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

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CHI 2015, April 21st, 2015

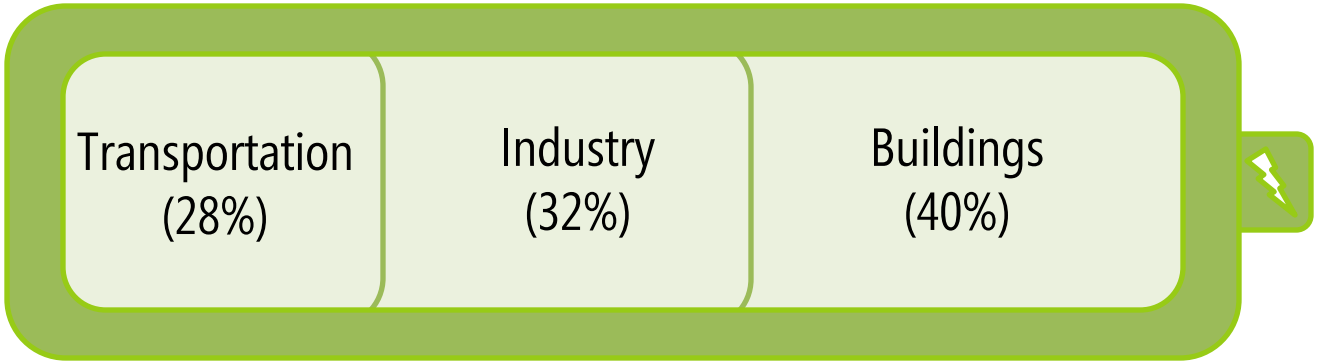
Human Computer Interaction Laboratory

COMPUTER SCIENCE UNIVERSITY OF MARYLAND

makeability lab

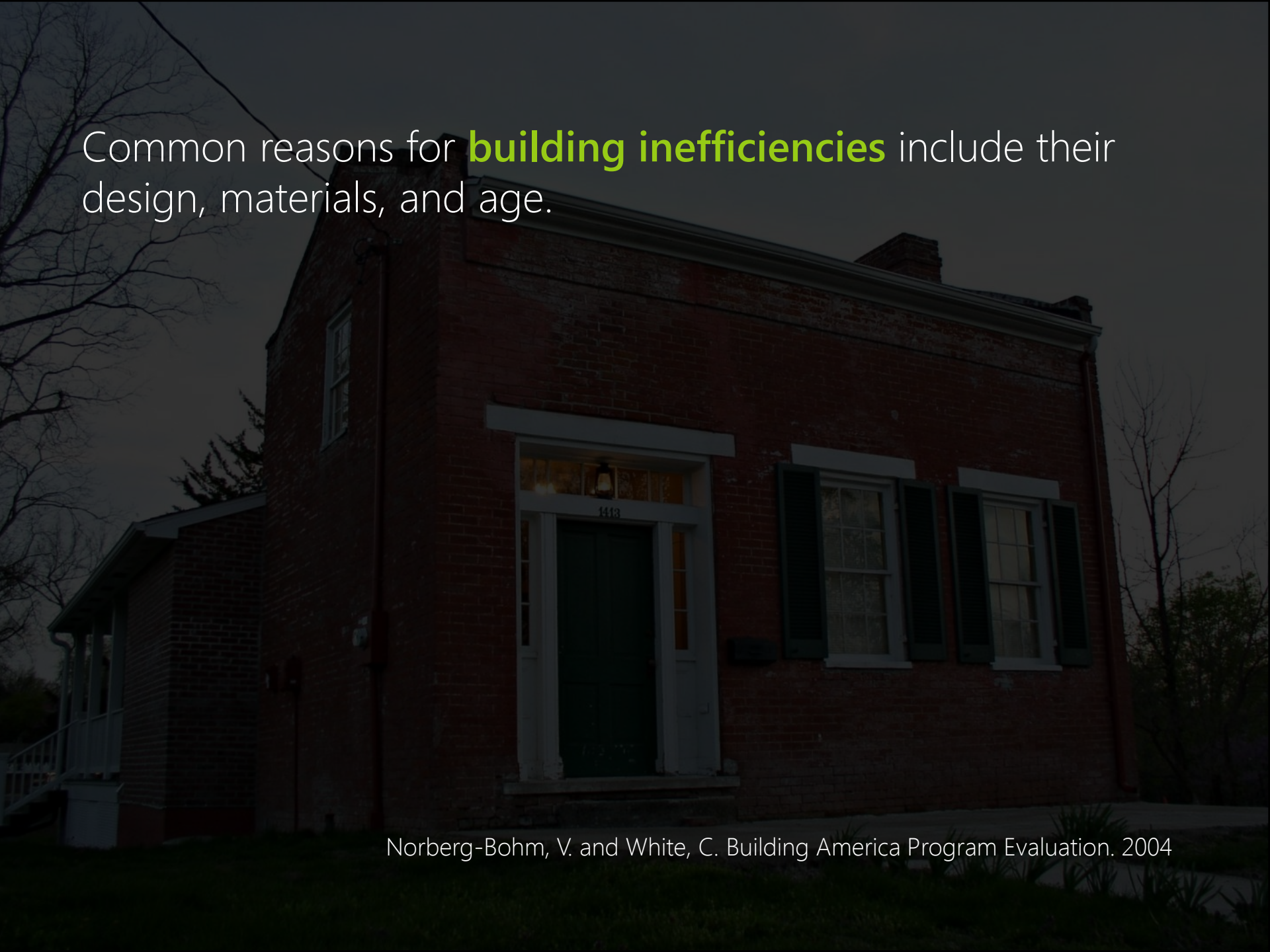
UNIVERSITY OF MARYLAND

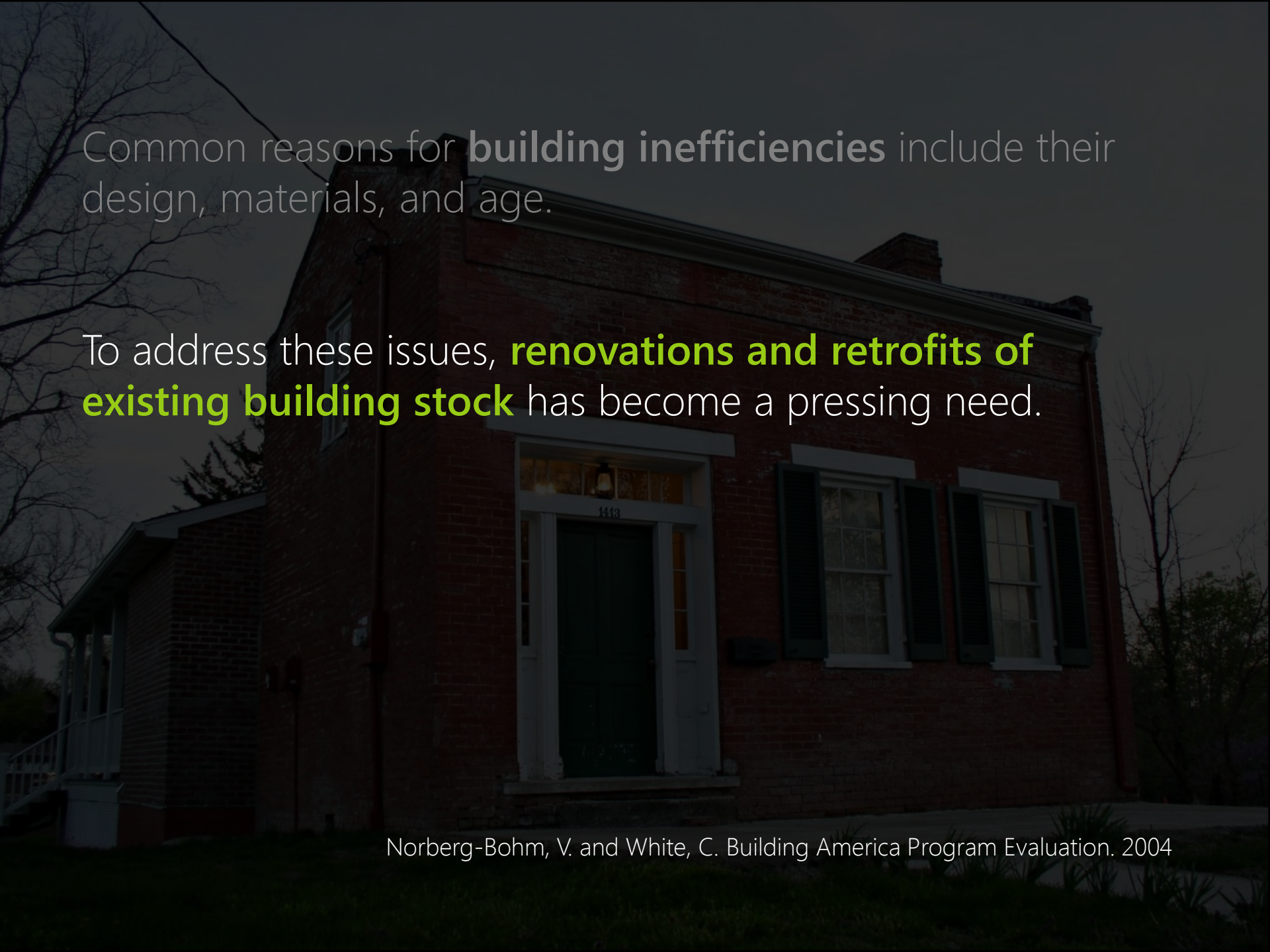
What does energy use look like in the United States. ?



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.


1413

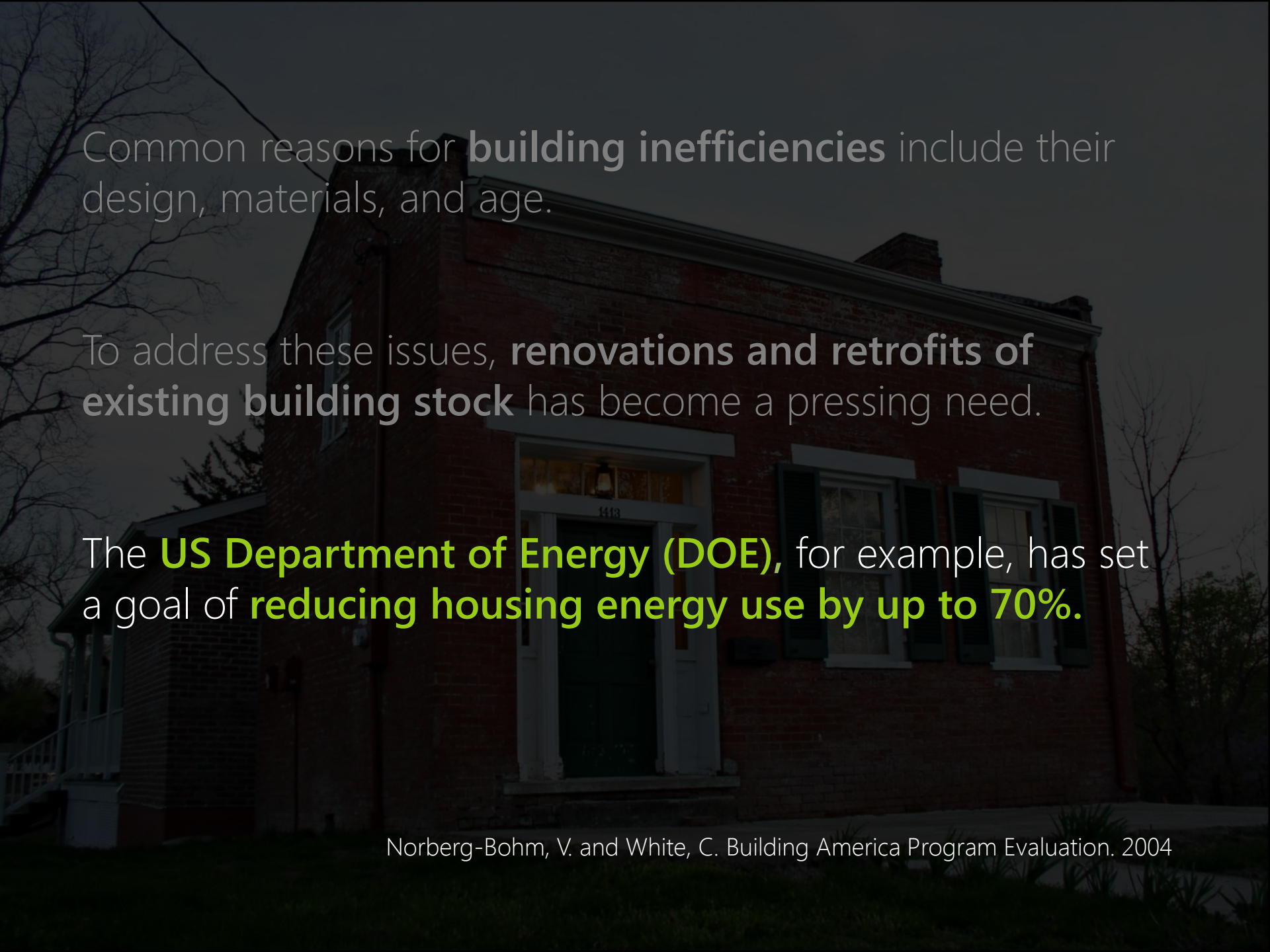

Common reasons for **building inefficiencies** include their design, materials, and age.
1413
Norberg-Bohm, V. and White, C. Building America Program Evaluation. 2004



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.

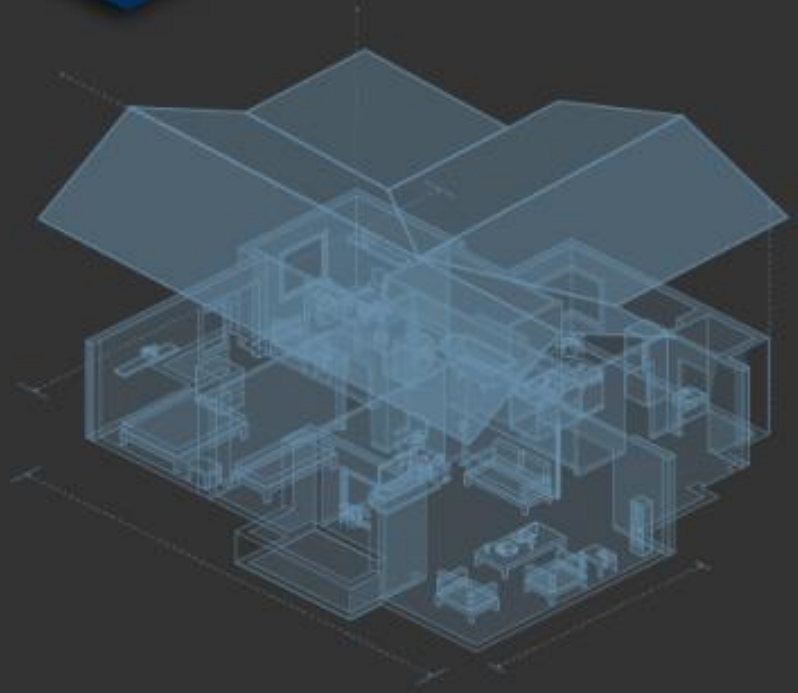
To address these issues, **renovations and retrofits of existing building stock** has become a pressing need.

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.



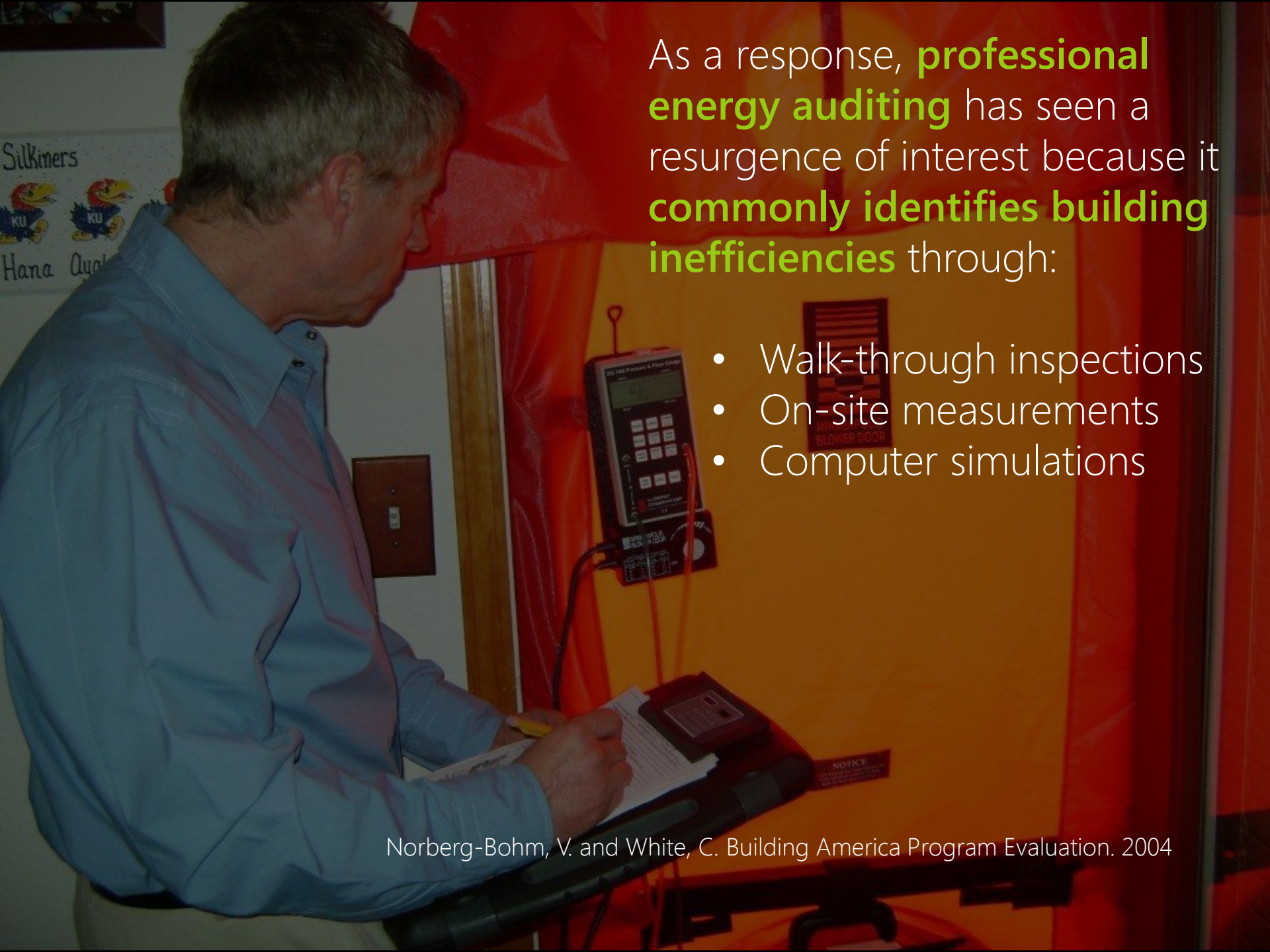
What is a home energy audit?

