Understanding the Role of Thermography in Energy Auditing: Current Practices and the Potential for Automated Solutions

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What does energy use look like in the United States?

The building sector is composed of both residential (22%) and commercial (18%) buildings; approximately a quarter (25%) of building energy consumption goes toward heating or cooling.
Common reasons for building inefficiencies include their design, materials, and age.

Norberg-Bohm, V. and White, C. Building America Program Evaluation. 2004
Common reasons for **building inefficiencies** include their design, materials, and age.

To address these issues, **renovations and retrofits of existing building stock** has become a pressing need.

Norberg-Bohm, V. and White, C. Building America Program Evaluation. 2004
Common reasons for building inefficiencies include their design, materials, and age.

To address these issues, renovations and retrofits of existing building stock has become a pressing need.

The **US Department of Energy (DOE)**, for example, has set a goal of **reducing housing energy use by up to 70%**.

Norberg-Bohm, V. and White, C. Building America Program Evaluation. 2004
**Energy Saver 101: Home Energy Audits**

Take the first step to improving your home’s energy efficiency: get a home energy audit.

**What is a home energy audit?**

A home energy audit helps you pinpoint where your house is losing energy and what you can do to save money. A home energy auditor will also assess health and safety issues that might exist in your home.

The audit involves two parts: the home assessment and analysis using computer software.

**DID YOU KNOW?**

You could save 5 to 30 percent on your energy bill by making efficiency upgrades identified in your home energy audit.
As a response, professional energy auditing has seen a resurgence of interest because it commonly identifies building inefficiencies through:

- Walk-through inspections
- On-site measurements
- Computer simulations

Norberg-Bohm, V. and White, C. Building America Program Evaluation. 2004
Energy auditors may use thermography -- or infrared scanning -- to detect thermal defects and air leakage in building envelopes.

**WHAT DOES THIS MEAN FOR ME?**

- You can save 5%-30% on your energy bill by making upgrades following a home energy assessment.
- A professional energy auditor may conduct a thermographic inspection to detect where your home is losing heat.

**HOW THERMOGRAPHIC INSPECTIONS WORK**

Thermography measures surface temperatures by using infrared video and still cameras. These tools see light that is in the heat spectrum. Images on the video or film record the temperature variations of the building’s skin, ranging from white for warm regions to black for cooler areas. The resulting images help the auditor determine whether insulation is needed. They also serve as a record of the thermal condition of a building for the owner.
Largely Even Surface Temperatures
Example of good insulation
Air Infiltration
Cold air seeping in around door frame
Uneven Surface Temperatures
Could indicate an insulation problem
**THERMAL CAMERAS**

Thermal cameras (or infrared cameras) **detect electromagnetic radiation** with lower frequencies than visible light (i.e., infrared frequencies).

All objects above absolute zero emit infrared radiation, so **thermal cameras can ‘see’ in the dark** without external illumination.

The amount of radiation emitted by an object increases with temperature, so **thermal cameras can** also measure heat.
Commercial Cameras
FLIR (1960)
FLIR ONE

Thermal imaging device for your iPhone 5/5s.

WATCH THE VIDEO
LAUNCH SIMULATOR
BUY NOW

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1. Connect with FLIR ONE on Facebook, Twitter and Instagram
2. Capture your most creative photo or video with the FLIR ONE
3. Submit a photo or video using #FLIRONEcontest
4. Tag @FLIRONE on Instagram or @FLIR_ONE on Twitter

SAMPLE POST
We're out here #skateboarding red hot with the @FLIRONE #FLIRONEcontest
Recent improvements in handheld sensor technology and falling costs, means auditors are increasingly using **thermographic inspections** and thermal cameras to **detect thermal defects** and **air leakage**.
Energy audits and thermographic surveying are time and labor intensive.
How can we **automate** thermographic assessments?

Data collection  Analysis  Modeling  Reporting
How can we **automate** thermographic assessments?

- **Data collection**
- **Analysis**
- **Modeling**
- **Reporting**
How can we automate thermographic assessments?

Data Collection from Unmanned Aerial Vehicles

Source: Applied Geotechnologies Research Group, University of Vigo
How can we automate thermographic assessments?

Data Collection from Ground Robotics

Irma3D Ground Robot
Equipped with Reigl VZ-400 laser scanner & Optris Imager PI thermal camera

How can we **automate** thermographic assessments?

