Thermporal: An Easy-to-Deploy Temporal Thermographic Sensor System to Support Residential Energy Audits

CHI 2019 | May 9th
Session on Sustainable HCI

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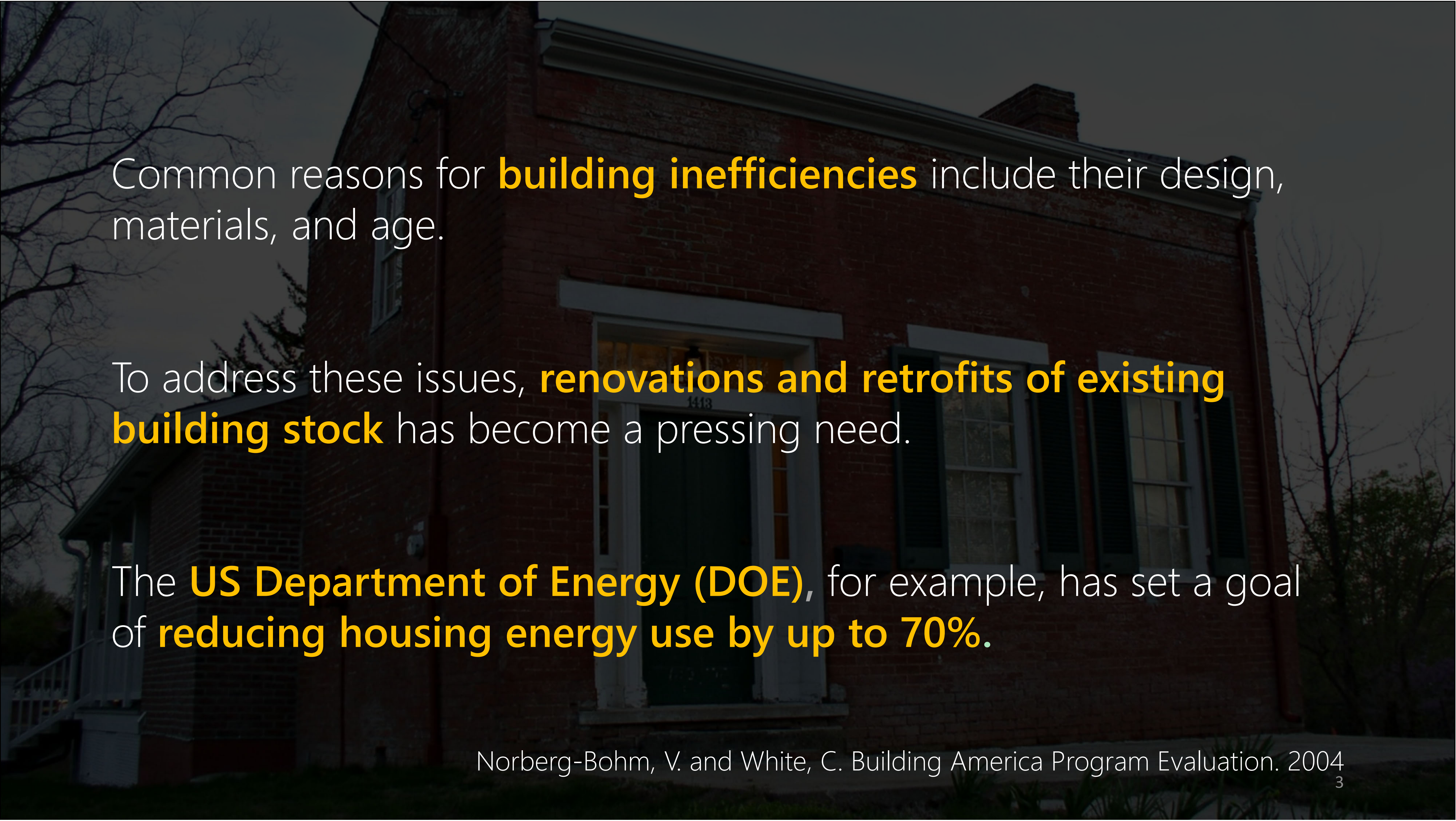
MAKEABILITY LAB
W PAUL G. ALLEN SCHOOL OF COMPUTER SCIENCE & ENGINEERING
HCIL Human Computer Interaction Laboratory
COMPUTER SCIENCE UNIVERSITY OF MARYLAND
UNIVERSITY OF MARYLAND


1413



Common reasons for **building inefficiencies** include their design, materials, and age.

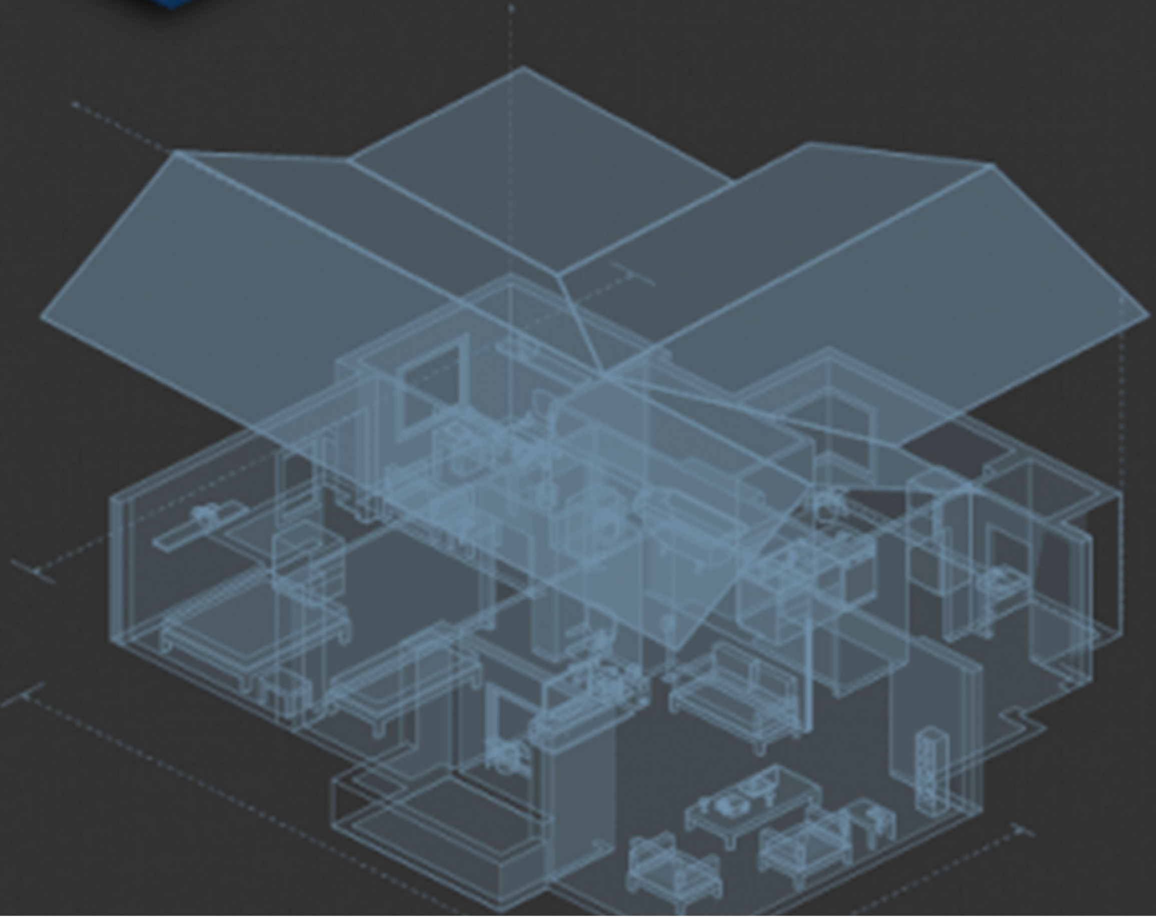
To address these issues, **renovations and retrofits of existing building stock** has become a pressing need.