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

Thermographic Inspections

June 25, 2012 - 3:27pm

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

Energy auditors may use thermography -- or infrared scanning -- to detect thermal defects and air leakage in building envelopes.

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

RELATED ARTICLES

Professional Home Energy Audits

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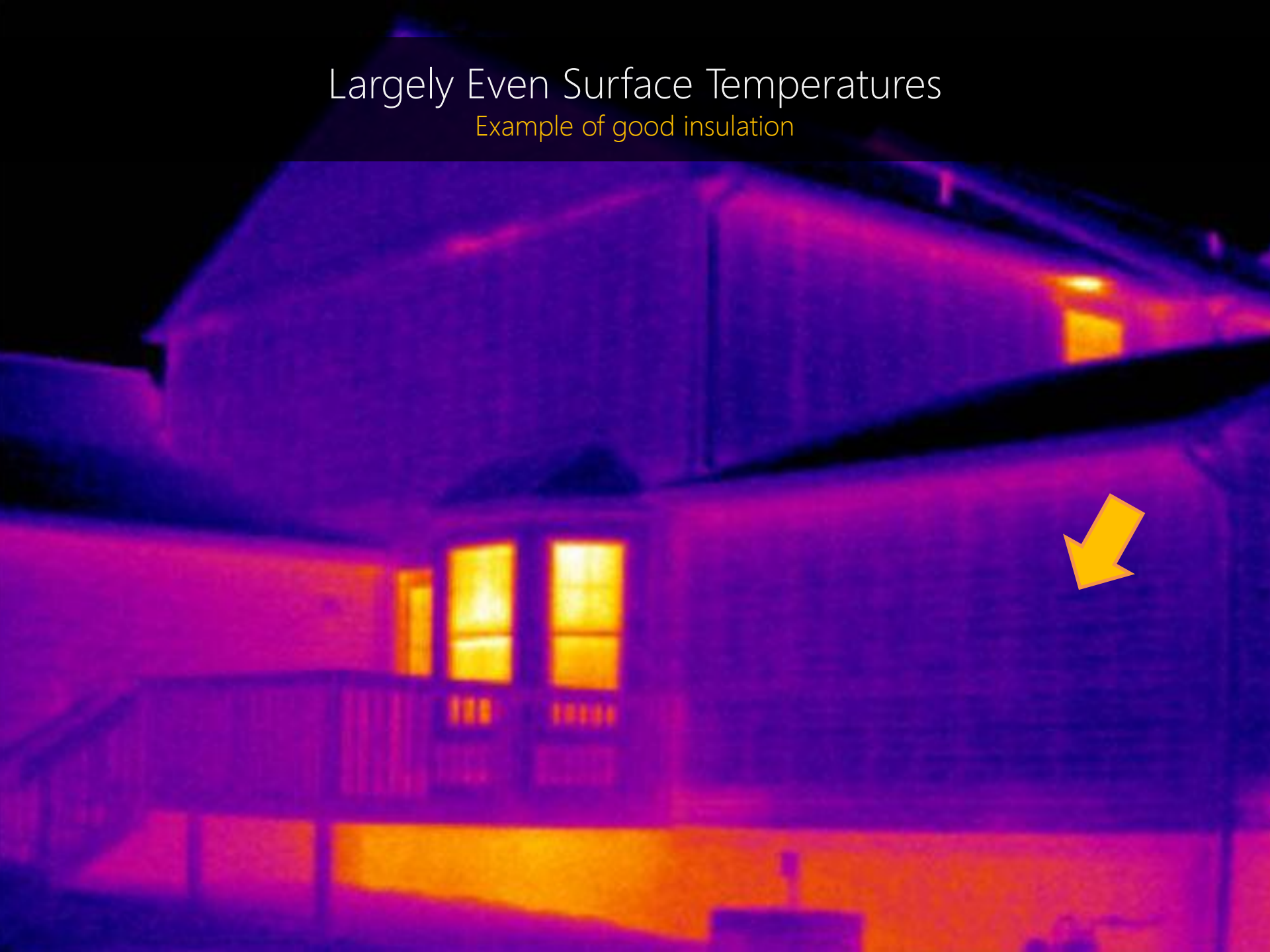
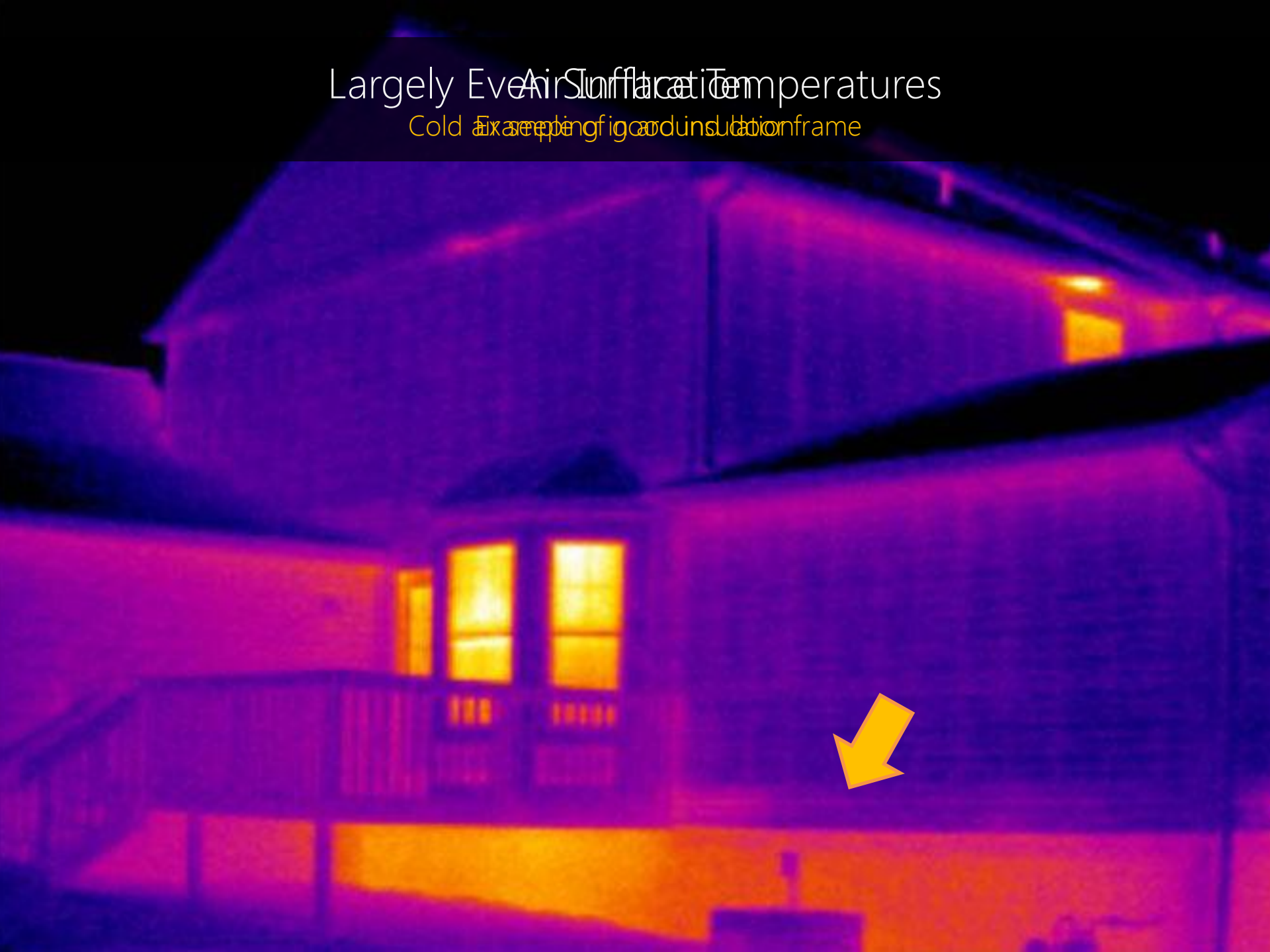
Largely Even Surface Temperatures

Example of good insulation




Largely Even Air Infiltration
Surface Temperatures
Cold air seeping around frame
Exposed concrete foundation
Lack of insulation


Uneven Surface Temperatures
Air Infiltration
Could indicate an insulation problem
Cold air seeping in

Thermal Cameras

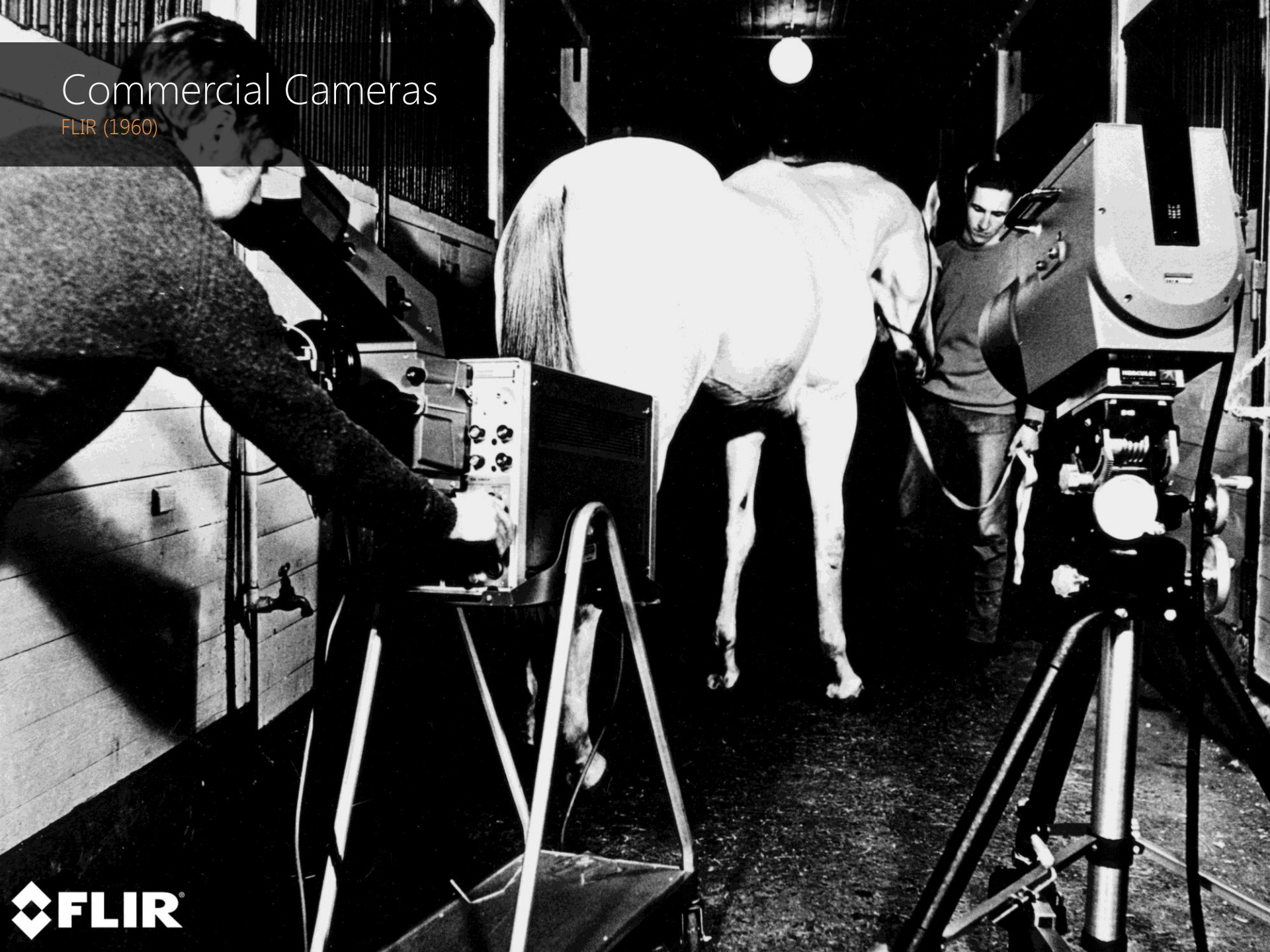
Thermal cameras (or infrared cameras) **detect electromagnetic radiation** with lower frequencies than visible light (*i.e.,* infrared frequencies)

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.

$249.99

WATCH THE VIDEO

LAUNCH SIMULATOR

BUY NOW

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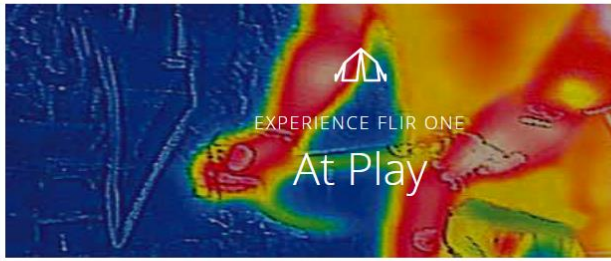

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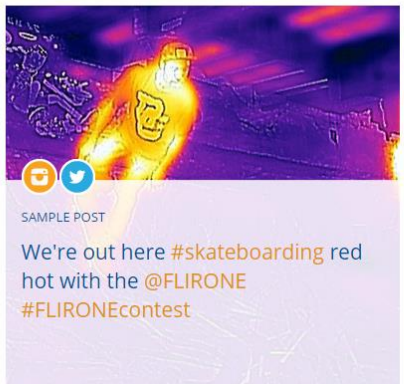
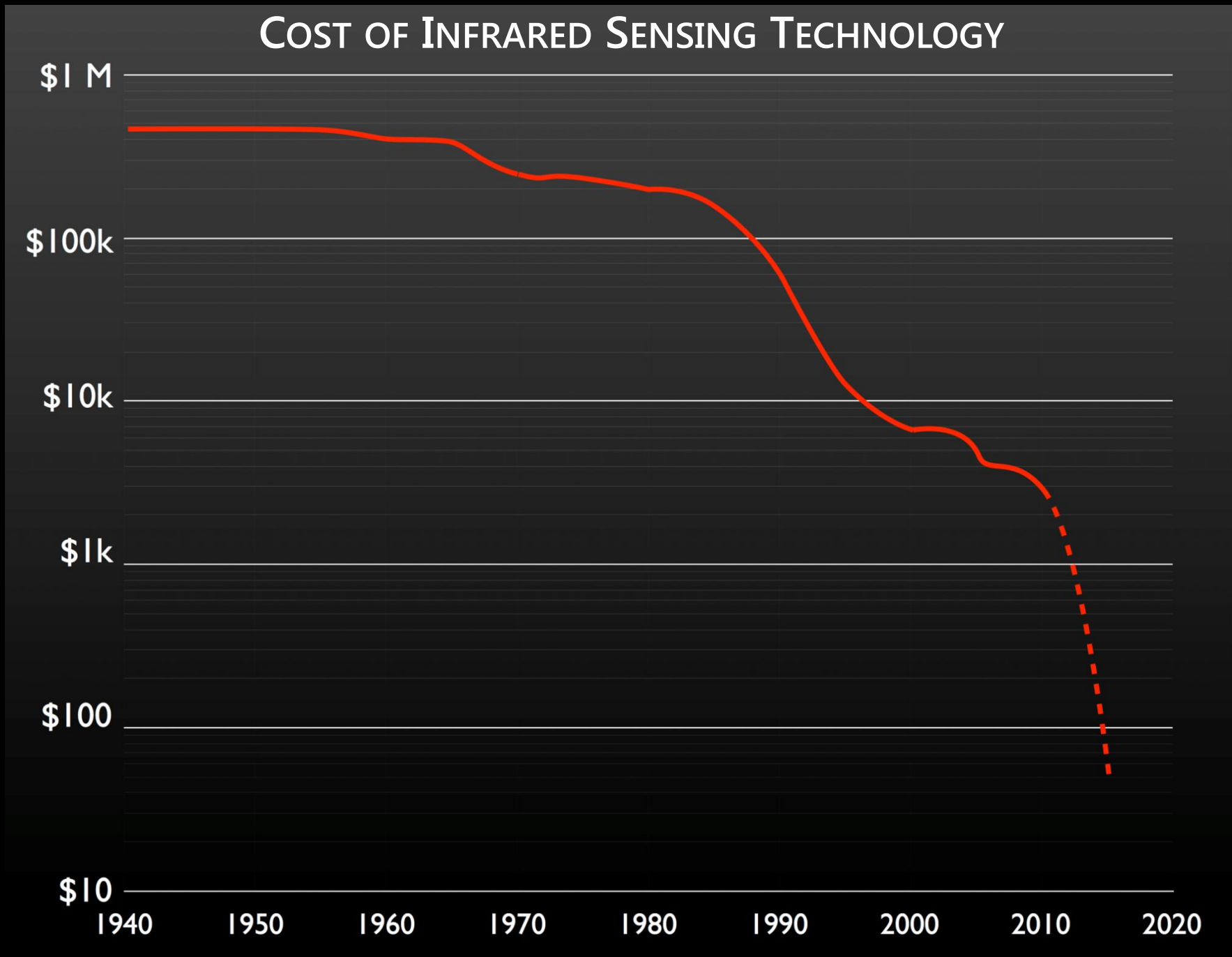
WATCH VIDEO