Data collection  
Analysis  
Modeling  
Reporting
How can we **automate** thermographic assessments?

What types of analyses might this **automation enable**? For example, more frequent scanning may enable temporal analyses.
How can we **automate** thermographic assessments?

Data collection  Analysis  Modeling  Reporting
How can we automate thermographic assessments?

High Fidelity Model Generation

How can we **automate** thermographic assessments?

Data collection  Analysis  Modeling  Reporting
How can we **automate** thermographic assessments?

Data collection  Analysis  Modeling  

How will the resulting data be used by **end-users**? For example, providing energy efficiency recommendations to facilities managers.
NO HUMAN PERSPECTIVE IN AUTOMATED THERMOGRAPHY LITERATURE

Reviewed over 30 papers in ‘automated thermography.’ No user studies, no investigations of how professional auditors may use or perceive emerging systems, no discussions of human-centered design, etc.

Previtali et al., Applied Geomatics’14
Bormann et al., Adv. Eng. Informatics’14
Laguela et al., Q. Infrared Thermography’14
Laguela et al., Energy and Buildings’14
Previtali et al., J. Mobile Multimedia’14

Ham et al., Adv. Eng. Informatics’13
Vidas et al., IEEE Sensors’14
Wang et al., J. Comp. Civil Engineering’13
Ham et al., J. Comp. Civil Engineering’14
Research Questions

1. How is thermography currently being used by auditors?
**Research Questions**

1. How is thermography currently being used by auditors?

2. What benefits and drawback do auditors identify when envisioning the use of robotics for thermographic data collection?
How is thermography currently being used by auditors?

What benefits and drawbacks do auditors identify when envisioning the use of robotics for thermographic data collection?

What are the implications for the design of these automated thermography tools?
Understanding the Role of Thermography in Energy Auditing

Study Design
Summary of Participants
Interview Results
Probes
Observation Overview
Reflection
Study Design

Part 1:
Semi-Structured Interviews
~50 Minutes

Part 2:
Presentation of Design Probes
~40 Minutes

Study 1

Study 2

Observational Case Study:
Residential Energy Audit
~120 Minutes
STUDY 1, PART 1: SEMI-STRUCTURED INTERVIEWS

• Background
• Practices and Procedures
• Challenges
• Thermography Data
• Strengths and Weakness
• Sustainability and Energy Efficiency
• The Future of Thermography
STUDY 1, PART 2: DESIGN PROBES
STUDY 1, PART 2: DESIGN PROBES

Scenario 1 (Text)
Scenario 2 (Text)
Scenario 3 (Text)
STUDY 1, PART 2: DESIGN PROBES

Scenario 1 (Text)
Scenario 2 (Text)
Scenario 3 (Text)
Scenario 4 (Video)
STUDY 1, PART 2: DESIGN PROBES

Scenario 1 (Text)
Scenario 2 (Text)
Scenario 3 (Text)
Scenario 4 (Video)
Scenario 5 (Mid-Fi Prototype)
“You are responsible for a small fleet of **thermography UAVs**. The UAVs fly around **semi-autonomously** collecting thermal data about each building on your campus. When abnormalities are detected, the UAVs are programmed to more closely examine these areas and provide **high resolution reports** of potential problems. The UAVs reduce labor costs compared with manual assessments, can investigate otherwise **inaccessible areas** of buildings (e.g., high exterior floors), and enable **historical reports** showing thermal **performance over time**.”
STUDY 1, PART 2: DESIGN PROBES

Scenario 1 (Text)
Scenario 2 (Text)
Scenario 3 (Text)
Scenario 4 (Video)
Scenario 5 (Mid-Fi Prototype)
Scenario 4 (Video)

UAV Data Collection

UAV system booting up...
STUDY 1, PART 2: DESIGN PROBES

Scenario 1 (Text)
Scenario 2 (Text)
Scenario 3 (Text)
Scenario 4 (Video)
Scenario 5 (Mid-Fi Prototype)
We qualitatively coded the interview and design probe data to uncover themes.
Understanding the Role of Thermography in Energy Auditing

- Study Design
- Summary of Participants
- Interview Results
- Design Probes
- Observation Overview
- Reflection
Building Thermography Practitioners Needed for Interview Study

Do you perform energy audits of buildings? Do you use a thermal camera for your inspections? We need your help!