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.

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Home » Thermographic Inspections

Thermographic Inspections

June 25, 2012 - 3:27pm

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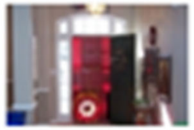
RELATED ARTICLES

Professional Home Energy Audits

Energy Audits



Home Energy Audits Can Help You Keep That New Year's Resolution

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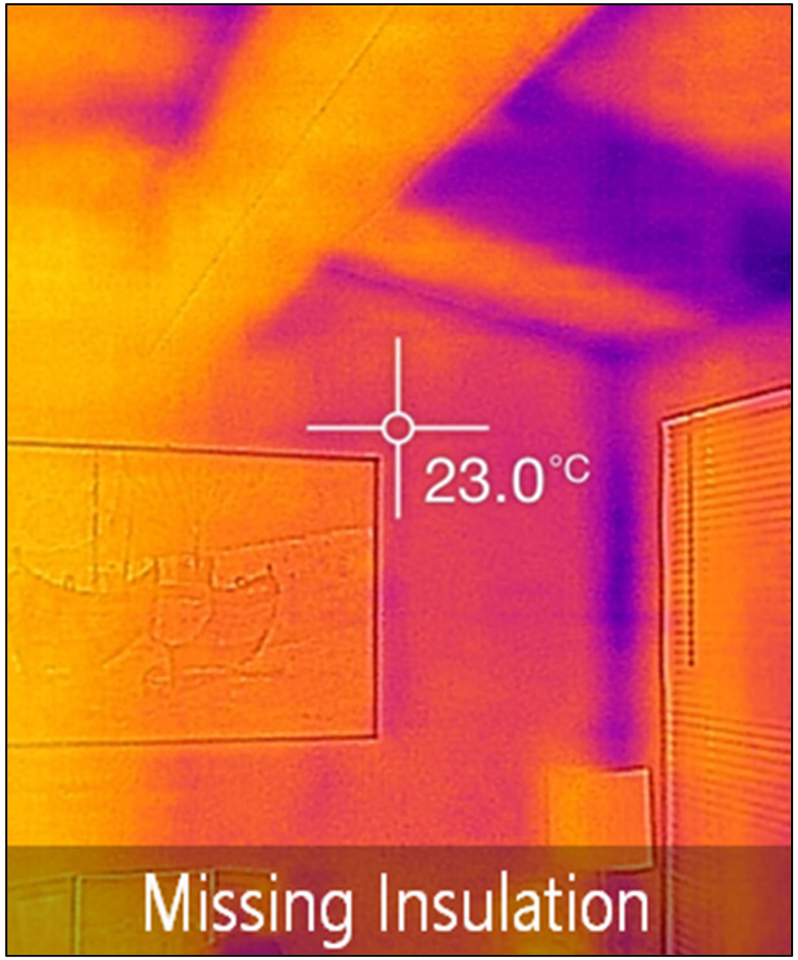
WHAT DOES THIS MEAN FOR ME?

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

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.

Common Thermographic Issues



THERMAL CAMERA FOR SMART PHONES

FLIR ONE Gen 3

MODEL: FLIR ONE GEN 3 - IOS

Go to Support Page »

There's an invisible world right next to the one you see every day, just waiting for you to explore it with the FLIR ONE. Whether you're seeing the world in a whole new way or just finding problems around the house, FLIR ONE's thermal camera gives you a new view of your everyday world. Discover what's been around you all the time, with FLIR ONE. The FLIR ONE app requires sign in, which enables automatic warranty registration and access to all the latest updates from FLIR.

PRODUCT VARIATIONS:

FLIR ONE Gen 3 - iOS

$199.99

BUY NOW

Thermal Imaging Camera Attachment

THE DIY'ERS BEST FRIEND

Find problems around the home fast, like where you're losing heat, how your insulation's holding up,

EXPLORE THE GREAT OUTDOORS

See in the dark and explore the natural world safely with the FLIR ONE. Watch animals in their

EXPAND YOUR WORLD

Detecting tiny variations in heat means that you can see in total darkness, create new kinds of art,

