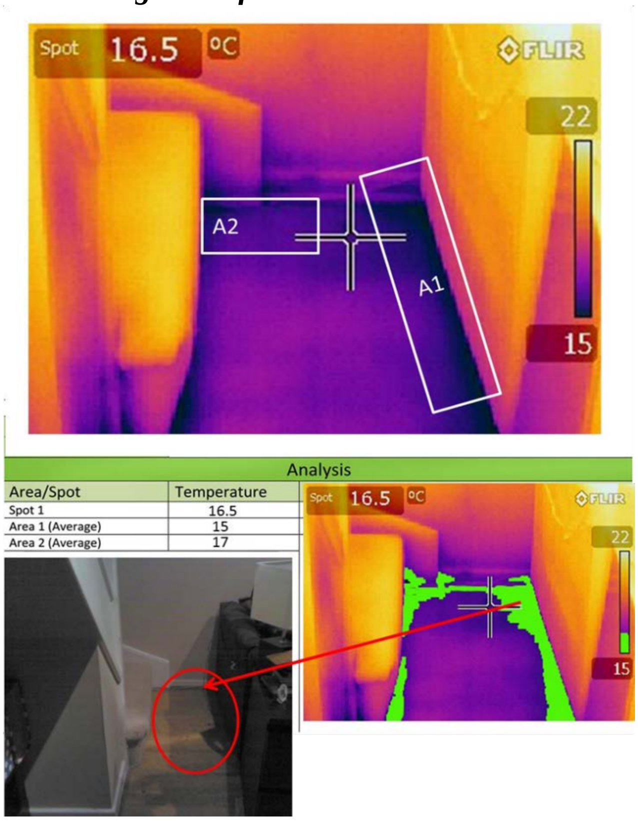

Figure 17: Living room floor under thermography

- ***Stair case***

Figure 18: Analysis of staircase walls

The green highlighted isotherm in the infrared image shows the area where the surface temperature is below the critical surface temperature which is on average 22°C (Figure 17), and which is on average 20°C (Figure 18).

The large difference between the floor temperature and another surrounding surface (Figure 18) which is around 7°C illustrates a cold area where the heat is lost; this is likely due to missing insulation.

This cold area causes air leakage and also heat loss (Figure 18) this is likely due to the thermal bridge having been made by the winder and missing the insulation.

Openings

Entrance door

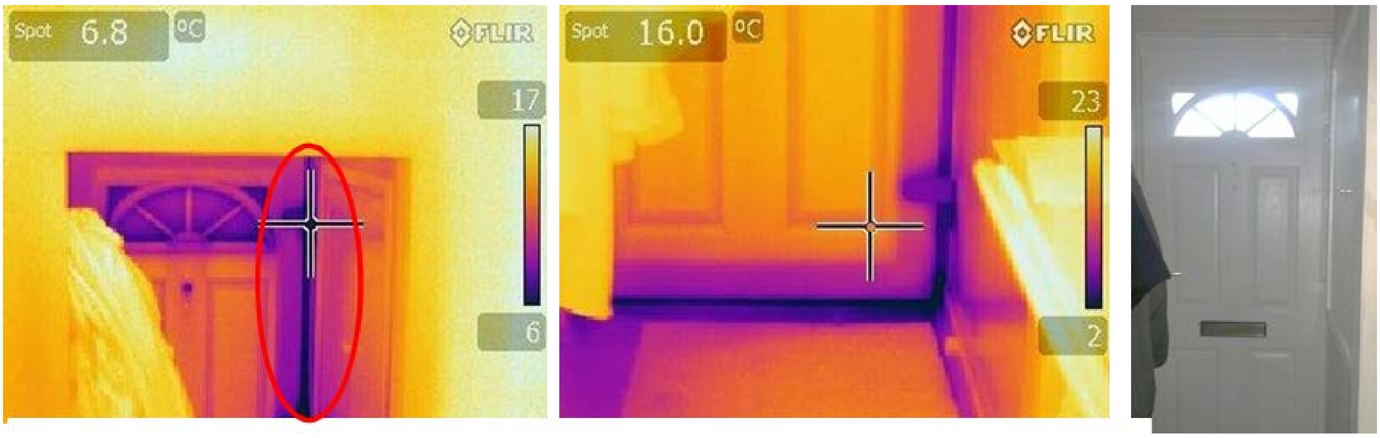

Figure 19: Investigation of entrance door under thermography

The black area (Figure 19) represents the area where the cold area is due to air infiltration, this is related to the defective seals on the top and bottom of the door profile.