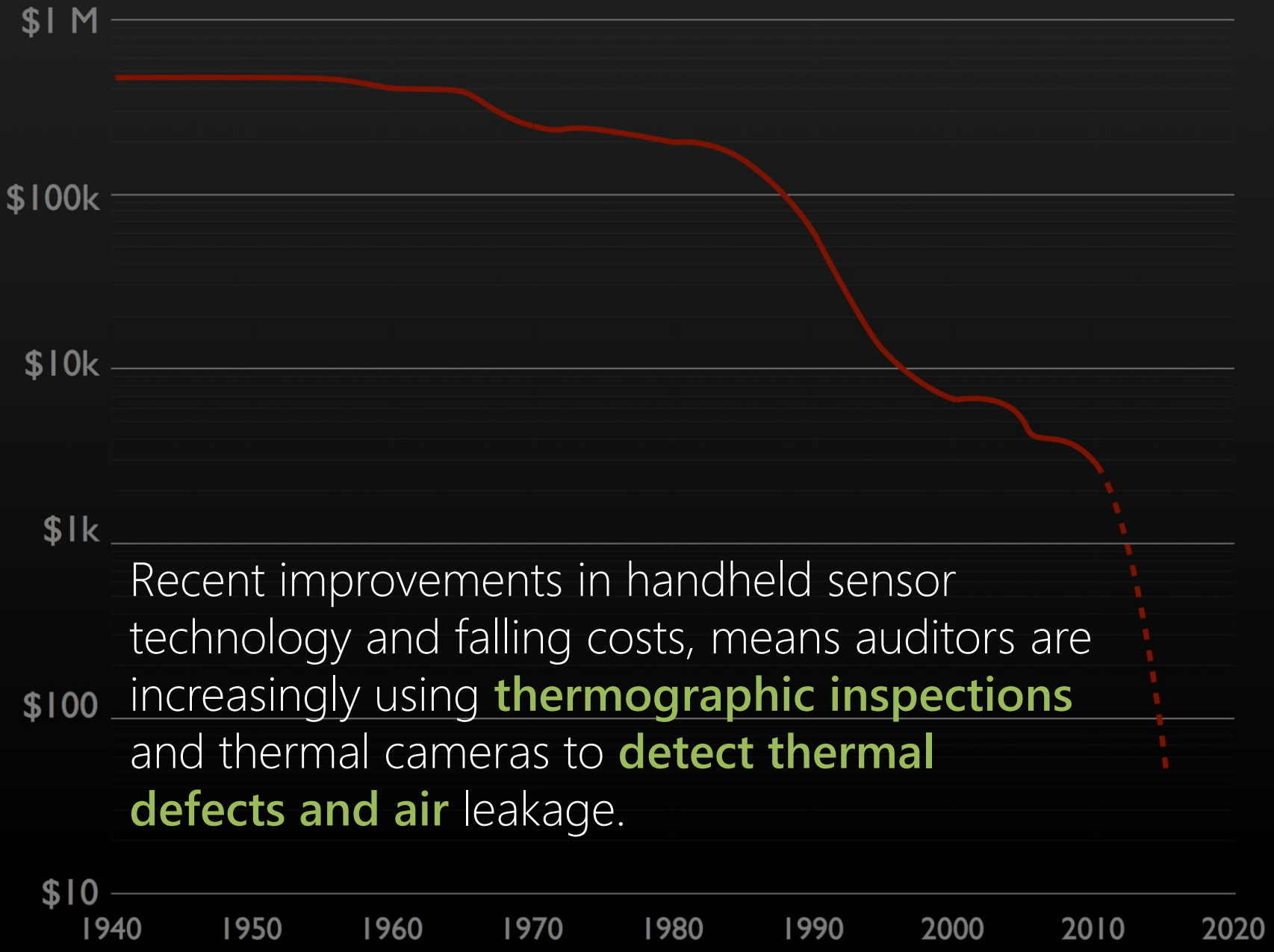


Cost of Infrared Sensing Technology



Source: Larson *et al.,* CHI2011, http://www.slideshare.net/ericcooperlarson/heatwave-chi2011

Cost of Infrared Sensing Technology

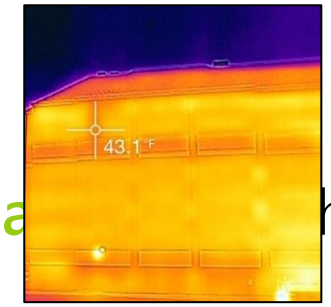


Recent improvements in handheld sensor technology and falling costs, means auditors are increasingly using **thermographic inspections** and thermal cameras to **detect thermal defects and air** leakage.

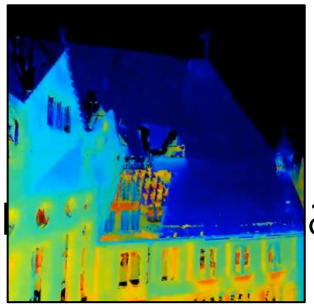
Source: Larson *et al.,* CHI2011, http://www.slideshare.net/ericcooperlarson/heatwave-chi2011

Energy audits and thermographic surveying are time and labor intensive

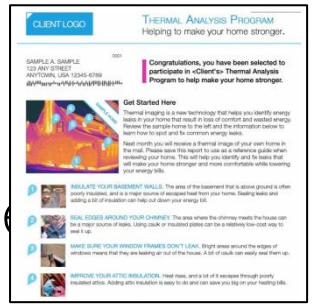
Data collection



Analysis



Modeling

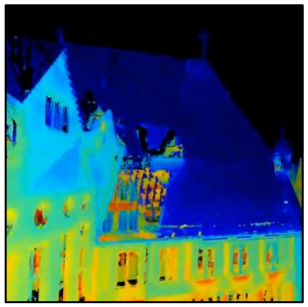


Reporting

How can we **automate** thermographic assessments?

Data collection

Analysis



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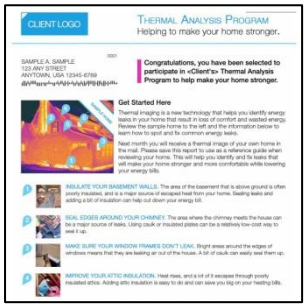


Reporting

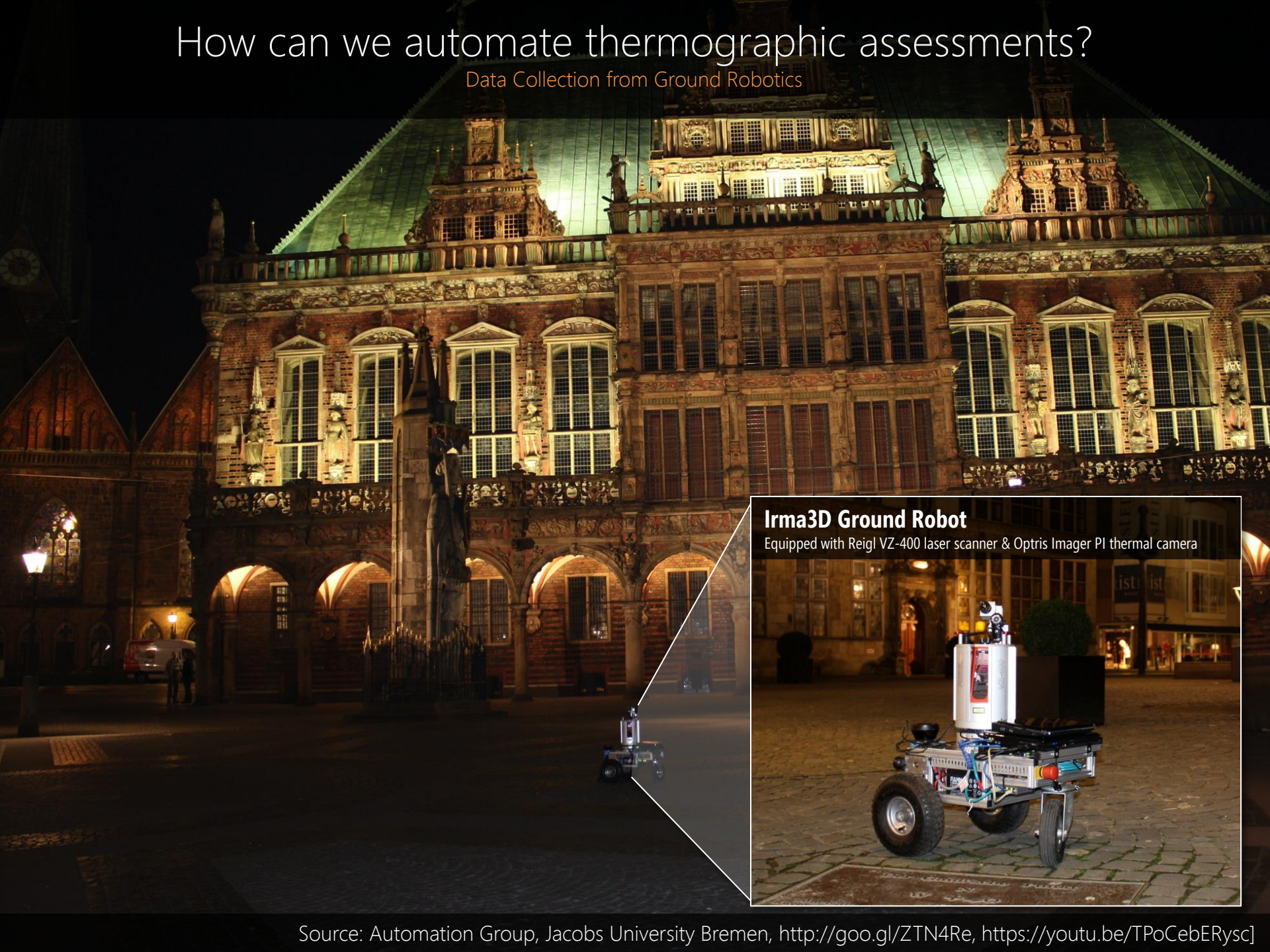
How can we automate thermographic assessments?

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

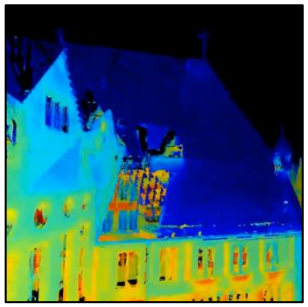
Equipped with Reigl VZ-400 laser scanner & Optris Imager PI thermal camera

Source: Automation Group, Jacobs University Bremen, http://goo.gl/ZTN4Re, https://youtu.be/TPoCebERysc]

How can we **automate** thermographic assessments?

Data collection

Analysis



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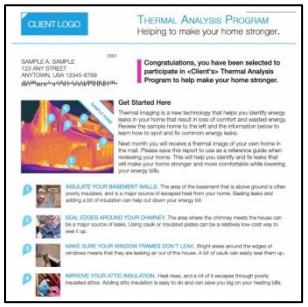

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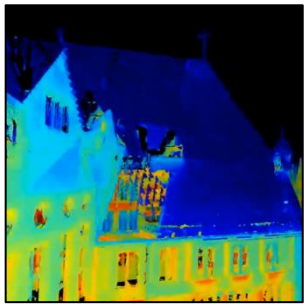

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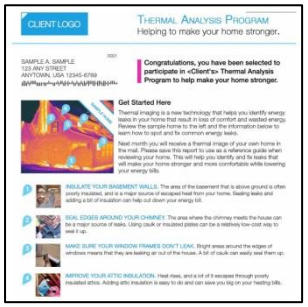

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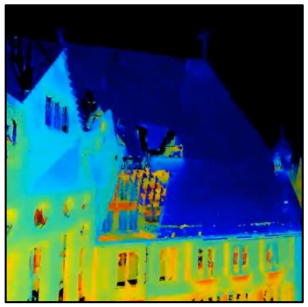

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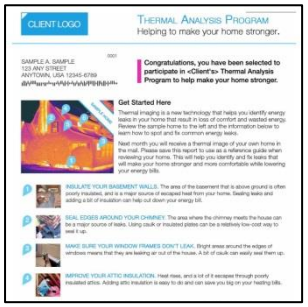


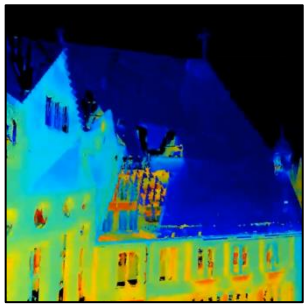
Reporting

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



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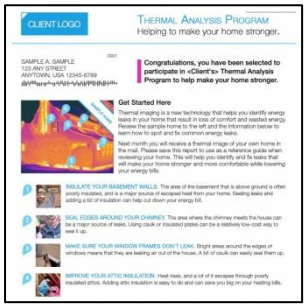

Reporting

How can we automate thermographic assessments?

High Fidelity Model Generation

Source: Automation Group, Jacobs University Bremen, http://goo.gl/ZTN4Re, https://youtu.be/TPoCebERysc]

How can we **automate** thermographic assessments?

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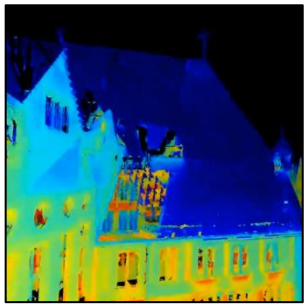

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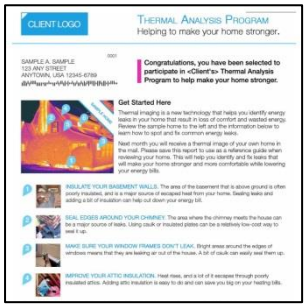

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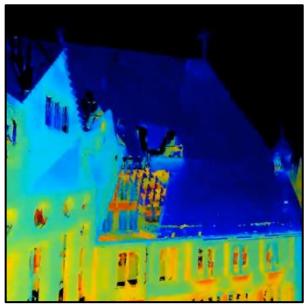
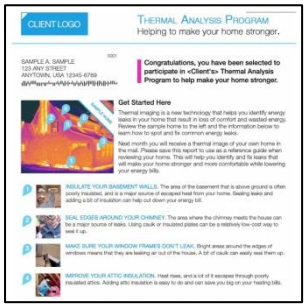


Modeling



Reporting

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.

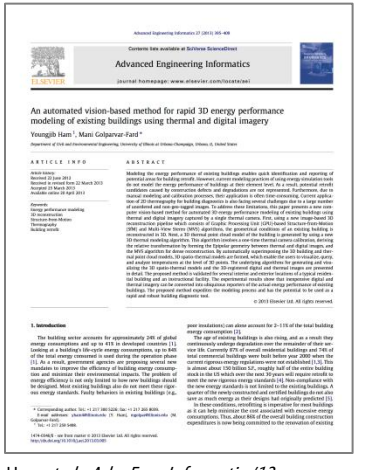
Previtali *et al.,Applied Geomatics'14*

Bormann *et al., Adv. Eng. Informatics'14*

Laguela *et al., Q. Infrared Thermography'14*

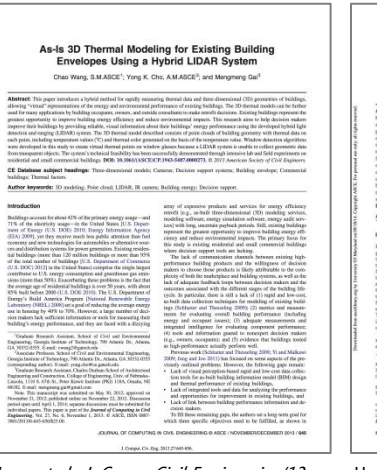
Laguela *et al., Energy and Buidlings'14*

Previtali *et al., J. Mobile Multimedia'14*

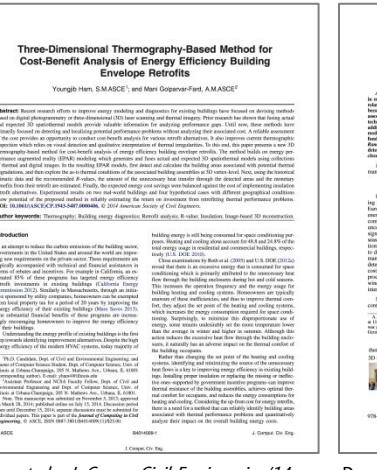


Ham*et al., Adv. Eng. Informatics'13*

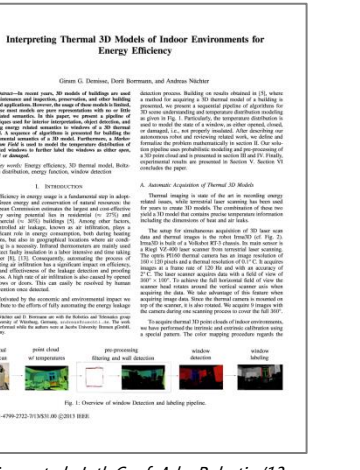
Vidas *et al., IEEE Sensors'14*



Wang *et al., J. Comp. Civil Engineering'13*



Ham *et al., J. Comp. Civil Engineering'14*



Demisse *et al., Intl. Conf. Adv. Robotics'13*

Research Questions

1. How is thermography currently being used by auditors?

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

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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?
3. 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

Design Probes Results

Observation Overview

Reflection

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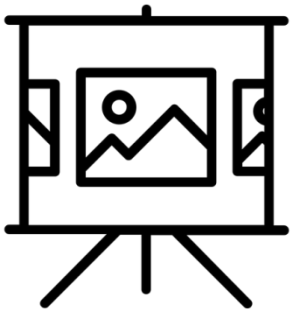
Study Design

Study 1

Part 1:
Semi-Structured Interviews
~50 Minutes



Part 2:
Presentation of Design Probes
~40 Minutes

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)

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)