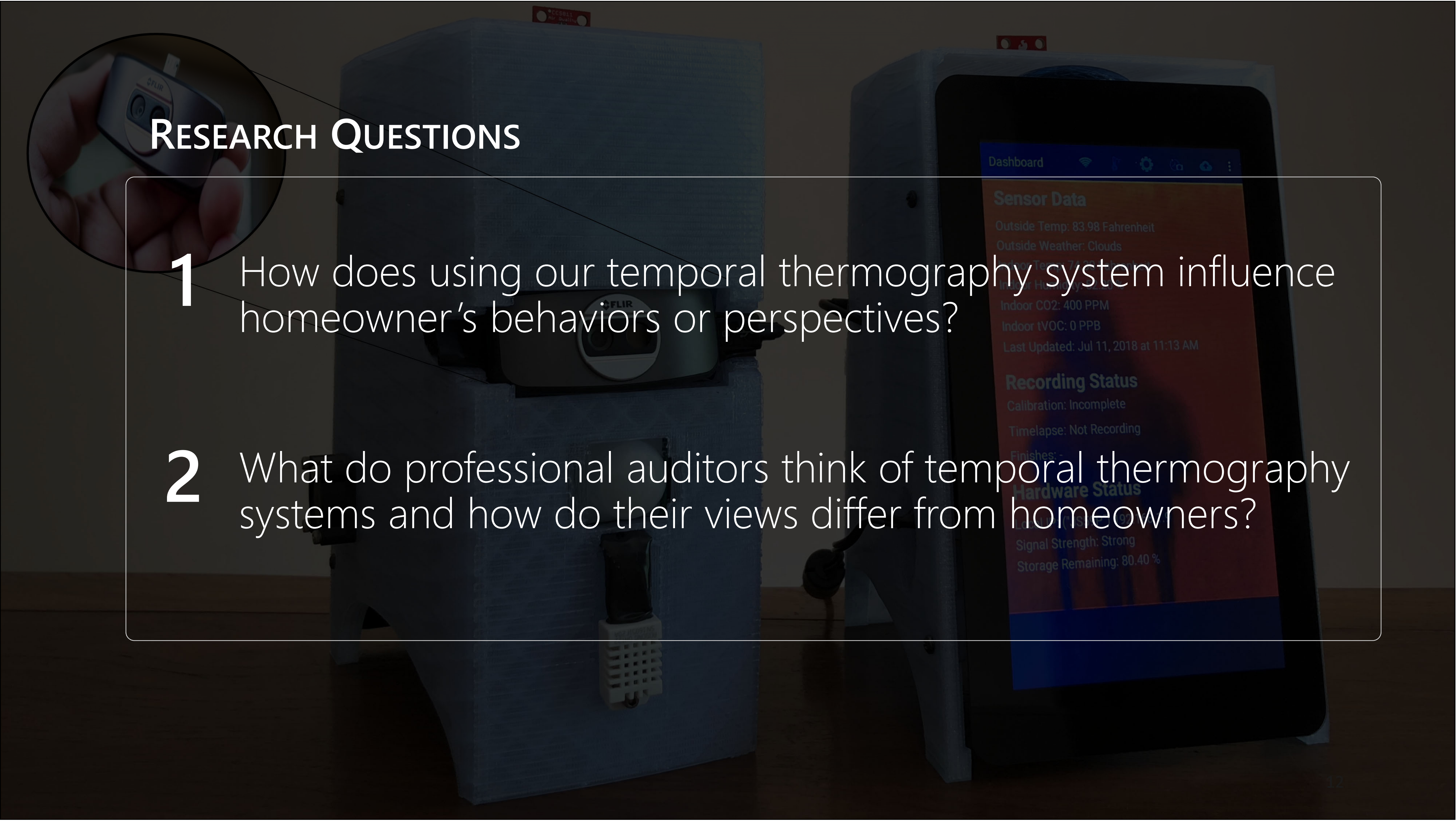
Energy audits and thermographic surveying are time and labor intensive

Recent Work at CHI

Mauriello *et al.* , 2015, 2017

- Energy auditors who use building thermography techniques experience varying degrees of certainty when interpreting thermograms.
- Energy auditors generally have limited time to conduct scans, collect data, and review their results.


FLIR
FLIR
Dashboard
Sensor Data
Outside Temp: 83.98 Fahrenheit
Outside Weather: Clouds
Indoor Temp: 74.30 Fahrenheit
Indoor Humidity: 52.20 %
Indoor CO2: 400 PPM
Indoor tVOC: 0 PPB
Last Updated: Jul 11, 2018 at 11:13 AM
Recording Status
Calibration: Incomplete
Timelapse: Not Recording
Finishes: -
Hardware Status
Local IP: ("JS59P") 192.168.1.9
Signal Strength: Strong
Storage Remaining: 80.40 %