As sustainability researchers at the University of Maryland, we are exploring current methods and practices for performing energy audits of buildings and, specifically, the role of thermography in these audits. We are looking for experienced building thermographers, facilities managers, and building inspectors to participate in a short interview about their experiences as energy auditors. Some example questions include:

- How are thermographic assessment of buildings performed and how useful is this data for making sustainability improvements to residential, commercial, industrial, and institutional constructions?
- What tools are used to collect and analyze energy audit and thermographic data?
- What are the primary challenges in performing energy audits and using thermography?

Study sessions should last approximately one hour including a short demographic survey, a semi-structured interview about your professional experiences assessing buildings, and a brief design elicitation exercise aimed at informing the design of future thermographic systems.

Interview participants will be reimbursed $20 for their time. Interview sessions can be conducted in-person at a specific location of your choice in the DC metro area or via Skype, Google Hangout, or another video chatting service. All participants must be 18 years of age or older and be active or formerly active building thermographers, facilities managers, or building inspectors with hands-on thermographic experience. Apart from these restrictions, we encourage people of all genders and ethnicities to participate. If you are interested in participating, please email Matthew Mauriello (matti@cs.umd.edu) the following information:

- Brief description of professional experience with thermography
- Current industry status (i.e., active or formerly active)
- Years involved in thermography and/or working with thermographic data
- Desired communication mechanism (i.e., in-person or by a video chatting service)
- Desired meeting time and location

Feel free to take a look at our research lab’s website to find out more about our research program: http://www.cs.umd.edu/hcil/. Please also feel free to redistribute this posting.

Sincerely,

~Matthew Mauriello, MS
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Participant Recruitment

Cold calling
Participant Recruitment

Cold calling

Doubt

Hours later
Participant Recruitment

Cold calling

Exhaustion

Days later
Participant Recruitment

Some study sessions conducted via Skype.
Participant Recruitment

6 States Represented

[Map showing 6 states are highlighted in red: Kansas, Ohio, Nevada, Washington, South Carolina, Georgia]
10 Participants (1 Female)
Average Age: 44.8 Years
Average Exp.: 6.7 Years
Participant Demographics

Occupation

Former Thermographers (2)

Government Thermographers (2)

Private Thermographers (6)
Participant Demographics
Thermography Training

No Formal Training (2)

College or On-Job Training (3)

Professional Training (5)
Understanding the Role of Thermography in Energy Auditing

Study Design | Summary of Participants | Interview Results | Design Probes Results | Observation Overview | Reflection

- Study Design
- Summary of Participants
- Interview Results
- Design Probes Results
- Observation Overview
- Reflection
Understanding the Role of Thermography in Energy Auditing

Study Design  Summary of Participants  Interview Results  Design Probes  Observation Overview  Reflection
Study 1, Part 1: Semi-Structured Interview Results

Required Knowledge

Client Interactions

Challenges
STUDY 1, PART 1: SEMI-STRUCTURED INTERVIEW RESULTS

Required Knowledge
Client Interactions
Challenges
6 of 10 auditors felt that an understanding of building materials and construction were necessary for proper thermographic inspections.
6 of 10 auditors felt that an understanding of building materials and construction were necessary for proper thermographic inspections.

5 of 10 auditors expressed that an understanding of the physics behind heat transfer and airflow were crucial to interpreting results.
"The thing that is most critical to understand is how heat behaves and interacts with different materials."

-P2
STUDY 1, PART 1: SEMI-STRUCTURED INTERVIEW RESULTS

Required Knowledge

Client Interactions

Challenges
STUDY 1, PART 1: SEMI-STRUCTURED INTERVIEW RESULTS

Required Knowledge

Client Interactions

Challenges
9 of 10 energy auditors agreed that client interactions were crucial to a successful audit, especially related to:

- information gathering
- understanding a client's motivations and perceptions
- establishing trust
“...give the customer the thermal camera and have them look around. It’s very engaging and opens them up to a discussion about the dynamic of what's happening.”