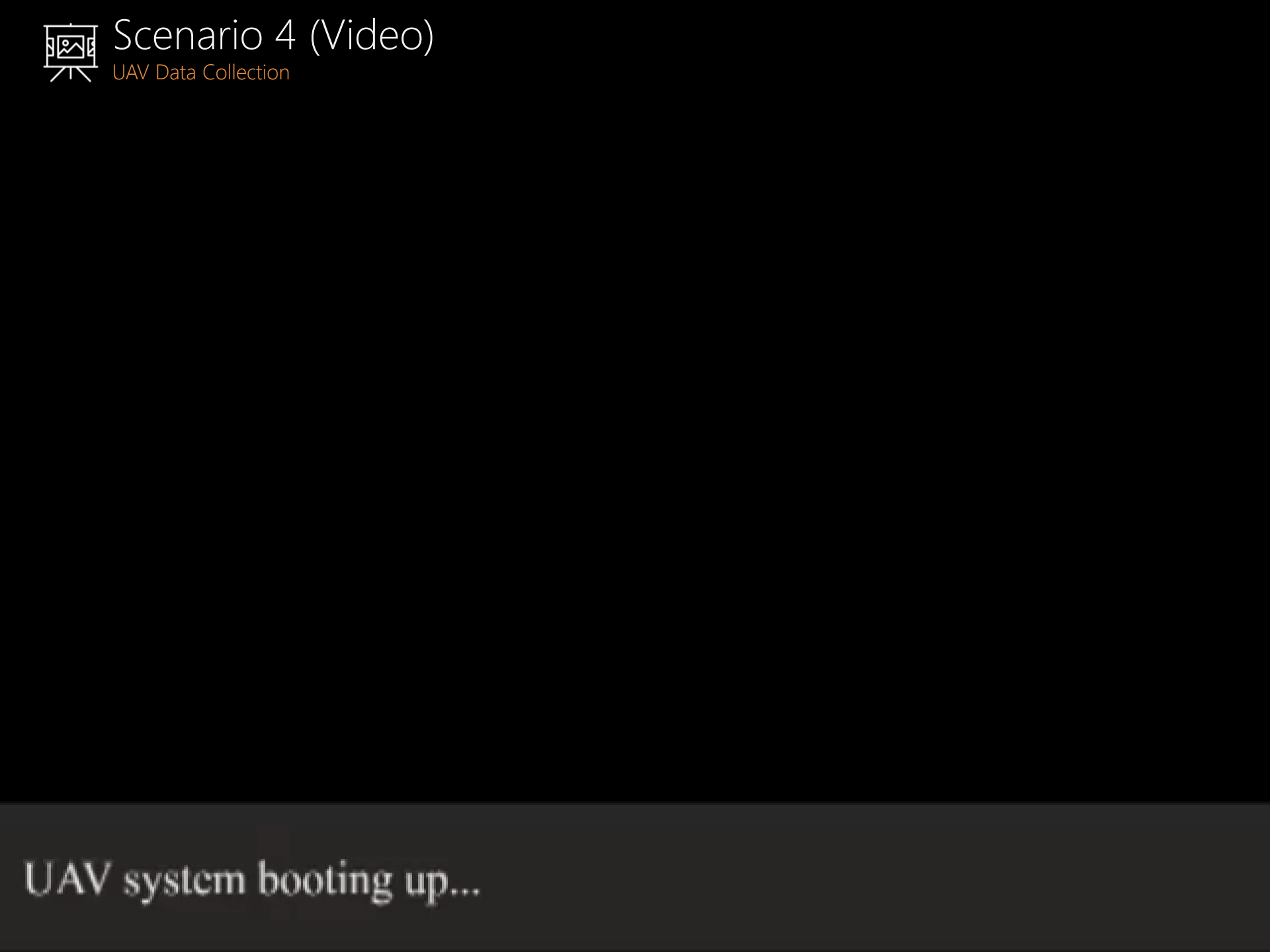
Scenario 3
(Text)

Scenario 4
(Video)

Scenario 5
(Mid-Fi Prototype)

Scenario 4 (Video)

UAV Data Collection



Study 1, Part 2: Design Probes

Scenario 1
(Text)

Scenario 2
(Text)

Scenario 3
(Text)

Scenario 4
(Video)

Scenario 5
(Mid-Fi Prototype)

Analysis of Study 1

We qualitatively coded the interview and design probe data to uncover themes.

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makeability lab

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 is for making sustainablity 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 (mattm@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.

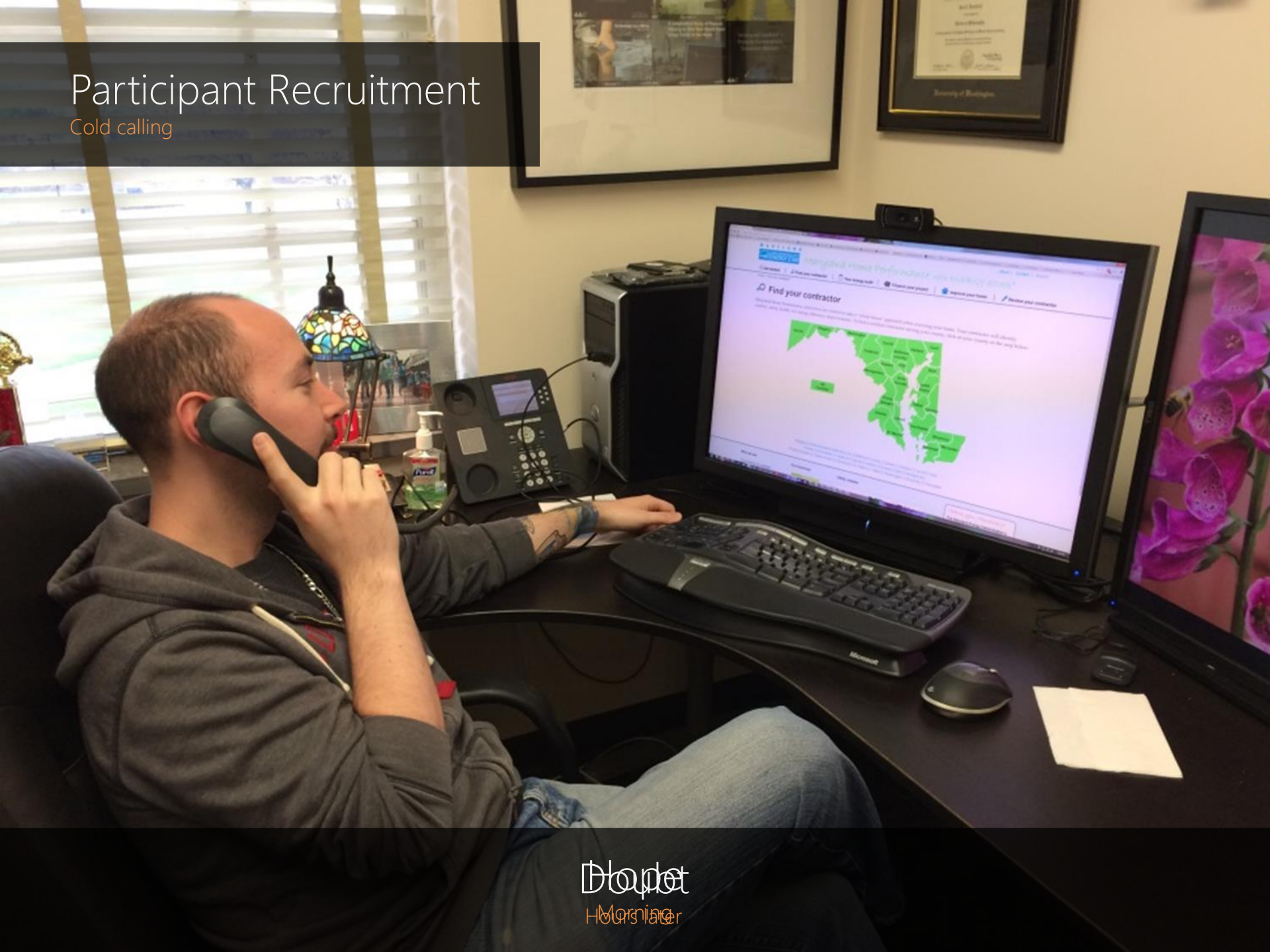
Sincerely,

~Matthew Mauriello, MS
Department of Computer Science
University of Maryland
A.V. Williams Building, 4122
College Park, MD 20742
--