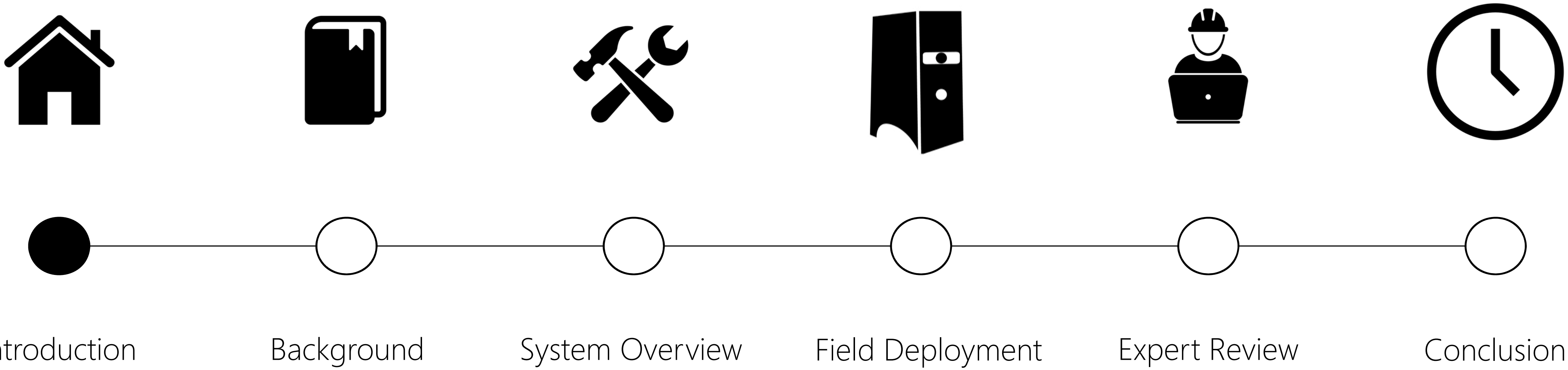


Research Questions

1. How does using our temporal thermography system influence homeowner's behaviors or perspectives?

2. What do professional auditors think of temporal thermography systems and how do their views differ from homeowners?

TALK OVERVIEW

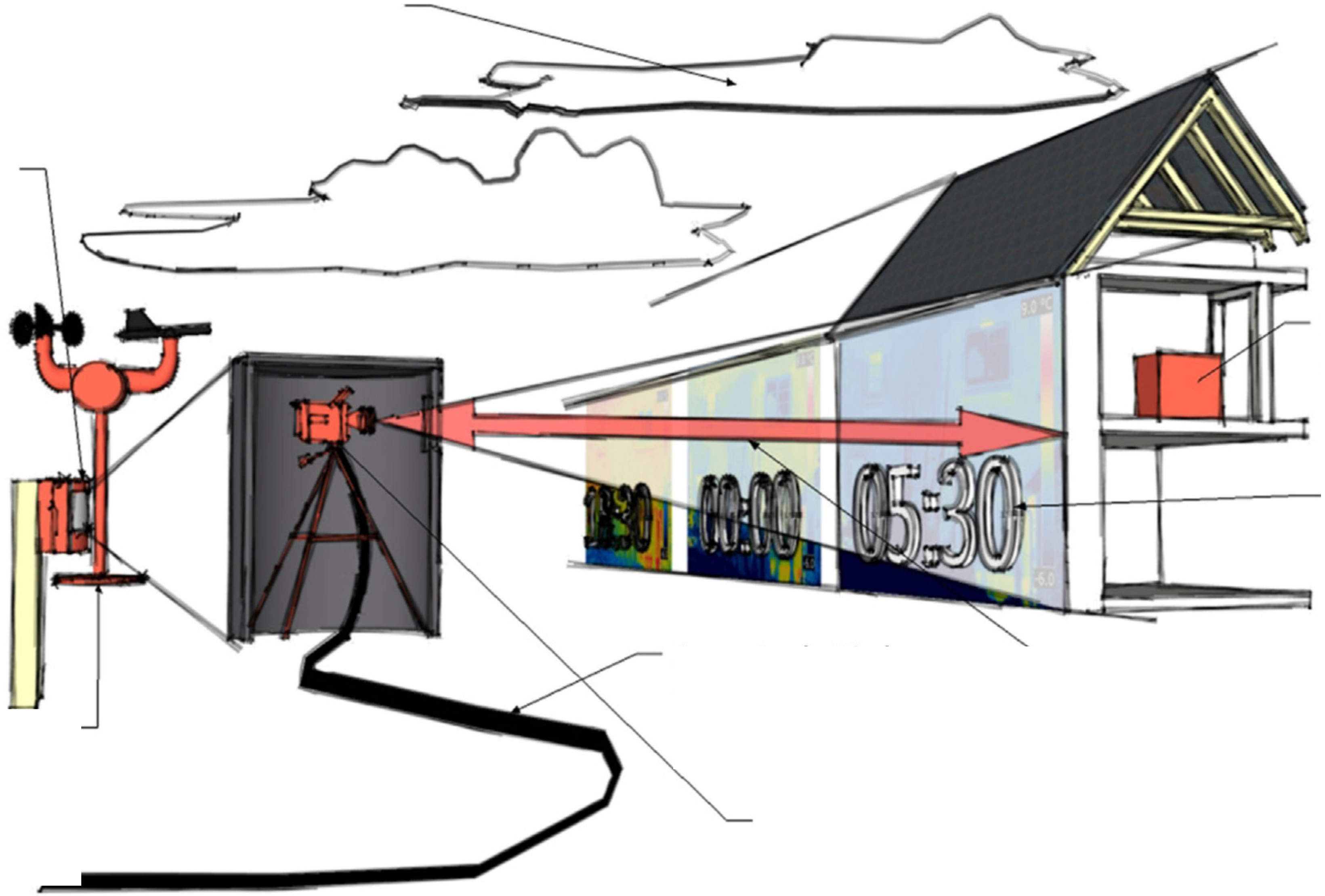


Talk Overview

Introduction | Background | System Overview | Field Deployment | Expert Review | Conclusion