-P10
STUDY 1, PART 1: SEMI-STRUCTURED INTERVIEW RESULTS

Required Knowledge

Client Interactions

Challenges
STUDY 1, PART 1: SEMI-STRUCTURED INTERVIEW RESULTS

Required Knowledge

Client Interactions

Challenges
CHALLENGES
All of our energy auditors brought up challenges related to the practice of thermography, especially related to:

- weather
- untrained or undereducated practitioners
- difficulty of interpreting results
“The reality is that you can have three guys with the same camera, looking at the same thing, and have three totally different reports.”

-P2
Understanding the Role of Thermography in Energy Auditing

Study Design  Summary of Participants  Interview Results  Design Probes  Results  Observation Overview  Reflection
Study 1, Part 2: Design Probes Results

Automation Benefits

Concerns
STUDY 1, PART 2: DESIGN PROBES RESULTS

Automation Benefits

Concerns
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

Saving time and money
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

Saving time and money

Assessing inaccessible areas
Assessing inaccessible areas
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

Saving time and money

Assessing inaccessible areas
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

Saving time and money
Assessing inaccessible areas
Scaling up data collection
Scaling up data collection

STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

- Saving time and money
- Assessing inaccessible areas
- Scaling up data collection
**STUDY 1, PART 1: DESIGN PROBE RESULTS** *(AUTOMATION BENEFITS)*

- Saving time and money
- Assessing inaccessible areas
- Scaling up data collection
- New types of analyses
New types of analyses

Source: AppliCAD, https://www.youtube.com/watch?v=ku51VPlaxT8
“If you could say, ‘Hey, for four months, we've had this problem. Let's look and see how it could be fixed.’ I like that idea.”

-P7
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

- Saving time and money
- Assessing inaccessible areas
- Scaling up data collection
- New types of analyses
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

- Saving time and money
- Assessing inaccessible areas
- Scaling up data collection
- New types of analyses
- Automatic anomaly detection
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

Saving time and money
Assessing inaccessible areas
Scaling up data collection

New types of analyses
Automatic anomaly detection
Model generation
Model generation

Source: GimGEOMATICS, https://www.youtube.com/watch?v=IrnSONGYSG4
“You spend a lot of time building this model, just measuring the outside of the house, counting the windows and the doors, and looking around... this would streamline that.”

-P10
STUDY 1, PART 1: DESIGN PROBE RESULTS (AUTOMATION BENEFITS)

- Saving time and money
- Assessing inaccessible areas
- Scaling up data collection
- New types of analyses
- Automatic anomaly detection
- Model generation


**STUDY 1, PART 2: DESIGN PROBES RESULTS**

*Automation Benefits*

*Concerns*
STUDY 1, PART 2: DESIGN PROBES RESULTS

Automation Benefits

Concerns
data quality:
automated approaches lack control of environment
data overload:
how to manage orders of magnitude more data?
privacy:
who owns the data? how can you opt-out?
social process:
energy auditing is a socio-technical process
STUDY 2: OBSERVATION

We observed of a residential energy audit; we recruited one thermographer, gained consent from the home owner, and then collected field notes while shadowing the participant during the audit.
We analyzed pictures and field notes to extract themes in order to provide additional context for Study 1.
Audit Procedure
Client-Interaction
Primary Challenges
Observation Results

Audit Procedure

Client-Interaction

Primary Challenges
“Many people expect the bill to be wrong, not to have an issue in the home.” -01
Understanding the Role of Thermography in Energy Auditing

- Study Design
- Summary of Participants
- Interview Results/Design Probes
- Observation Overview
- Reflection
Automated thermography promises to transform how and where thermal data can be collected.

What are the implications for privacy?

Who ‘owns’ the thermal energy leaking out of a building structures?
Drive-by heat mapping

Startup’s thermal-imaging cars can quickly track energy leaks in thousands of homes and buildings.

Rob Matheson | MIT News Office
January 5, 2015

In 2007, Google unleashed a fleet of cars with roof-mounted cameras to provide street-level images of roads around the world. Now MIT spinout Essess is bringing similar “drive-by” innovations to energy efficiency in homes and businesses.

The startup is also working with the thermography software in their thermal-imaging cars to mark hot and cold spots on the street images, making it easier for cities and urban planners to prioritize energy-saving projects.
Congratulations, you have been selected to participate in <Client's> Thermal Analysis Program to help make your home stronger.

Get Started Here

Thermal imaging is a new technology that helps you identify energy leaks in your home that result in loss of comfort and wasted energy. Review the sample home to the left and the information below to learn how to spot and fix common energy leaks.