LinkedIn

Participant Recruitment

Cold calling



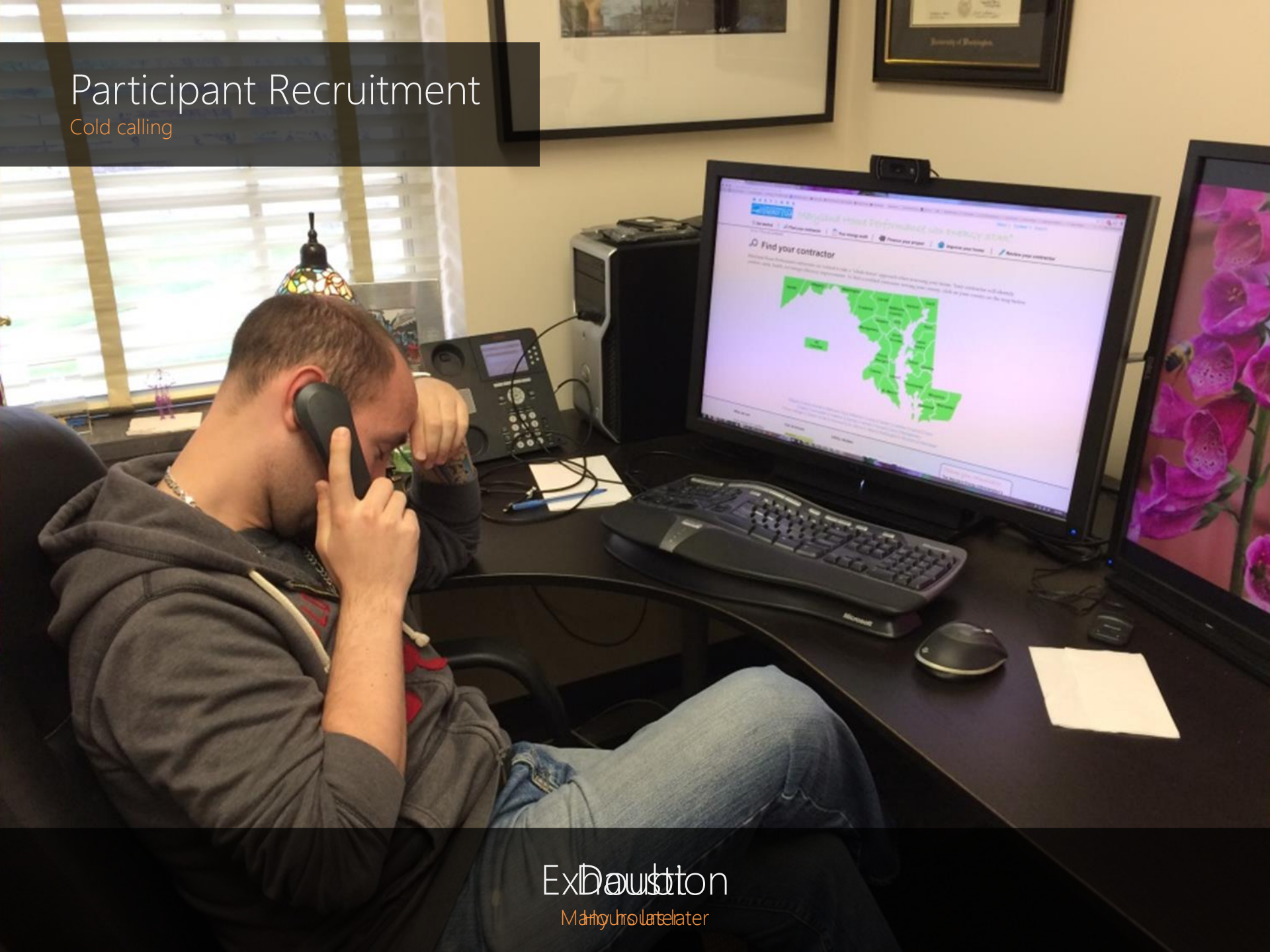
Doubt

Morning

Hours later

Participant Recruitment

Cold calling



Exhaustion

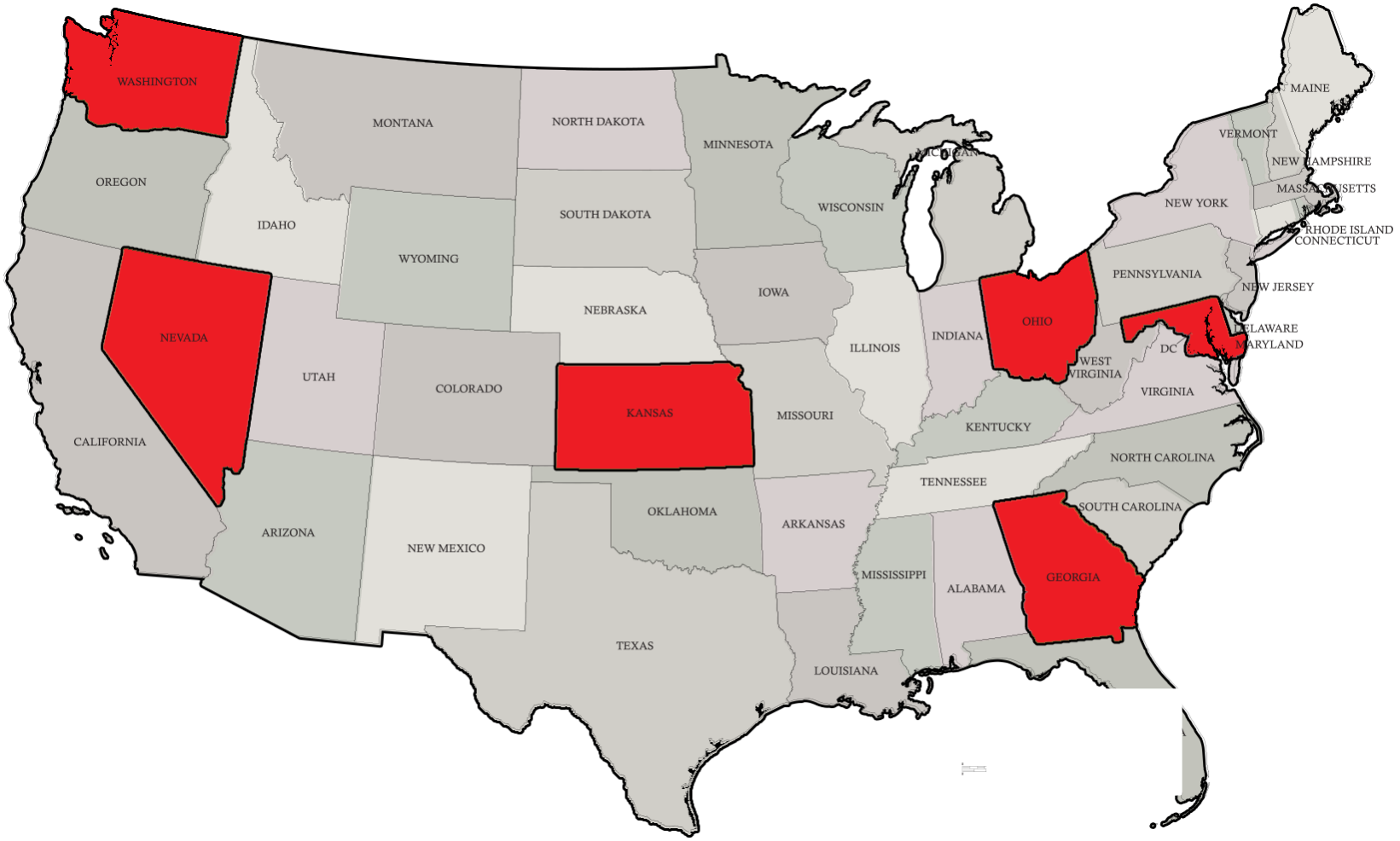
Many hours later

Participant Recruitment

Some study sessions conducted via Skype

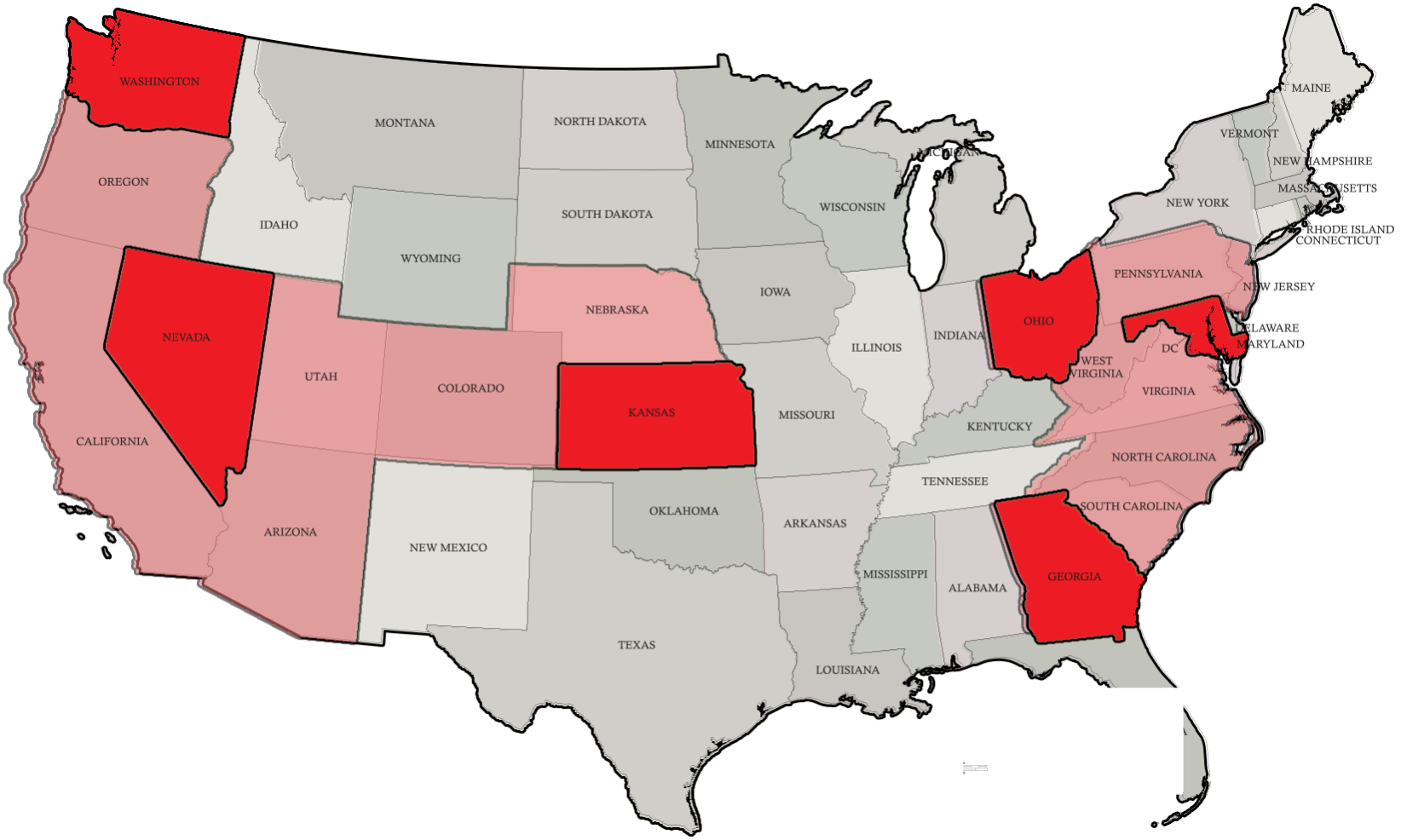
Participant Recruitment

6 States Represented



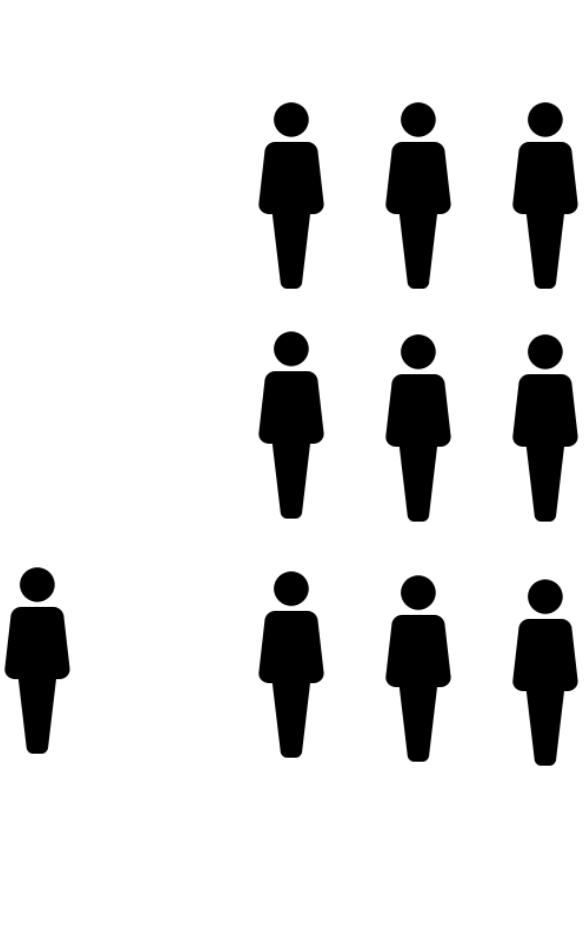
Participant Recruitment

Regional Experience Coverage



Participant Demographics

Summary Data



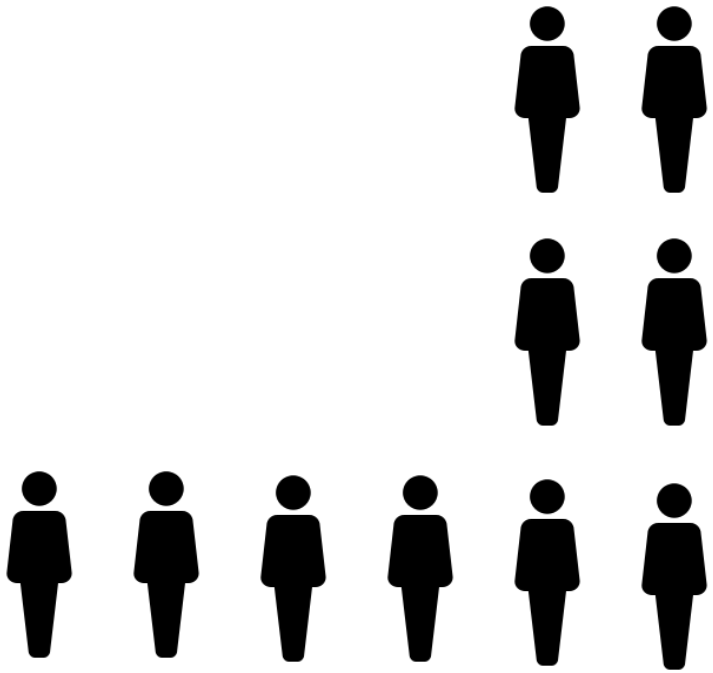
10 Participants (1 Female)

Average Age: 44.8 Years

Average Exp.: 6.7 Years

Participant Demographics

Occupation



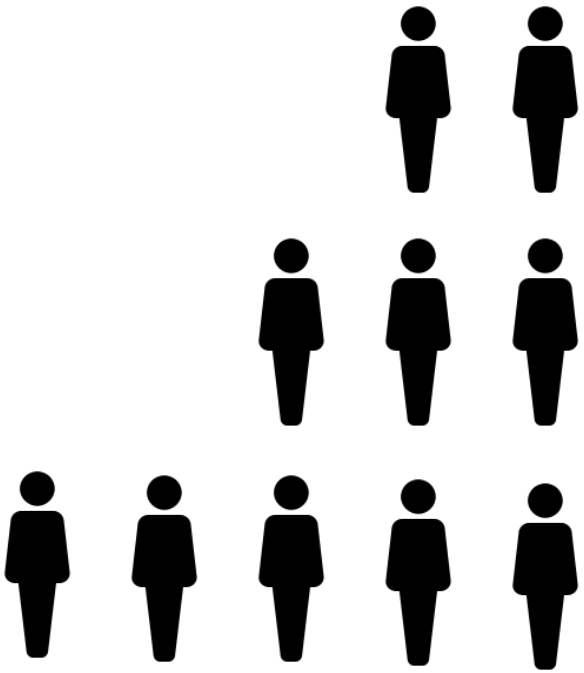
Former Thermographers (2)

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

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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

Study 1, Part 1: Semi-Structured Interviews Results

Required Knowledge

6 of 10 auditors felt that an understanding of building materials and construction were necessary for proper thermographic inspections.

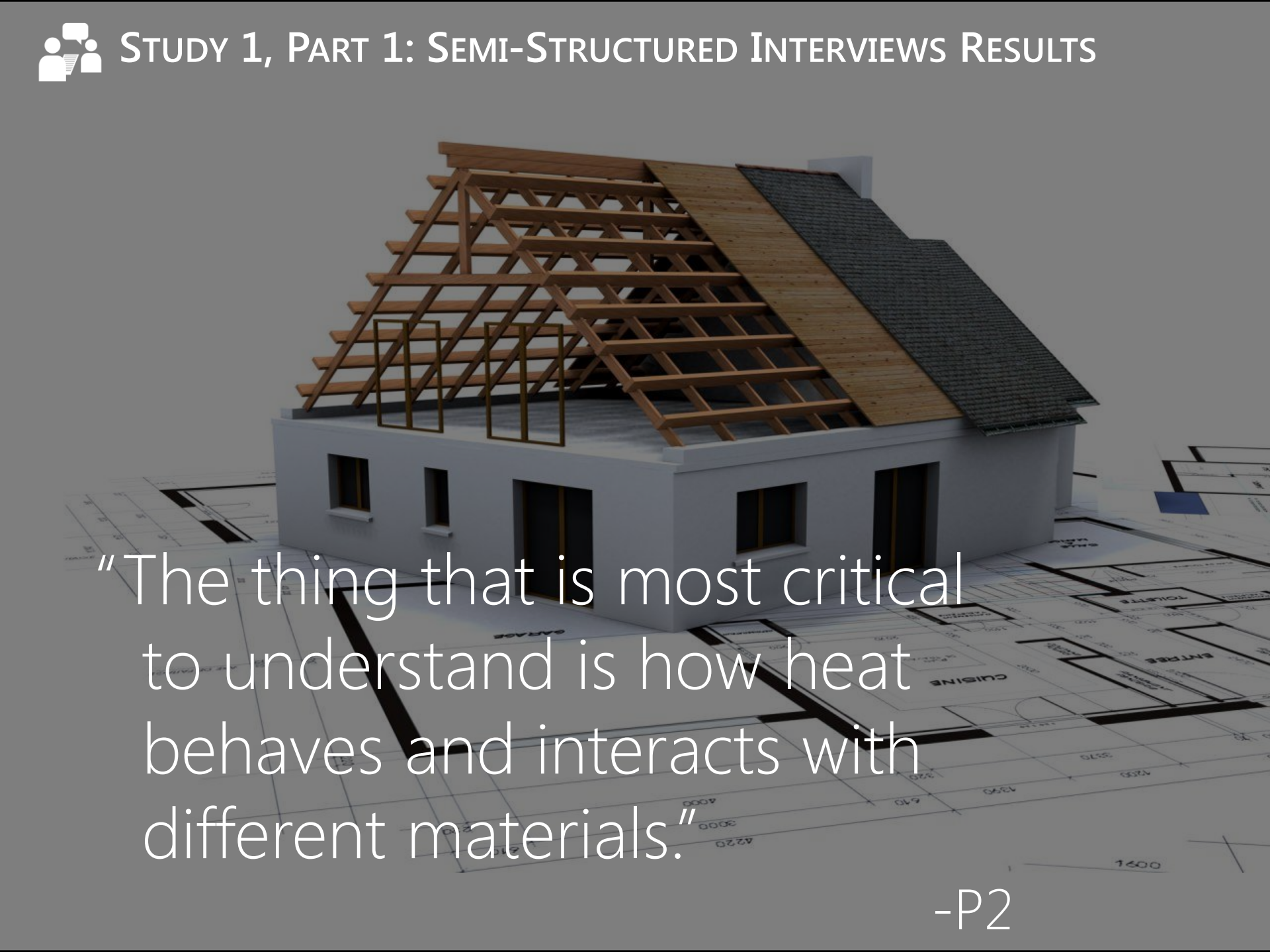
Study 1, Part 1: Semi-Structured Interviews Results

Required Knowledge

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 a understanding of the physics behind heat transfer and airflow were crucial to interpreting results.

Study 1, Part 1: Semi-Structured Interviews 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

Study 1, Part 1: Semi-Structured Interviews Results

Client Interactions

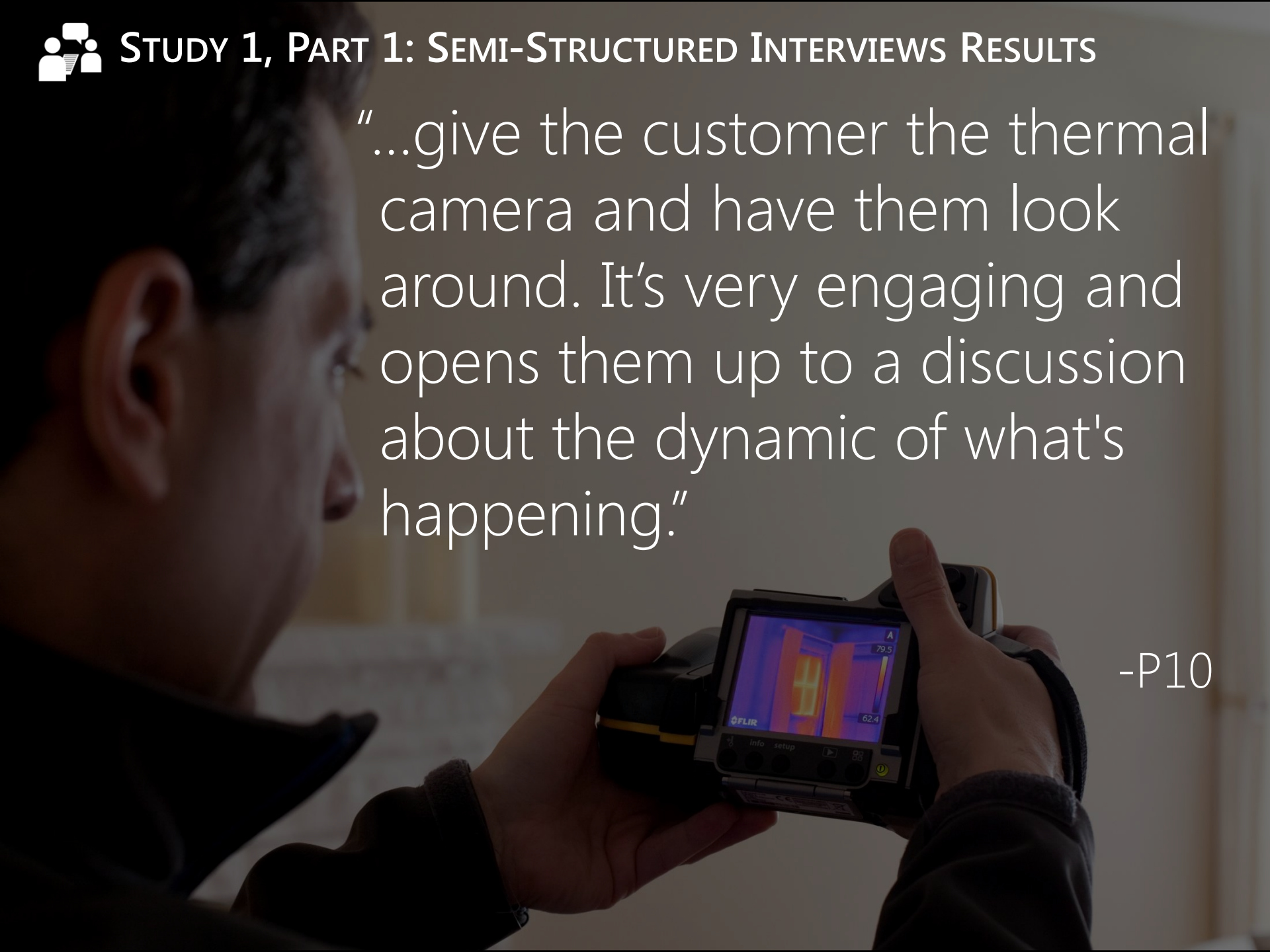
9 of 10 energy auditors agreed that client interactions were crucial to a successful audit, especially related to:

- information gathering
- understanding a clients motivations and perceptions
- establishing trust

Study 1, Part 1: Semi-Structured Interviews Results

"...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

Study 1, Part 1: Semi-Structured Interviews Results

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

Study 1, Part 1: Semi-Structured Interviews 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

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Study 1, Part 2: Design Probes Results

Automation Benefits

Concerns

Study 1, Part 2: Design Probes Results

Automation Benefits

Concerns

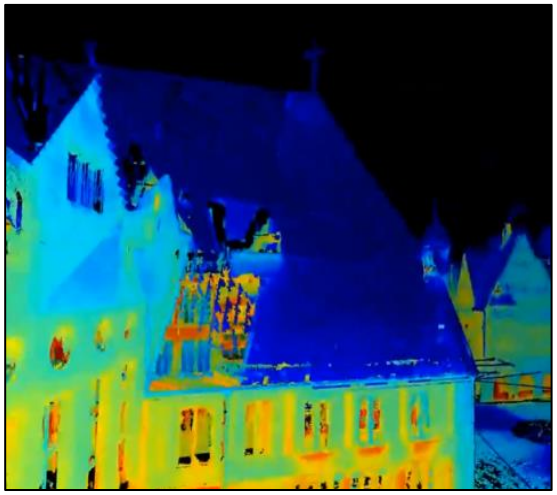
Study 1, Part 1: Design Probe Results (Automation Benefits)

Study 1, Part 1: Design Probe Results (Automation Benefits)