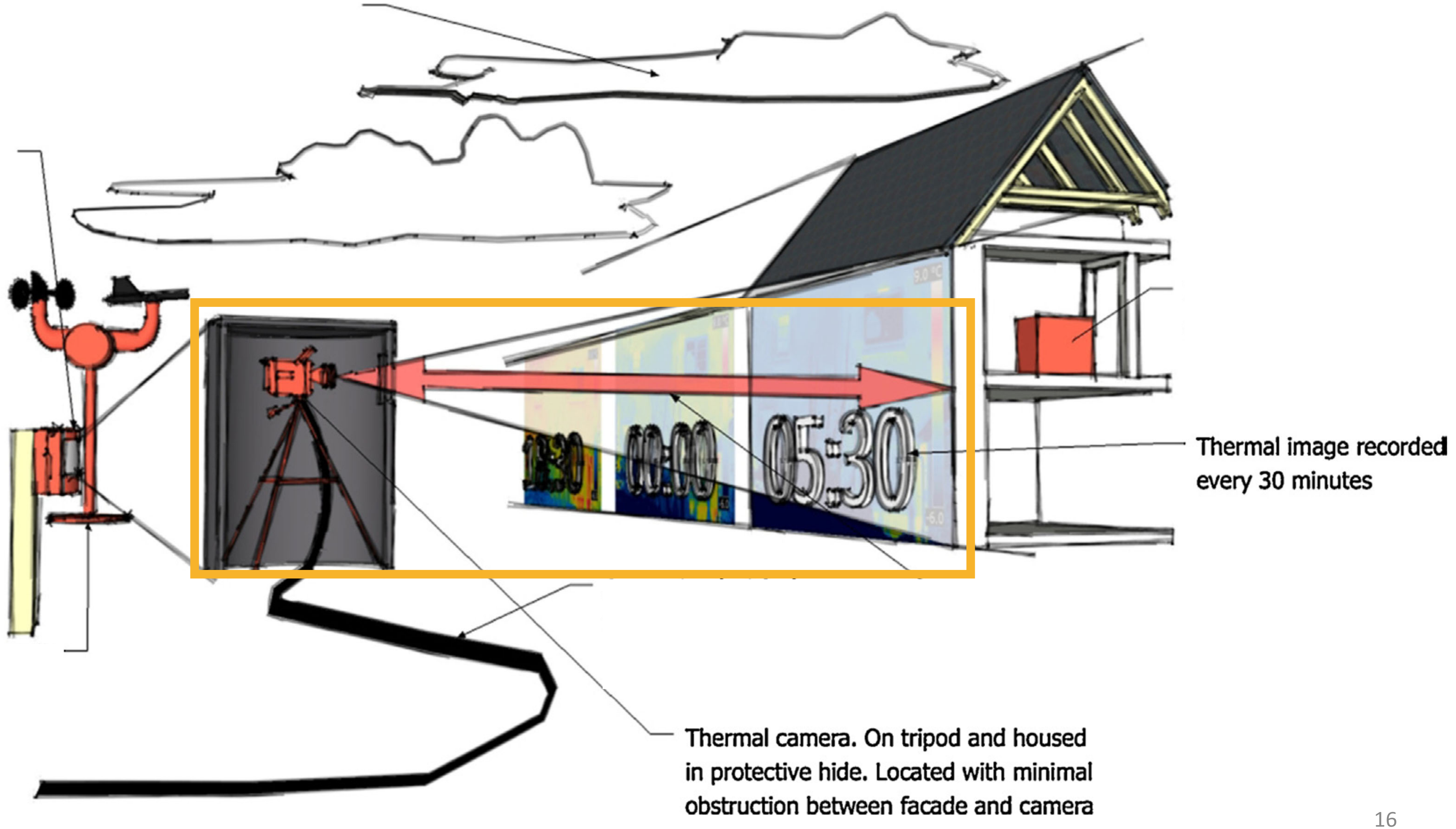
Related Work: Temporal Data Collection

Fox *et al.*, *Energy and Buildings '14*



RELATED WORK: TEMPORAL DATA COLLECTION

Fox *et al.*, *Energy and Buildings '14*



Related Work: Temporal Data Collection

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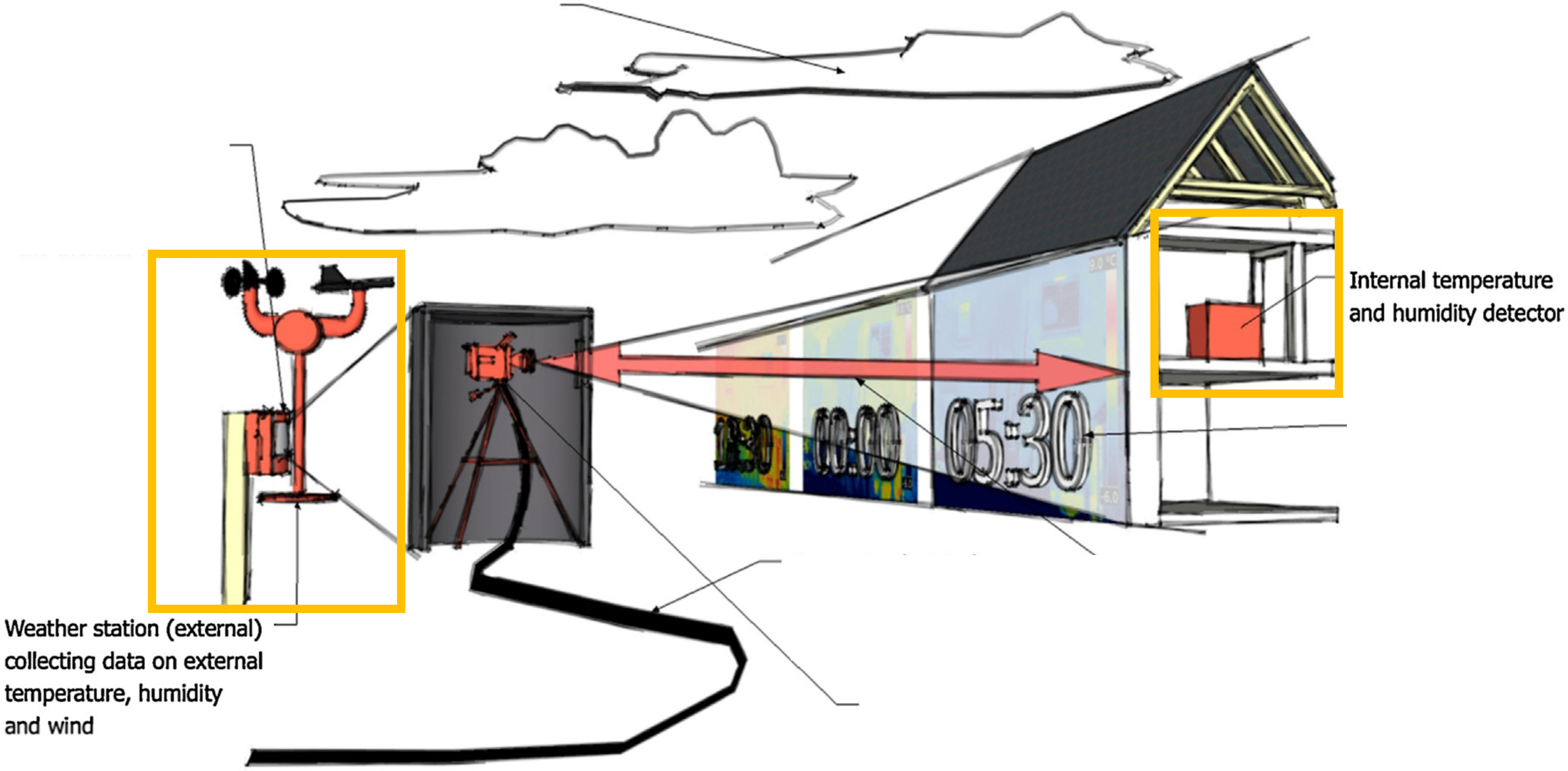
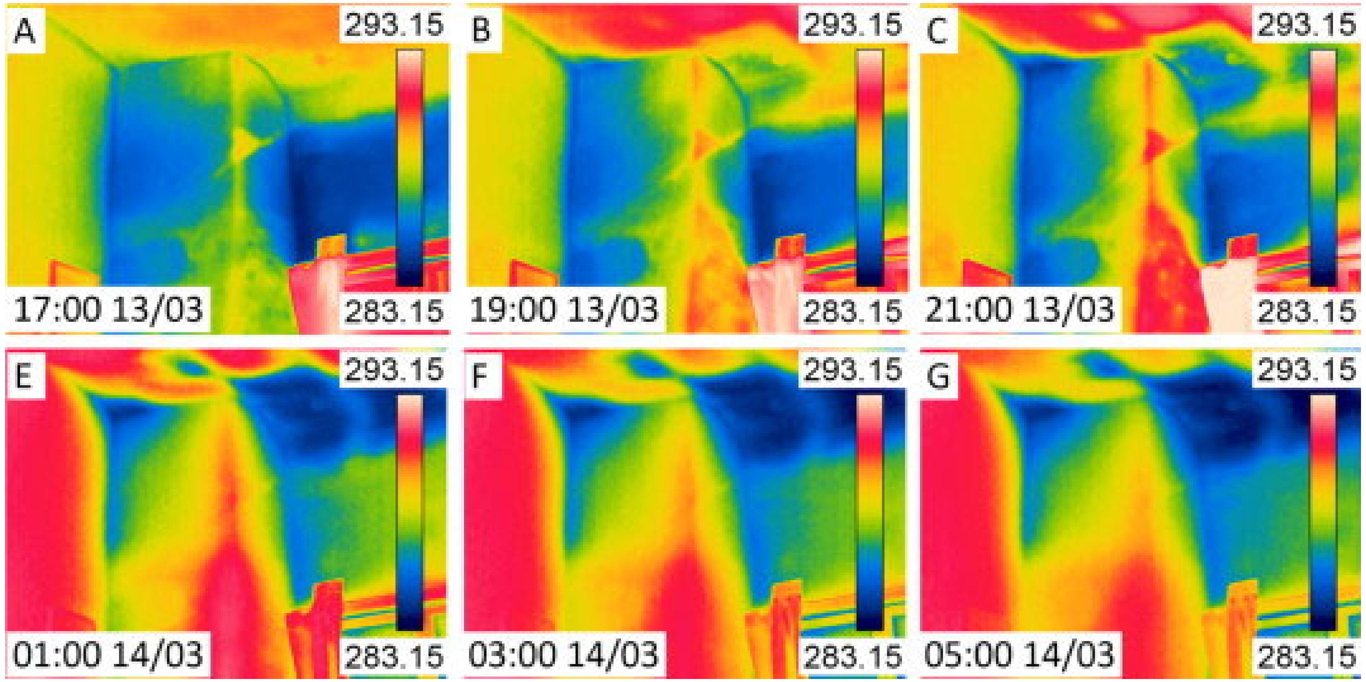