Next month you will receive a thermal image of your own home in the mail. Please save this report to use as a reference guide when reviewing your home. This will help you identify and fix leaks that will make your home stronger and more comfortable while lowering your energy bills.

1. **Insulate Your Basement Walls.** The area of the basement that is above ground is often poorly insulated, and is a major source of escaped heat from your home. Sealing leaks and adding a bit of insulation can help cut down your energy bill.

2. **Seal Edges Around Your Chimney.** The area where the chimney meets the house can be a major source of leaks. Using caulk or insulated plates can be a relatively low-cost way to seal it up.

3. **Make Sure Your Window Frames Don’t Leak.** Bright areas around the edges of windows means that they are leaking air out of the house. A bit of caulk can easily seal them up.

4. **Improve Your Attic Insulation.** Heat rises, and a lot of it escapes through poorly insulated attics. Adding attic insulation is easy to do and can save you big on your heating bills.
ESSESS CAMBRIDGE, MA DATASET

Over 17,000 buildings surveyed without owner permission

[Source: http://www.essess.com/technology/scale/]
Bluesky Aerial Survey Data Helps London's Harrow Council Identify Illegal Dwellings

Thermal imaging and laser scan data collected by aircraft is helping London's Harrow Council tackle the growing problem of unscrupulous landlords renting out sheds and outbuildings as dwellings. Supplied by aerial mapping company Bluesky, the map accurate thermal images are combined with detailed LiDAR measurements to give staff at Harrow Council a much better understanding of where unpermitted developments may have been erected and their potential occupation evidenced as "hot spots" in the data.
The automated literature has a **techno-centric** slant and, consequently, completely misses the fact that energy auditing is a **socio-technical** process.

Which means that it’s about establishing **trust**, helping clients understand and interpret auditing results, as well as **providing recommendations**.
**Future Work**

Engage in participatory design with auditors and continue ethnographic fieldwork

Investigate computer vision algorithms to automatically infer building features and materials

Explore benefits of temporal analyses and automatic anomaly detection

Examine opportunities for automating indoor thermographic inspections

Explore privacy and policy implications

LIMITATIONS
There are four primary limitations to this work:

• auditors specialized in residential buildings.
• design probes emphasized exterior data collection, anomaly detection, historical analysis, and 3D reconstruction.
• study method relied on self-report data and a single observation.
• potential dichotomy in asking professional auditors about scenarios that could be perceived as undercutting their jobs
First human-centered study of thermographic automation.
First human-centered study of thermographic automation.

Through semi-structured interviews and an observational case study, we assessed energy auditing practices and thermography’s role therein.
First human-centered study of thermographic automation.

Through semi-structured interviews and an observational case study, we assessed energy auditing practices and thermography’s role therein.

Through five design probes, we critically examined emerging automated thermographic solutions and our findings have implications for the design of these tools.
Our Research Team:

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Come up after the talk to try it out!
Design - Dan Helix
https://thenounproject.com/term/design/30483/

Presentation – Garrett Knoll
https://thenounproject.com/term/presentation/41538/

People – Wilson Joseph
https://thenounproject.com/term/people/48863/

Magnifying Glass – Dima Kolchan
https://thenounproject.com/term/magnifying-glass/63359/

Interview – Sarah Abraham
https://thenounproject.com/term/interview/9712/

Video – Philipp Koerner
https://thenounproject.com/term/video/102796/

Files – Stefan Parnarov
https://thenounproject.com/term/files/16662/

Laptop – iconsmind.com
https://thenounproject.com/term/laptop/71562/

Time – Dmitry Baranovskiy
https://thenounproject.com/term/time/6732/
“Home Energy Audits” (http://energy.gov/articles/energy-saver-101-infographic-home-energy-audits)

“Silkindner Residence” (http://www.advancedhomenergykc.com/Untitled/images/Silkiner%20Residence%20035.jpg)

“U.S. Map” (http://www.blanksusa.com/)

“Sarapul” (http://stroimdom-sarapul.ru/)

“Greenspun” (http://www.communitypowerworks.org/energy-auditing-is-serious-business-for-former-clown-simplicity-home-energy/)

“Information Overload” (https://sidoxia.files.wordpress.com/2010/01/information-overload.jpg)

“Online Privacy” (http://ireneogrizek.com)