Saving time and money

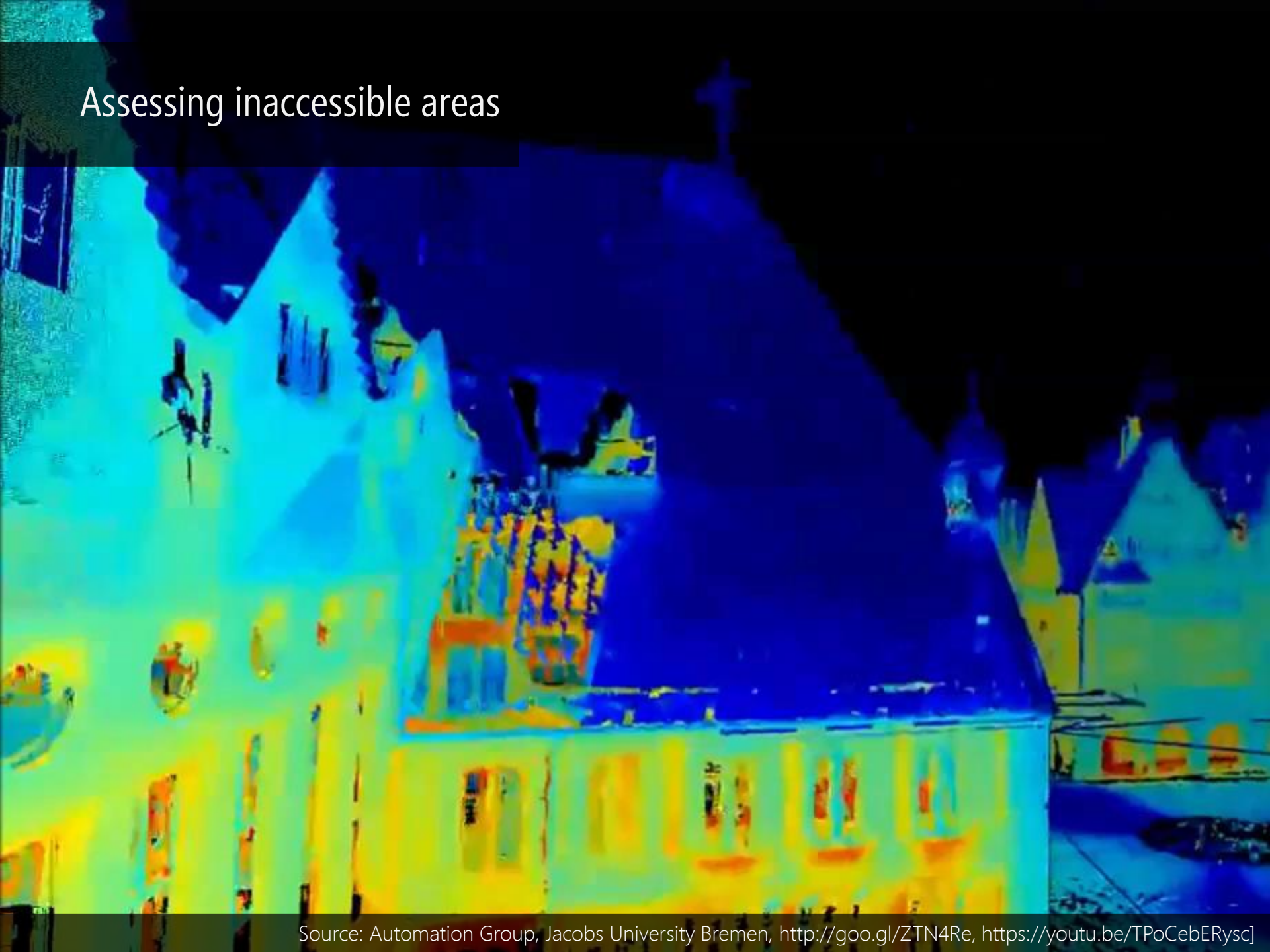
Study 1, Part 1: Design Probe Results (Automation Benefits)

Saving time and money



Assessing inaccessible areas

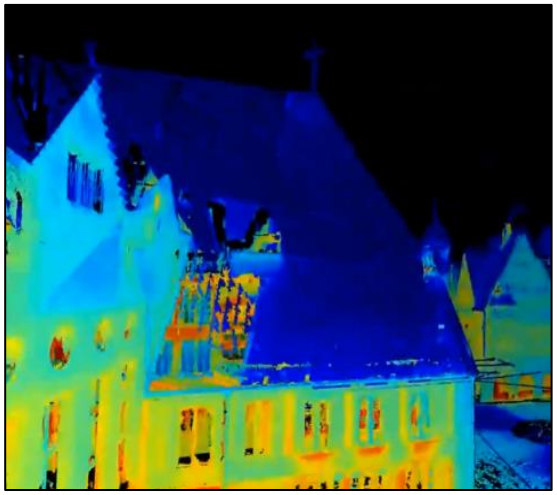
Assessing inaccessible areas



Source: Automation Group, Jacobs University Bremen, http://goo.gl/ZTN4Re, https://youtu.be/TPoCebERysc]

Study 1, Part 1: Design Probe Results (Automation Benefits)

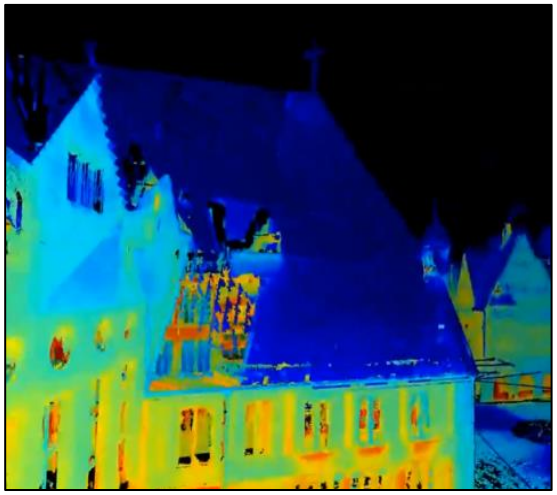
Saving time and money



Assessing inaccessible areas

Study 1, Part 1: Design Probe Results (Automation Benefits)

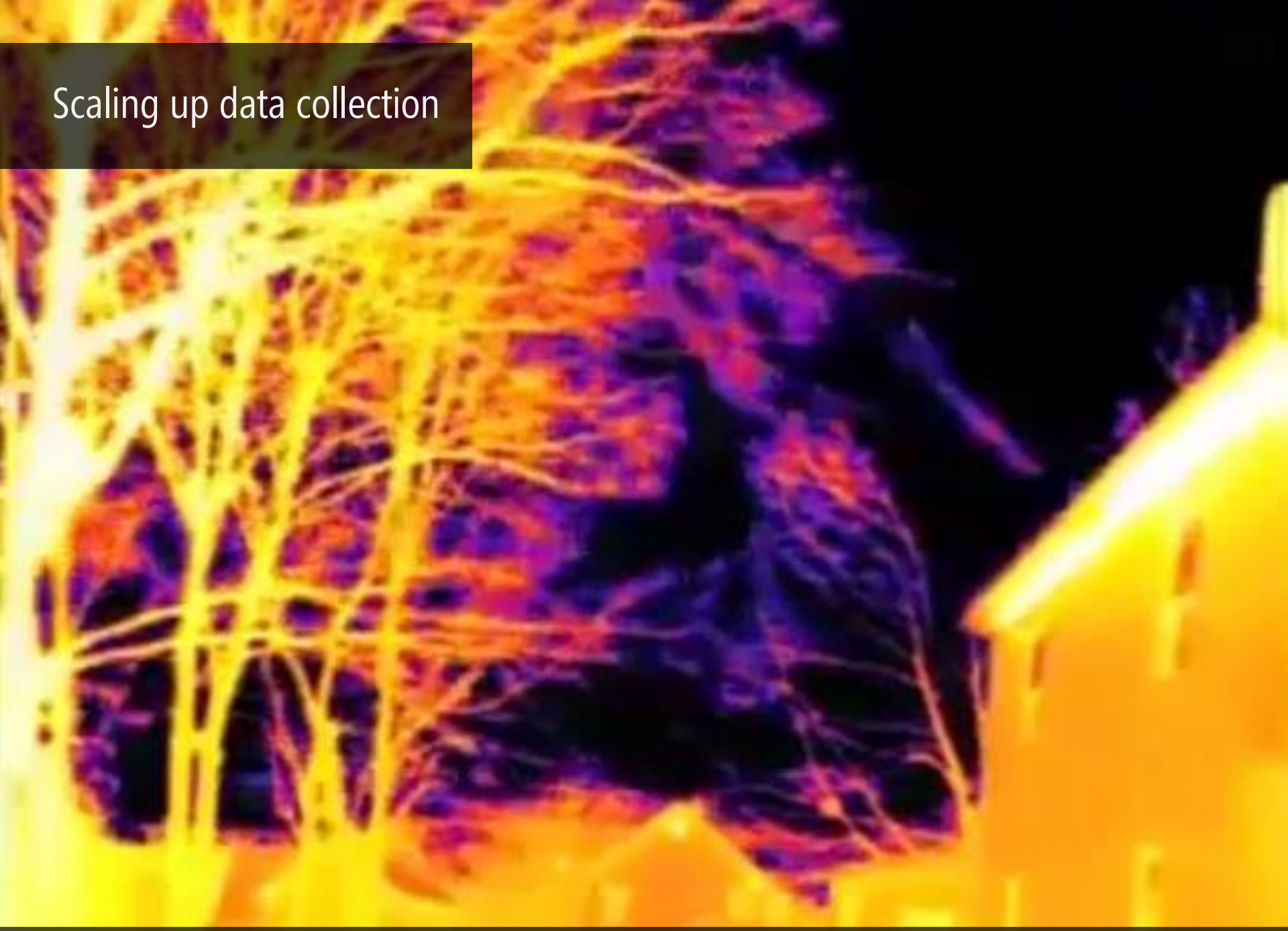
Saving time and money



Assessing inaccessible areas

Scaling up data collection

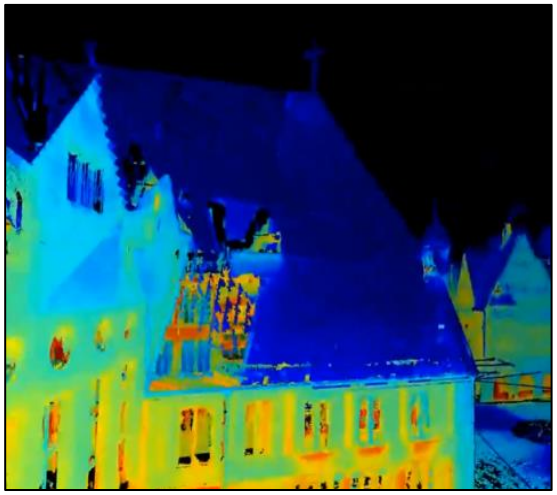
Scaling up data collection



Source: Reuters, http://uk.reuters.com/video/2015/01/29/mobile-heat-tech-the-google-maps-of-ener?videoId=363026586

Study 1, Part 1: Design Probe Results (Automation Benefits)

Saving time and money

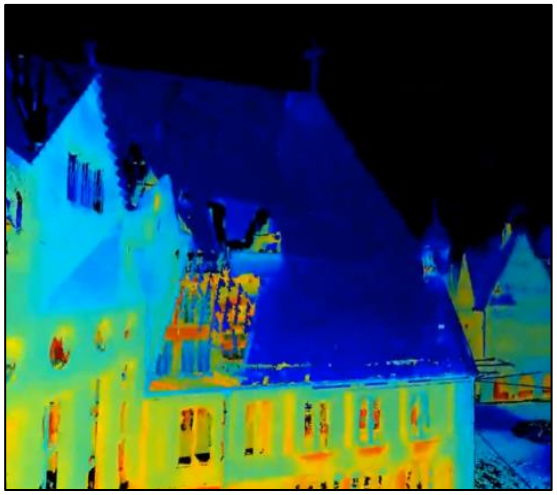


Assessing inaccessible areas

Scaling up data collection

Study 1, Part 1: Design Probe Results (Automation Benefits)

Saving time and money



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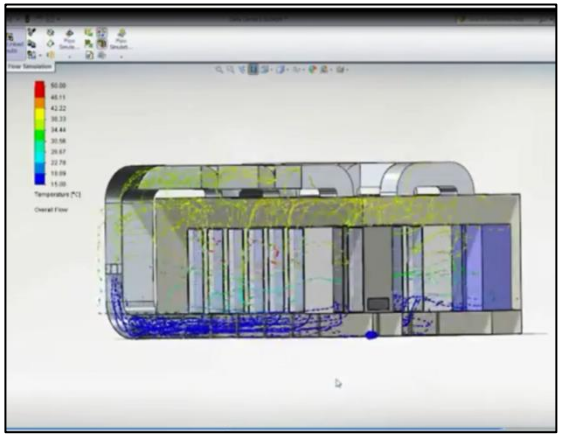
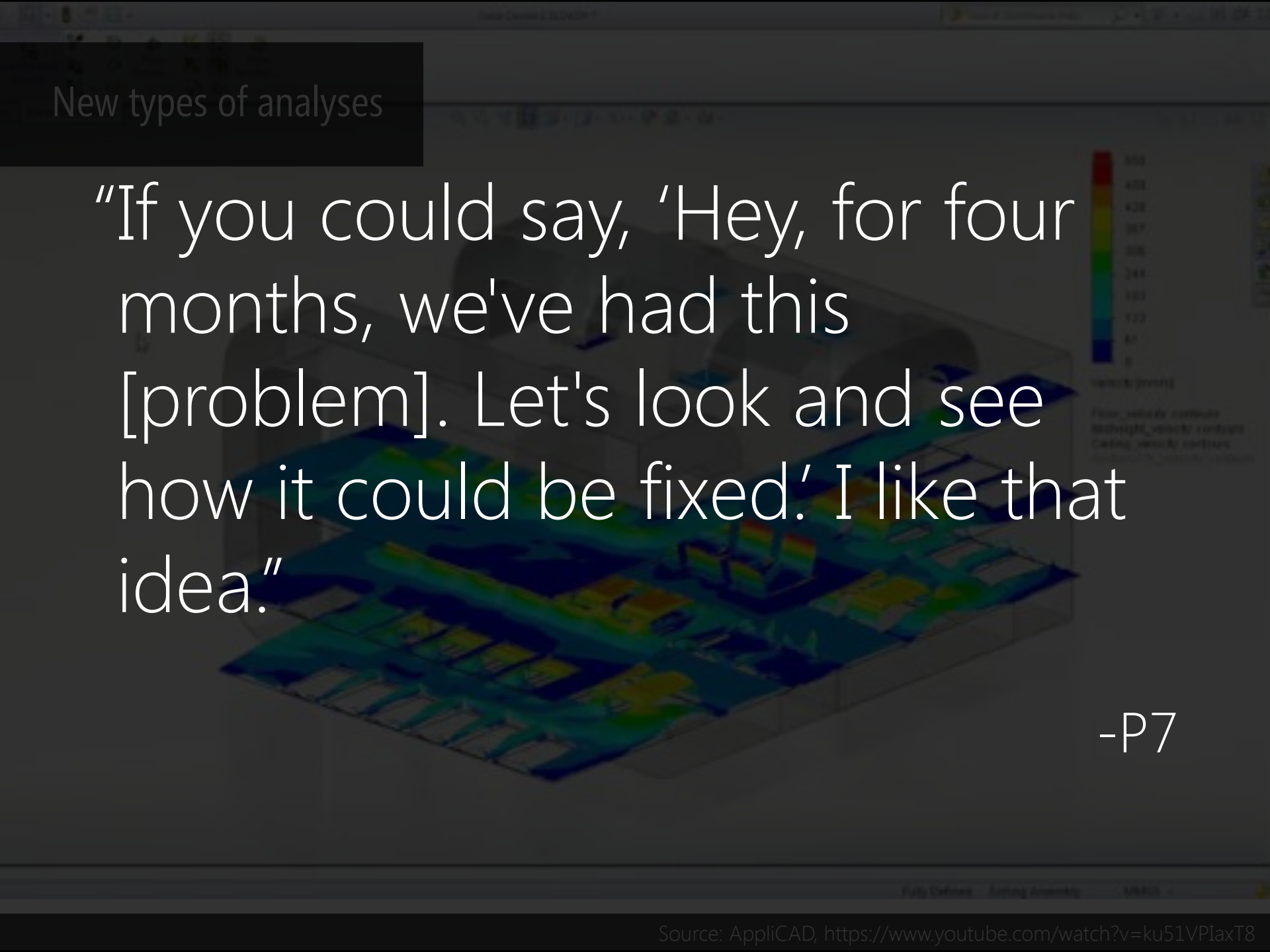


New types of analyses

New types of analyses



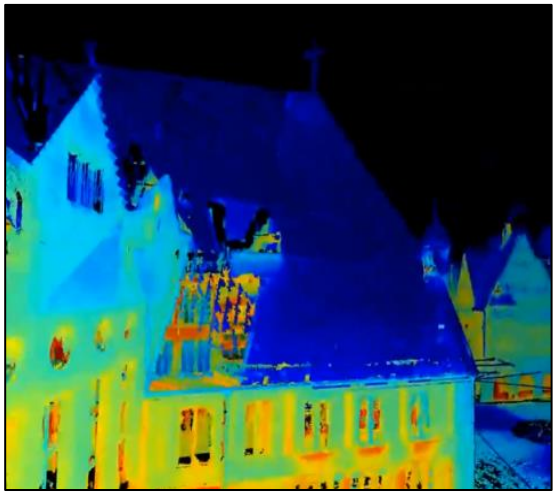
"If you could say, 'Hey, for four months, we've had this [problem]. Let's look and see how it could be fixed.' I like that idea."