RELATED WORK: TEMPORAL VISUALIZATIONS



Energy and Buildings 92 (2015) 95–106

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Time-lapse thermography for building defect detection

Matthew Fox[a,*], David Coley[b], Steve Goodhew[a], Pieter De Wilde[a]

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Transient behaviour
Defect detection

ABSTRACT

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

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1. Introduction

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

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

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

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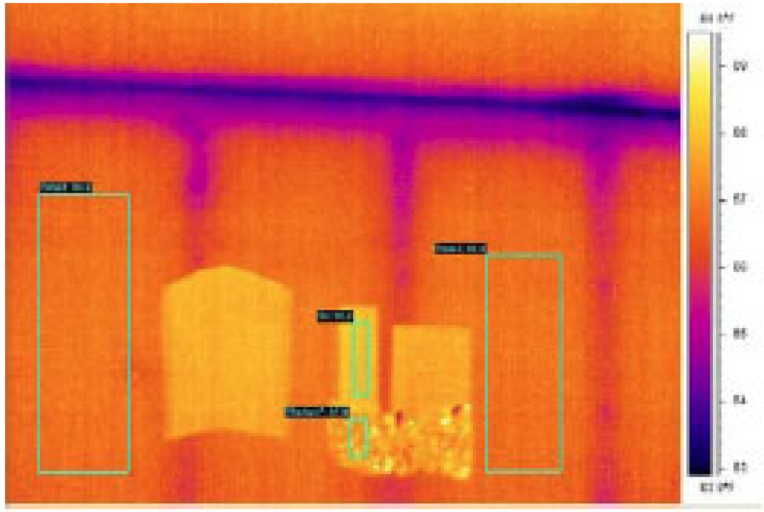
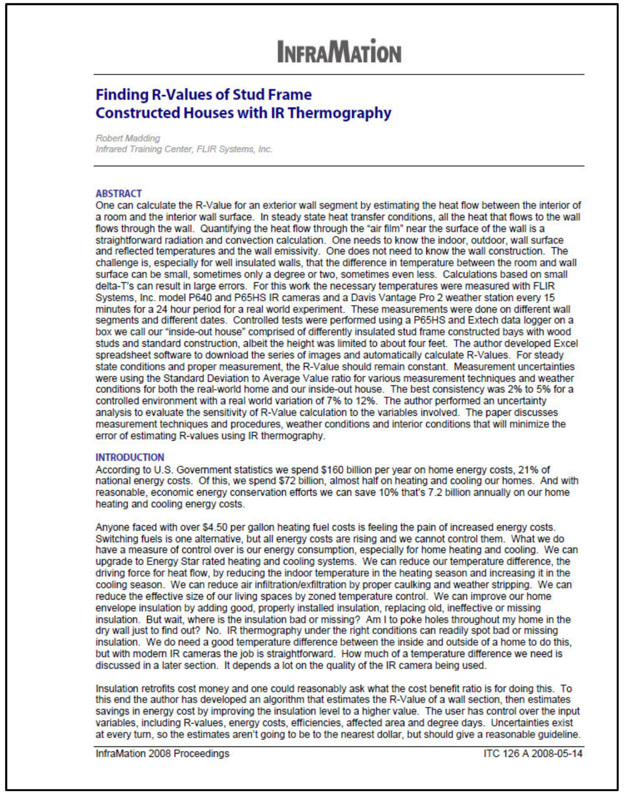
Fox *et al., Energy and Buildings '14*

Danese *et al., Archaeometry '08*

Related Work: Quantitative Thermography





INFRAMATION

Finding R-Values of Stud Frame Constructed Houses with IR Thermography

Robert Madding
Infrared Training Center, FLIR Systems, Inc.

ABSTRACT
One can calculate the R-Value for an exterior wall segment by estimating the heat flow between the interior of a room and the interior wall surface. In steady state heat transfer conditions, all the heat that flows to the wall flows through the wall. Quantifying the heat flow through the "air film" near the surface of the wall is a straightforward radiation and convection calculation. One needs to know the indoor, outdoor, wall surface and reflected temperatures and the wall emissivity. One does not need to know the wall construction. The challenge is, especially for well insulated walls, that the difference in temperature between the room and wall surface can be small, sometimes only a degree or two, sometimes even less. Calculations based on small delta-T's can result in large errors. For this work the necessary temperatures were measured with FLIR Systems, Inc. model P640 and P65HS IR cameras and a Davis Vantage Pro 2 weather station every 15 minutes for a 24 hour period for a real world experiment. These measurements were done on different wall segments and different dates. Controlled tests were performed using a P65HS and Extech data logger on a box we call our "inside-out house" comprised of differently insulated stud frame constructed bays with wood studs and standard construction, albeit the height was limited to about four feet. The author developed Excel spreadsheet software to download the series of images and automatically calculate R-Values. For steady state conditions and proper measurement, the R-Value should remain constant. Measurement uncertainties were using the Standard Deviation to Average Value ratio for various measurement techniques and weather conditions for both the real-world home and our inside-out house. The best consistency was 2% to 5% for a controlled environment with a real world variation of 7% to 12%. The author performed an uncertainty analysis to evaluate the sensitivity of R-Value calculation to the variables involved. The paper discusses measurement techniques and procedures, weather conditions and interior conditions that will minimize the error of estimating R-values using IR thermography.