By comparing these varying temperatures around the image, it is possible to identify cold air ingress in between the doors, and infer that by weatherproofing, comfort in that part of the home can be improved and energy costs reduced.

- ***Entrance to the backyard***

Figure 20: Defective seals on the top of the door profile

- ***Windows***

Figure 21: Detections around windows at the bottom.

The highlighted area (Figure 21) is cold air with a temperature of less than 14°C. This is likely due to the defective seals around the window frame and opening, allowing cold air to enter the house.

5.2 External Thermal Results and Analysis

Front elevation

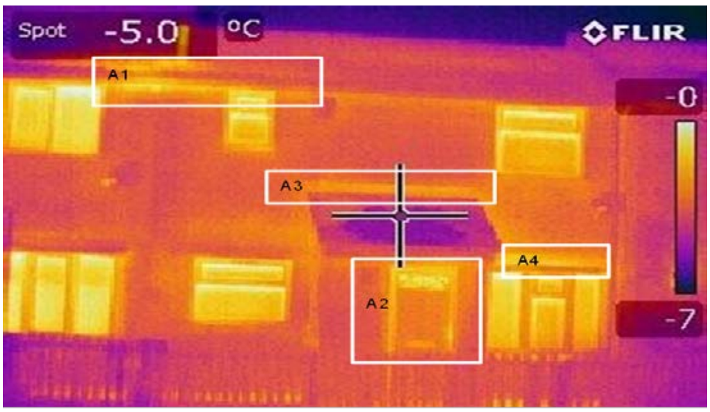

Figure 22: Thermography photo of the elevation walls.

Area 1 shows a comparative increase in surface temperature, due to missing/poorly fitted loft insulation at the eaves of the roof.

Area 2 is showing an increase in surface temperature around the door frames, possibly due to defective seals around the window openings allowing warm air to escape.

Area 3 is showing an increase in the temperature above and around the extension area and this is due to poor/ missing insulation in the joints which leads to heat loss.

Area 4 shows a comparative increase in surface temperature which is likely due to the window lintels creating a thermal bridge.

The temperatures of the windows appear to vary as well. Consider area 6, which looks to be cooler than area 5. Given that the two windows are in the same room and have the same temperature, the variation in infrared radiation is caused by infrared reflection from buildings on the opposite side of the road. They primarily measure infrared radiation, and various factors such as humidity, distance from the item, object emissivity, and reflection of infrared radiation from other sources can all influence the findings.

6 Discussion

Infrared technology, being a non-contact approach, offers the benefit of decreasing measuring time and covering a larger region than contact temperature measurement. Calibration and interpretation of infrared pictures, on the other hand, need extensive knowledge and sophisticated computations. Although aerial thermography can shorten surveying time, experimental work has revealed that quantifying loft insulation in buildings is challenging. This is related to the emissivity, view angle, and other background effects. Because of the higher resolution and finer features, ground thermography is simpler to understand.

Relative temperature measurement in both approaches may be more effective and practicable than attempting to measure exact temperature values. Based on the case studies, it was shown that heat losses from old buildings may be minimized by improving the insulation of walls and roofs. Better materials are used in modern construction. However, it has been shown that in some situations, heat losses from new frames may occur as a result of design flaws or installation methods.

From the studied house, the roof needs to be replaced prematurely due to moisture damage from leaks and improper insulation. This has been proved by the infrared thermography survey. The ceiling of the kitchen needs to be repaired from moisture and fixing the water leakage from the sanitary pipes of the bathroom. This needs an immediate solution before water damage rots the whole ceiling. Also, it should provide appropriate sufficient insulation to the ceiling and floor. Also, it should provide treatment to the bathroom wall to prevent water leakage to the wall around the bath equipment.

7 Conclusion

This research investigates the ability of thermal imaging to promote energy-efficient changes in single-family homes. The tool being used for this survey is the FLIR Infrared Camera, for testing the thermal performance of the existing house and its envelope using thermography. Thermography was used to look at different rooms and the outside of existing houses in new housing projects in Erbil, Kurdistan. Early identification of performance issues in existing typical houses is advantageous so that remedial work can be carried out in a timely and appropriate way.

To improve the thermal performance of the building envelope, it is required to add effective insulation to the external walls. This can be via providing cavity insulation or internal insulation. It should introduce sufficient floor insulation and cover the floor with carpeted wooden tiles. Connecting joints between the roof and the external wall with continuing insulation from the roof to prevent air infiltration through the corners. Also, it should introduce insulation material to the seals of windows and doors to prevent air leakage. Besides, it should provide insulation and treatment to the areas where the thermal bridge is accrued for instance in the winder of the staircase and the shed, and fitted insulation in the loft.

8 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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