-P7

Source: AppliCAD, https://www.youtube.com/watch?v=ku51VPIaxT8

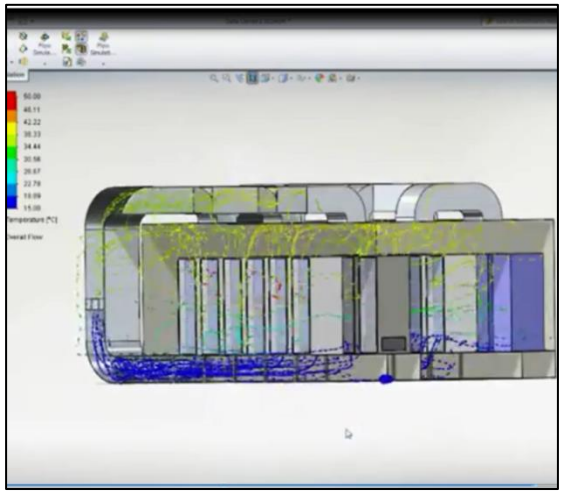
Study 1, Part 1: Design Probe Results (Automation Benefits)

Saving time and money



Assessing inaccessible areas

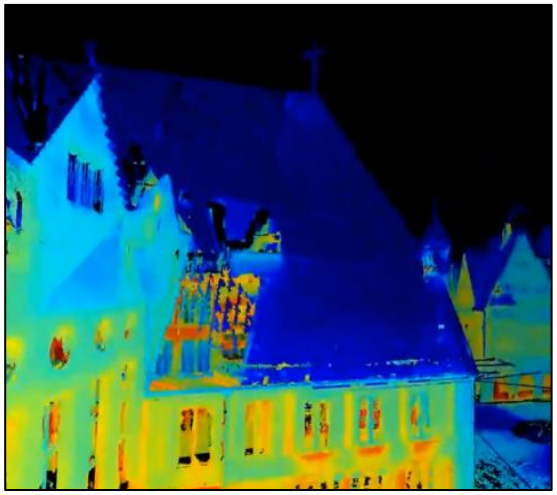
Scaling up data collection



New types of analyses

Study 1, Part 1: Design Probe Results (Automation Benefits)

Saving time and money



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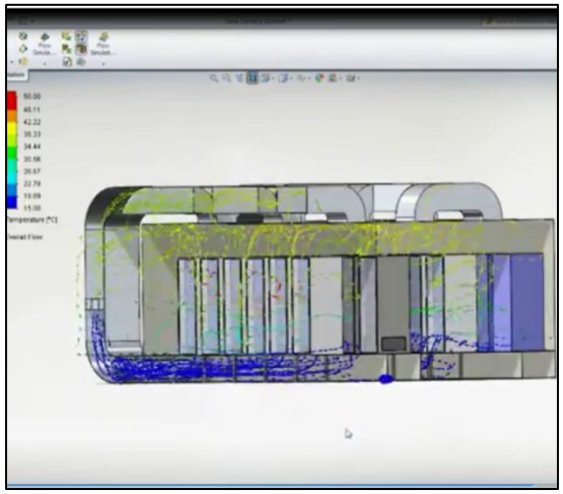
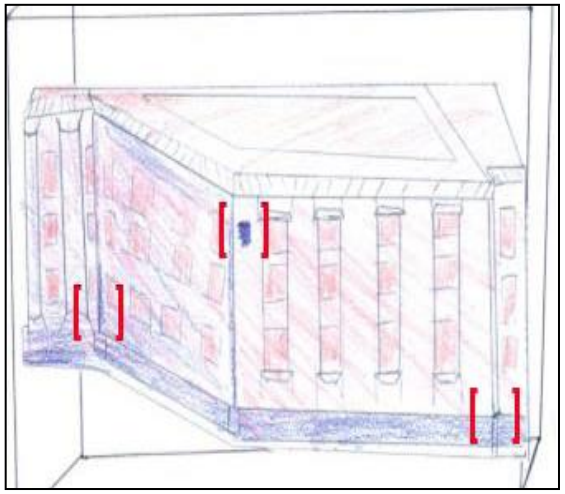


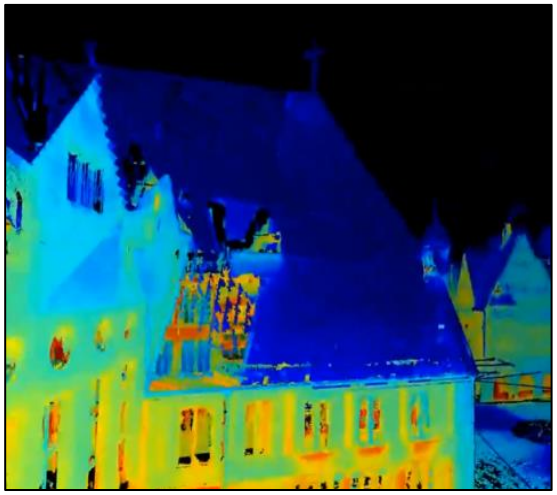
New types of analyses



Automatic anomaly detection

Study 1, Part 1: Design Probe Results (Automation Benefits)

Saving time and money



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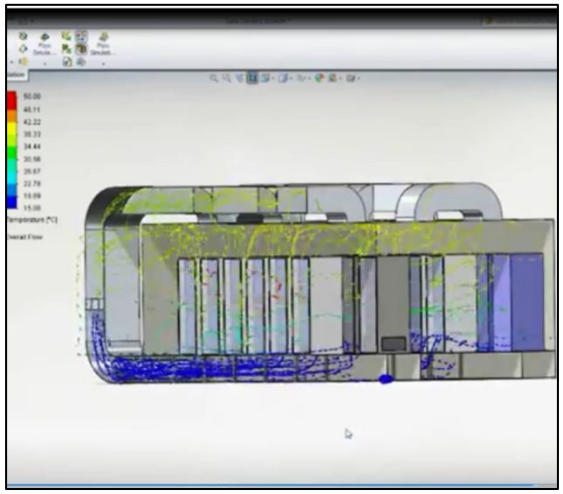

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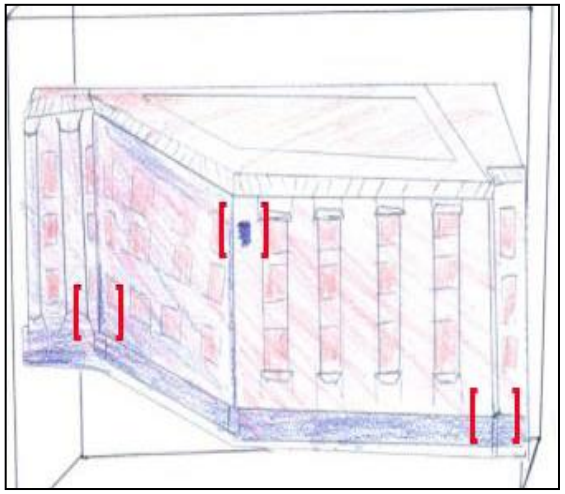
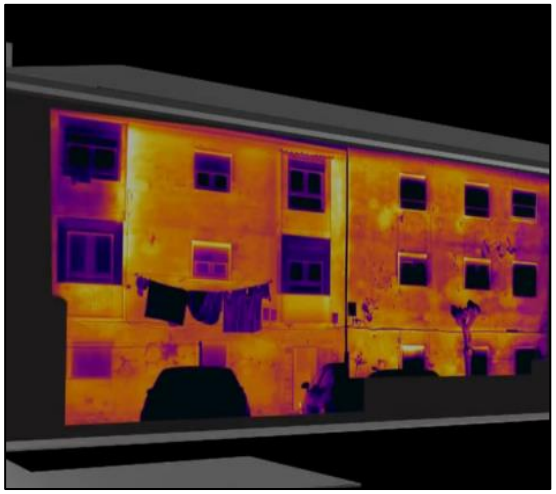


Automatic anomaly detection



Model generation

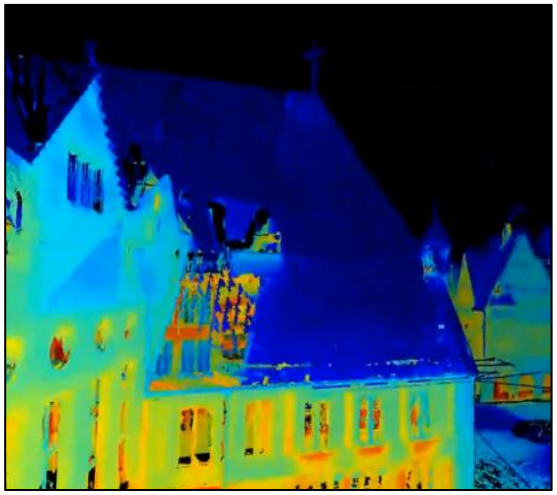
"You spend a lot of time building this model, just measuring the outside of the house, counting the windows and the doors, and looking around… this would streamline that."

-P10

Source: GimGEOMATICS, https://www.youtube.com/watch?v=lrnSOnGYSG4

Study 1, Part 1: Design Probe Results (Automation Benefits)

Saving time and money



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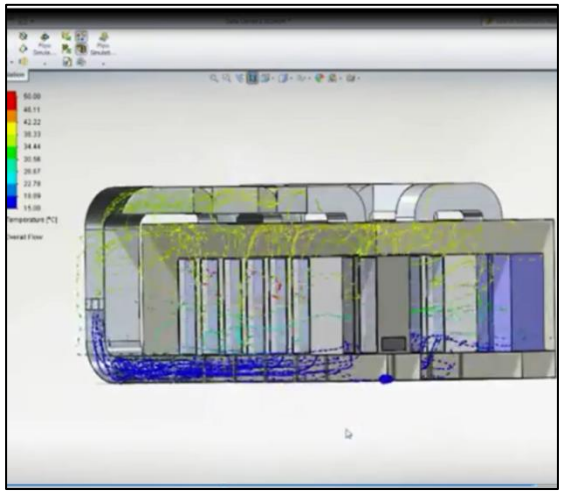

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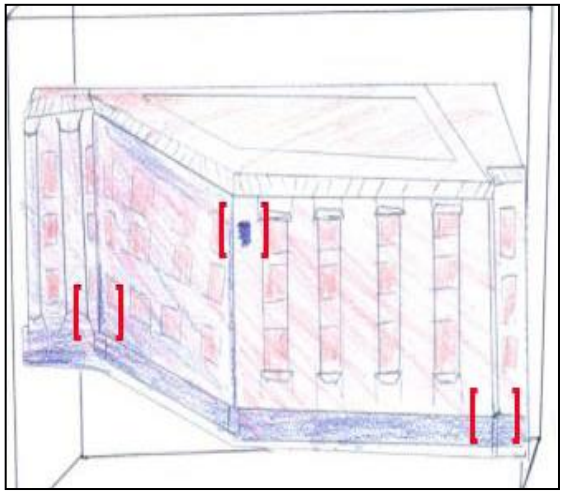

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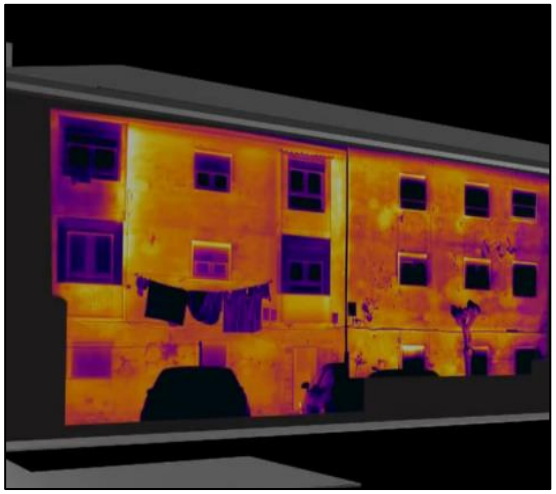


Model generation

Study 1, Part 2: Design Probes Results

Automation Benefits

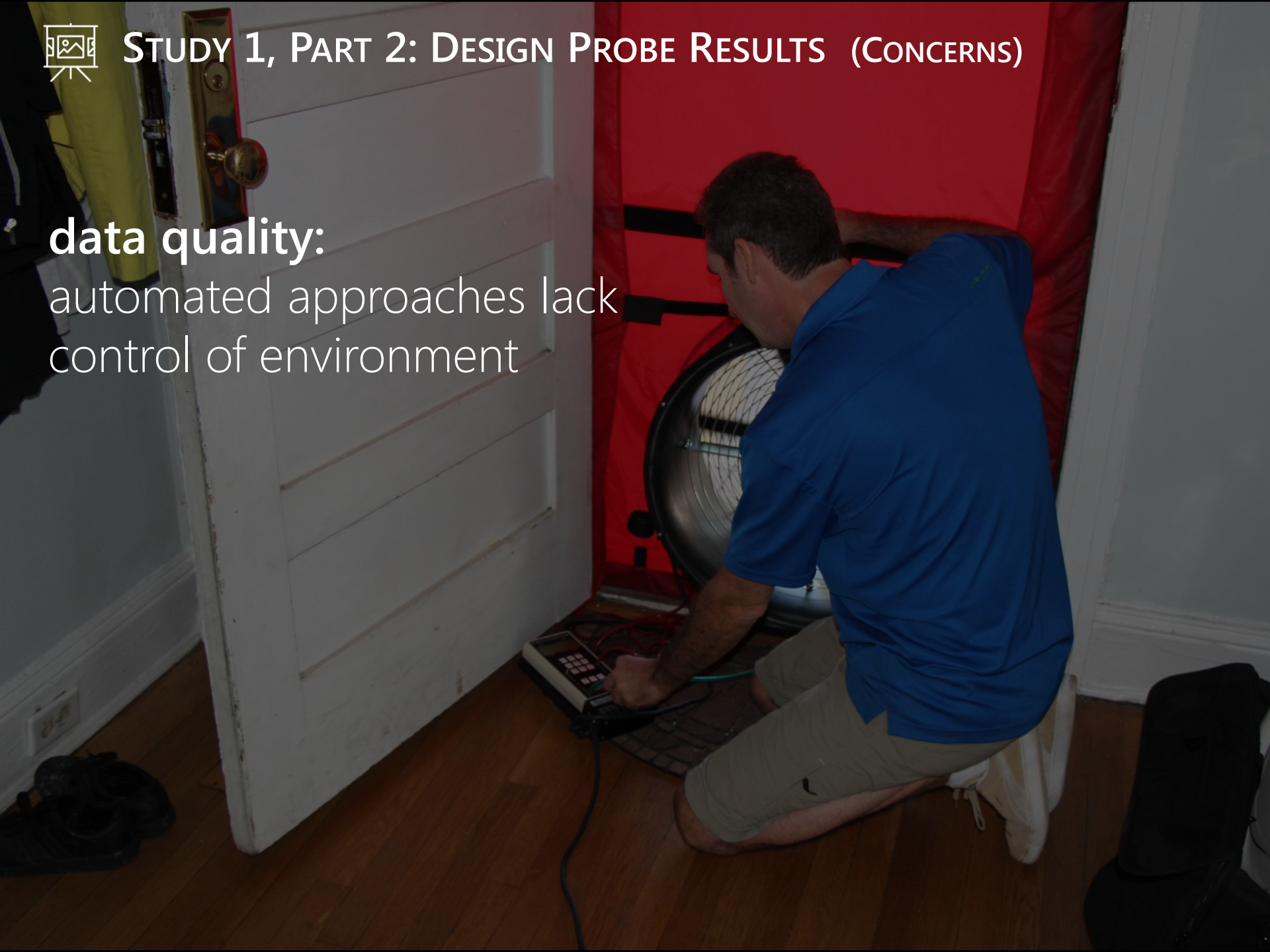
Concerns

Study 1, Part 2: Design Probes Results

Automation Benefits

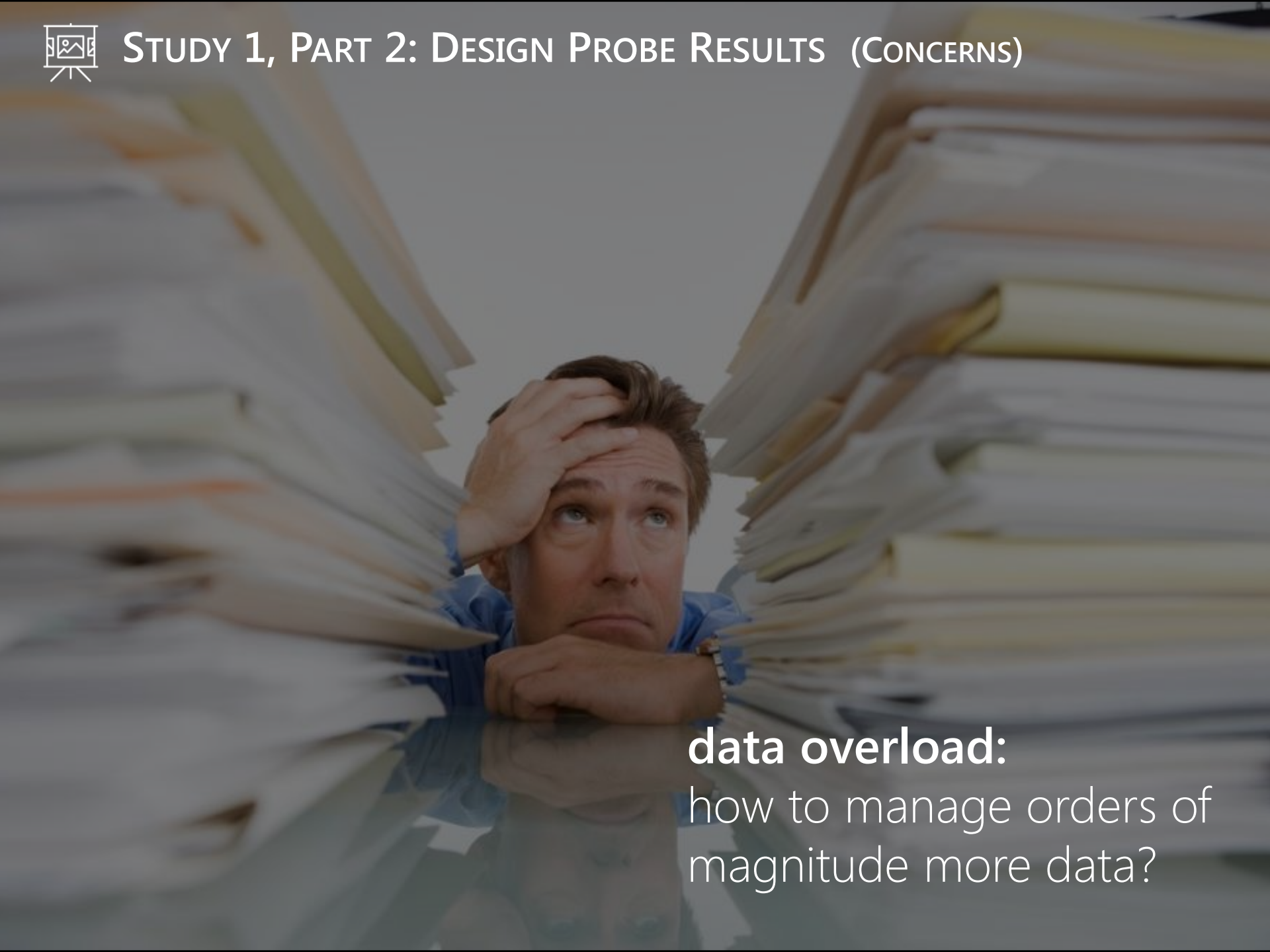
Concerns

Study 1, Part 2: Design Probe Results (Concerns)