INTRODUCTION
According to U.S. Government statistics we spend $160 billion per year on home energy costs, 21% of national energy costs. Of this, we spend $72 billion, almost half on heating and cooling our homes. And with reasonable, economic energy conservation efforts we can save 10% that's 7.2 billion annually on our home heating and cooling energy costs.

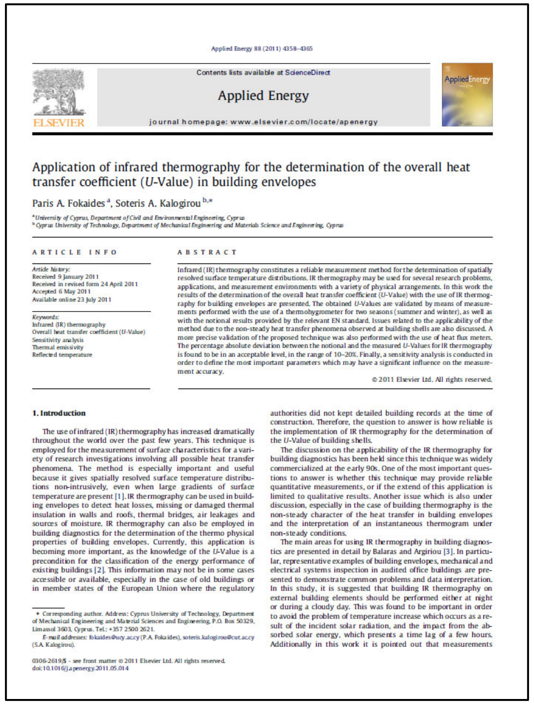
Anyone faced with over $4.50 per gallon heating fuel costs is feeling the pain of increased energy costs. Switching fuels is one alternative, but all energy costs are rising and we cannot control them. What we do have a measure of control over is our energy consumption, especially for home heating and cooling. We can upgrade to Energy Star rated heating and cooling systems. We can reduce our temperature difference, the driving force for heat flow, by reducing the indoor temperature in the heating season and increasing it in the cooling season. We can reduce air infiltration/exfiltration by proper caulking and weather stripping. We can reduce the effective size of our living spaces by zoned temperature control. We can improve our home envelope insulation by adding good, properly installed insulation, replacing old, ineffective or missing insulation. But wait, where is the insulation bad or missing? Am I to poke holes throughout my home in the dry wall just to find out? No. IR thermography under the right conditions can readily spot bad or missing insulation. We do need a good temperature difference between the inside and outside of a home to do this, but with modern IR cameras the job is straightforward. How much of a temperature difference we need is discussed in a later section. It depends a lot on the quality of the IR camera being used.

Insulation retrofits cost money and one could reasonably ask what the cost benefit ratio is for doing this. To this end the author has developed an algorithm that estimates the R-Value of a wall section, then estimates savings in energy cost by improving the insulation level to a higher value. The user has control over the input variables, including R-values, energy costs, efficiencies, affected area and degree days. Uncertainties exist at every turn, so the estimates aren't going to be to the nearest dollar, but should give a reasonable guideline.

$$R-Value = \frac{\Delta T_{io}}{4\varepsilon\sigma T_m^{\ 3}\Delta T_r + h_c \Delta T_a}$$

Madding, 2008

RELATED WORK: QUANTITATIVE TEMPORAL THERMOGRAPHY


Applied Energy 88 (2011) 4358–4365

Contents lists available at ScienceDirect

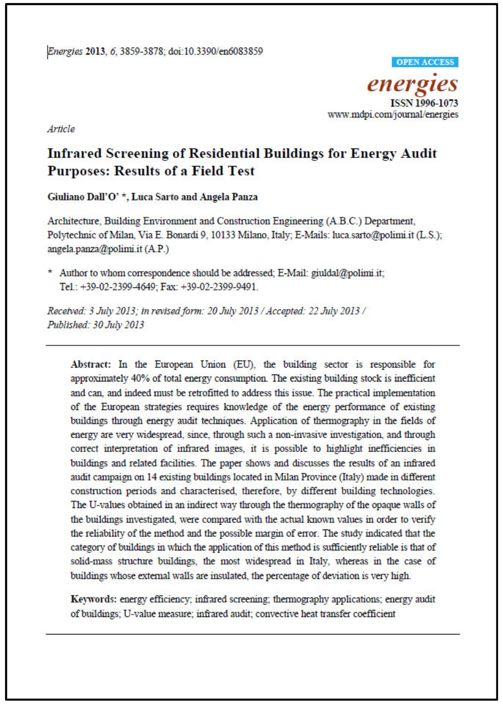
Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Application of infrared thermography for the determination of the overall heat transfer coefficient (U-Value) in building envelopes

Paris A. Fokaides, Soteris A. Kalogirou

Fokaides & Kalogirou, 2011


Energies 2013, 6, 3859-3878; doi:10.3390/en6083859

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energies

ISSN 1996-1073

www.mdpi.com/journal/energies

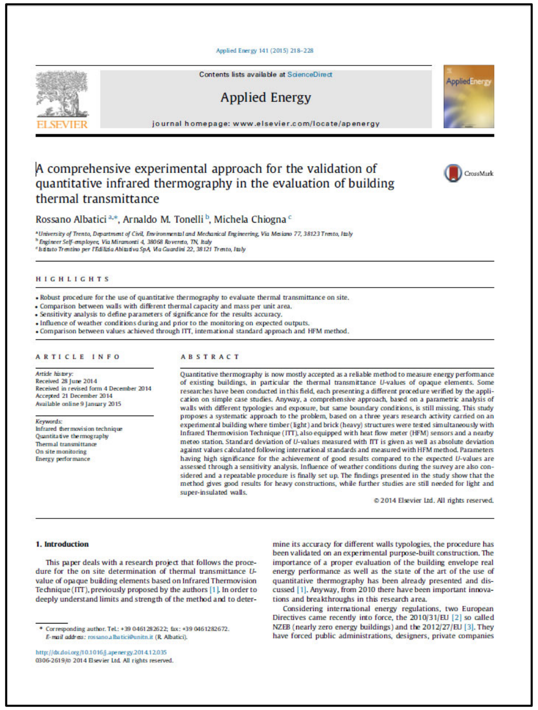
Article

Infrared Screening of Residential Buildings for Energy Audit Purposes: Results of a Field Test

Giuliano Dall'O' *, Luca Sarto and Angela Panza

Received: 3 July 2013; in revised form: 20 July 2013 / Accepted: 22 July 2013 / Published: 30 July 2013