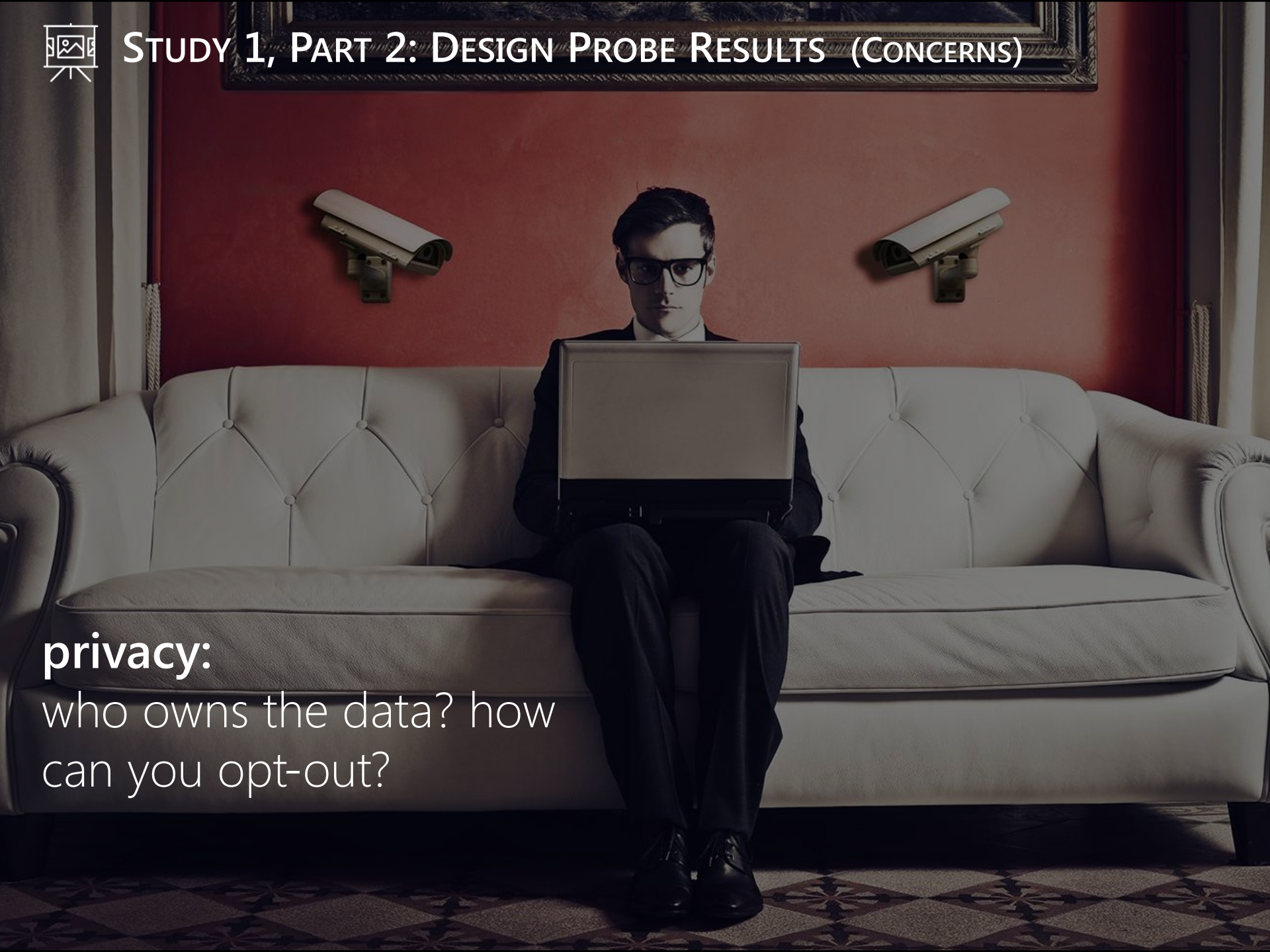
data quality:
automated approaches lack control of environment

Study 1, Part 2: Design Probe Results (Concerns)



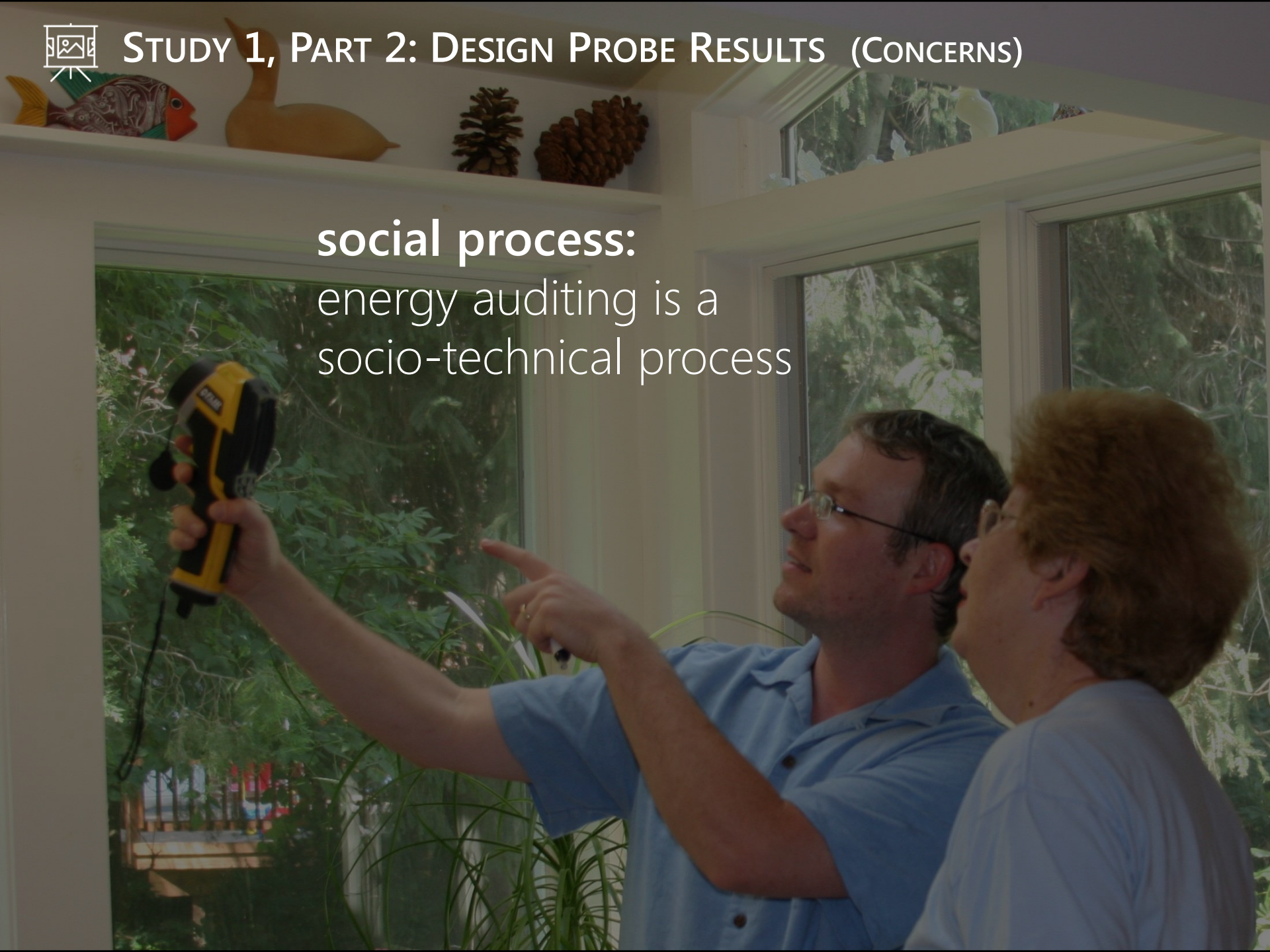
data overload:
how to manage orders of magnitude more data?

Study 1, Part 2: Design Probe Results (Concerns)



privacy:
who owns the data? how can you opt-out?

Study 1, Part 2: Design Probe Results (Concerns)



social process:
energy auditing is a
socio-technical process

Understanding the Role of Thermography in Energy Auditing

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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.

Analysis of Study 2

We analyzed pictures and field notes to extract themes in order to provide additional context for Study 1.

Observation

Residential Audit

Observation

Residential Audit

Observation Results

Audit Procedure

Client-Interaction

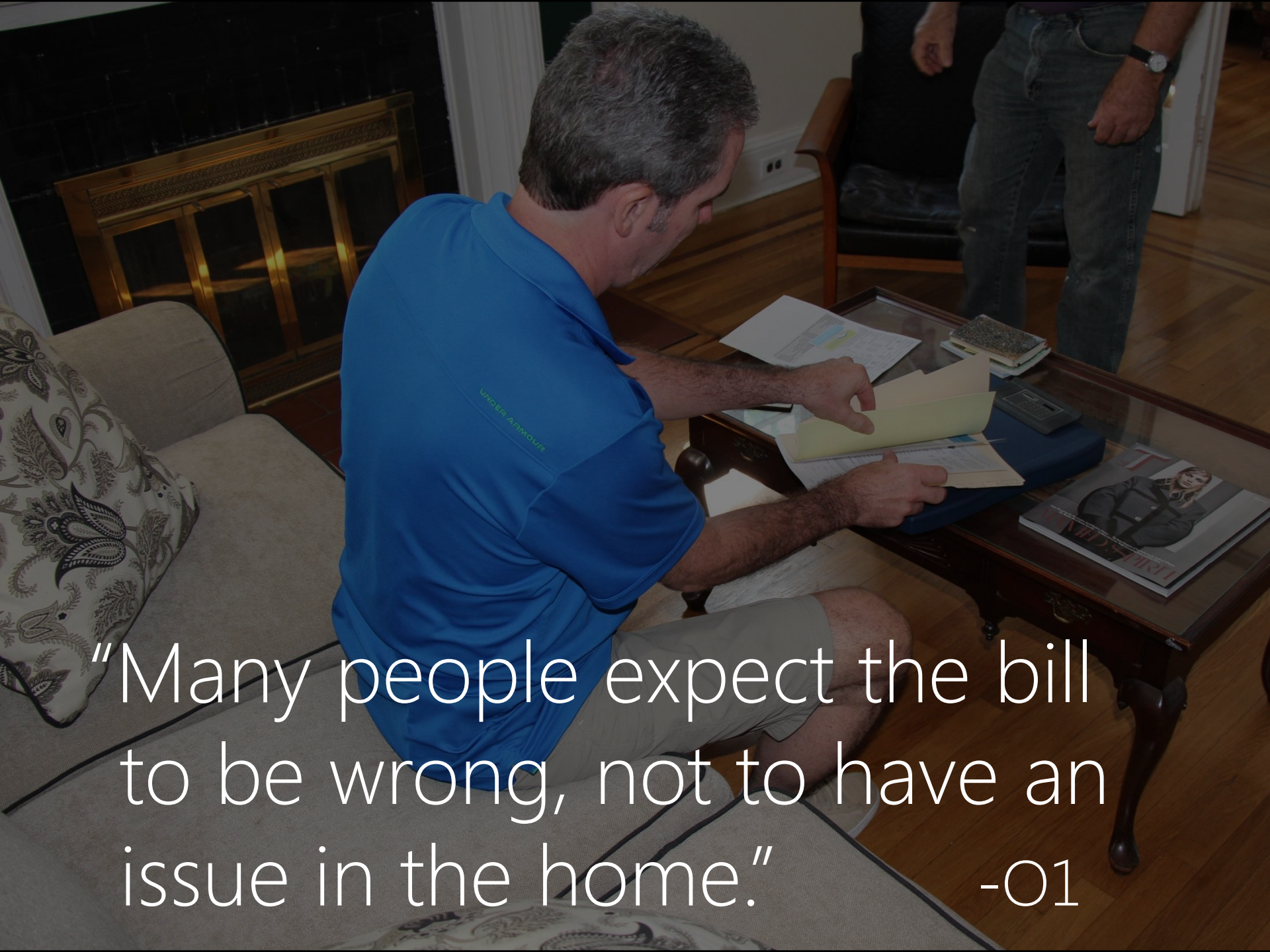
Primary Challenges

Observation Results

Audit Procedure

Client-Interaction

Primary Challenges



"Many people expect the bill to be wrong, not to have an issue in the home." -O1

Understanding the Role of Thermography in Energy Auditing

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Understanding the Role of Thermography in Energy Auditing

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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?

FULL SCREEN

A heat map of a home captured by one of Essess' thermal-imaging cars.

Courtesy of Essess

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.

RELATED

Essess

Sanja Sarma


Essess Car
http://www.essess.com

CLIENT LOGO

THERMAL ANALYSIS PROGRAM

Helping to make your home stronger.

0001

SAMPLE A. SAMPLE
123 ANY STREET
ANYTOWN, USA 12345-6789

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.

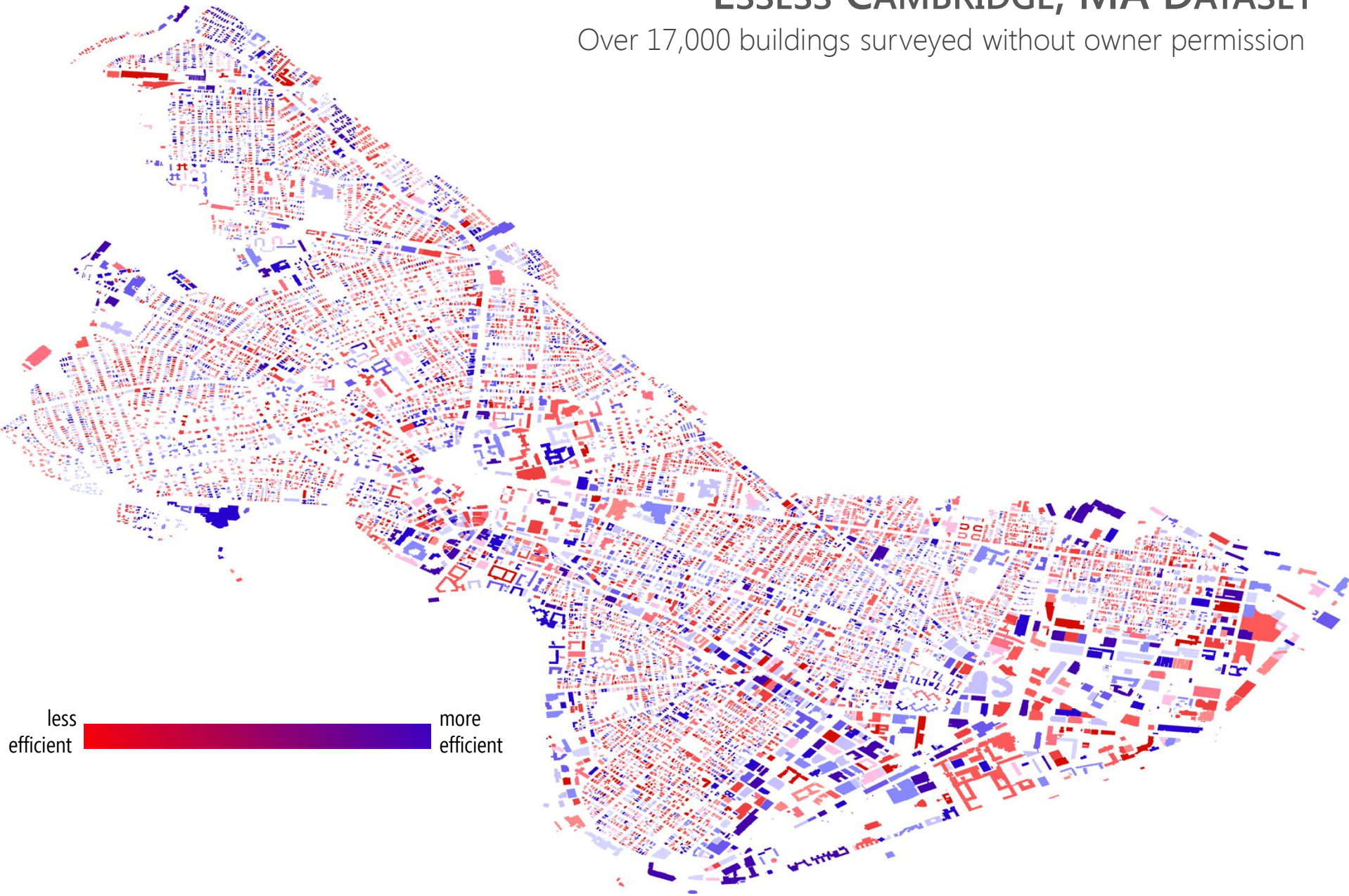
2. 
SEAL EDGES AROUND YOUR CHIMNEY. The area where the chimney meets the house can be a major source of leaks. Using caulk or insulated plates can be a relatively low-cost way to seal it up.

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

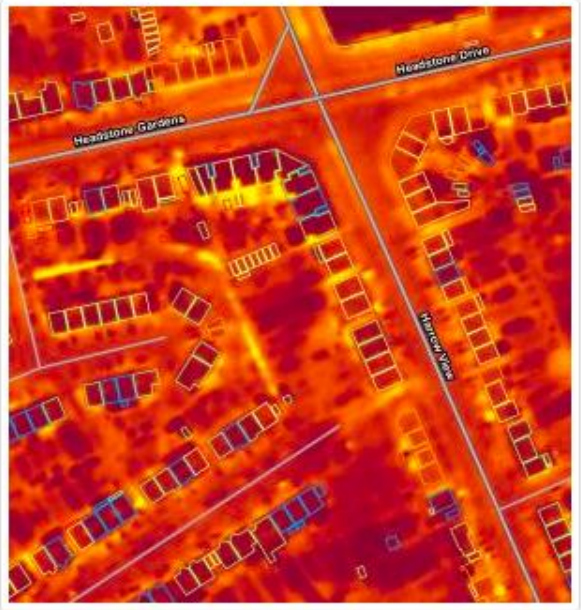
Over 17,000 buildings surveyed without owner permission



[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

Source: UAV Workswell Thermal Vision Pro, https://youtu.be/f3suOumbmrU

REFLECTION

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

Summary

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1. First human-centered study of thermographic automation.
2. Through semi-structured interviews and an observational case study, we assessed energy auditing practices and thermography's role therein.
3. Through five design probes, we critically examined emerging automated thermographic solutions and our findings have implications for the design of these tools

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