Dall'O *et al.*, 2013


Applied Energy 141 (2015) 218–228

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

A comprehensive experimental approach for the validation of quantitative infrared thermography in the evaluation of building thermal transmittance

Rossano Albatici, Arnaldo M. Tonelli, Michela Chiogna

Albatici *et al.*, 2015


Energy and Buildings 122 (2016) 211–221

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

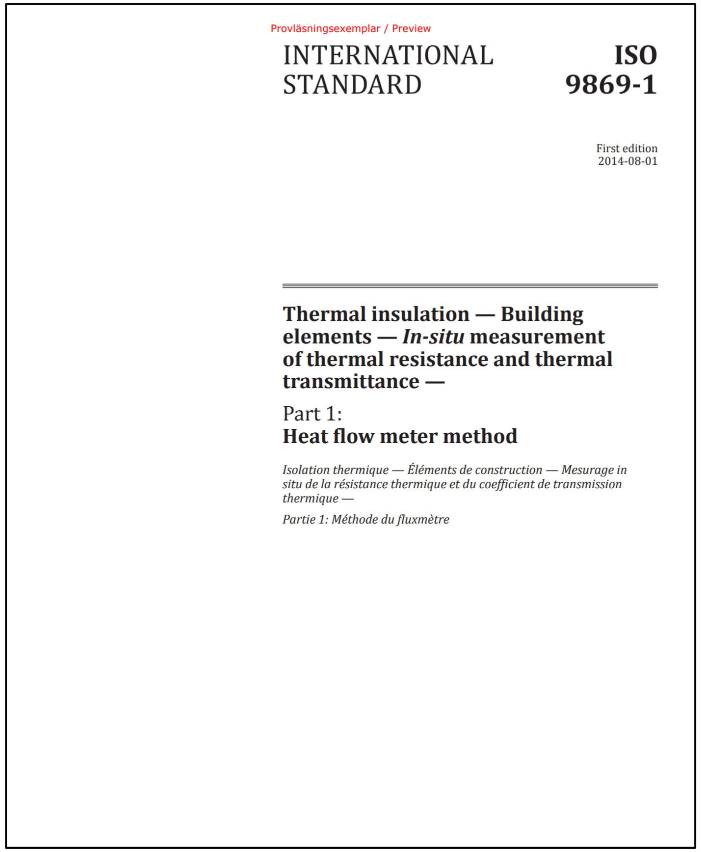
U-value assessment by infrared thermography: A comparison of different calculation methods in a Guarded Hot Box

Iole Nardi, Domenica Paoletti, Dario Ambrosini, Tullio de Rubeis, Stefano Sfarra

Nardi *et al.*, 2016

Related Work: Quantitative Measurement

Direct Contact Methods:
Heat Flux Sensors and Thermocouples



Provläsningsexemplar / Preview

INTERNATIONAL STANDARD

ISO 9869-1

First edition
2014-08-01

Thermal insulation — Building elements — *In-situ* measurement of thermal resistance and thermal transmittance —

Part 1:
Heat flow meter method

Isolation thermique — Éléments de construction — Mesurage in situ de la résistance thermique et du coefficient de transmission thermique —

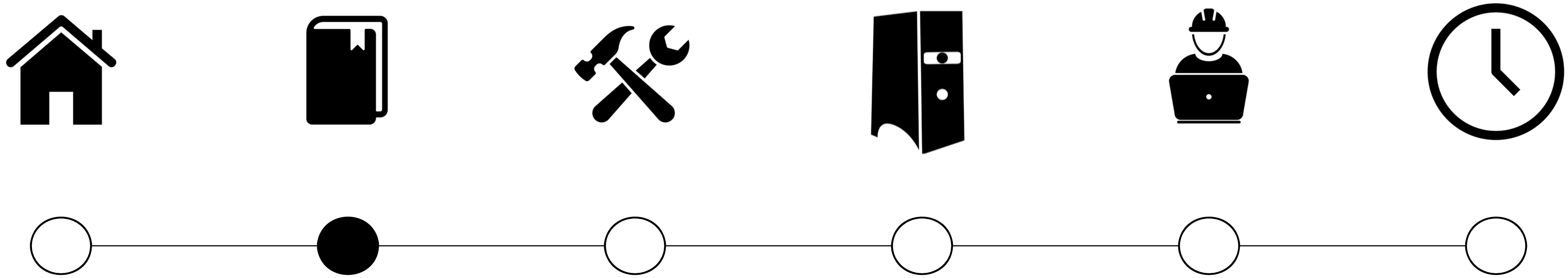
Partie 1: Méthode du fluxmètre

Research Contributions

Future work called for within these assessments includes real-world deployments with professional users

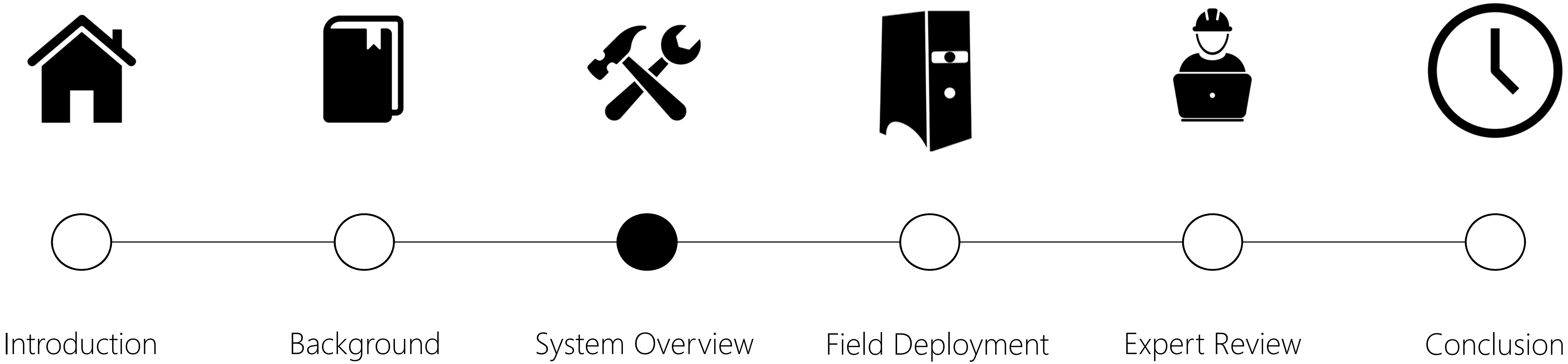
This work contributes the design of such a system, and evaluations with both professional and non-professionals

Talk Overview



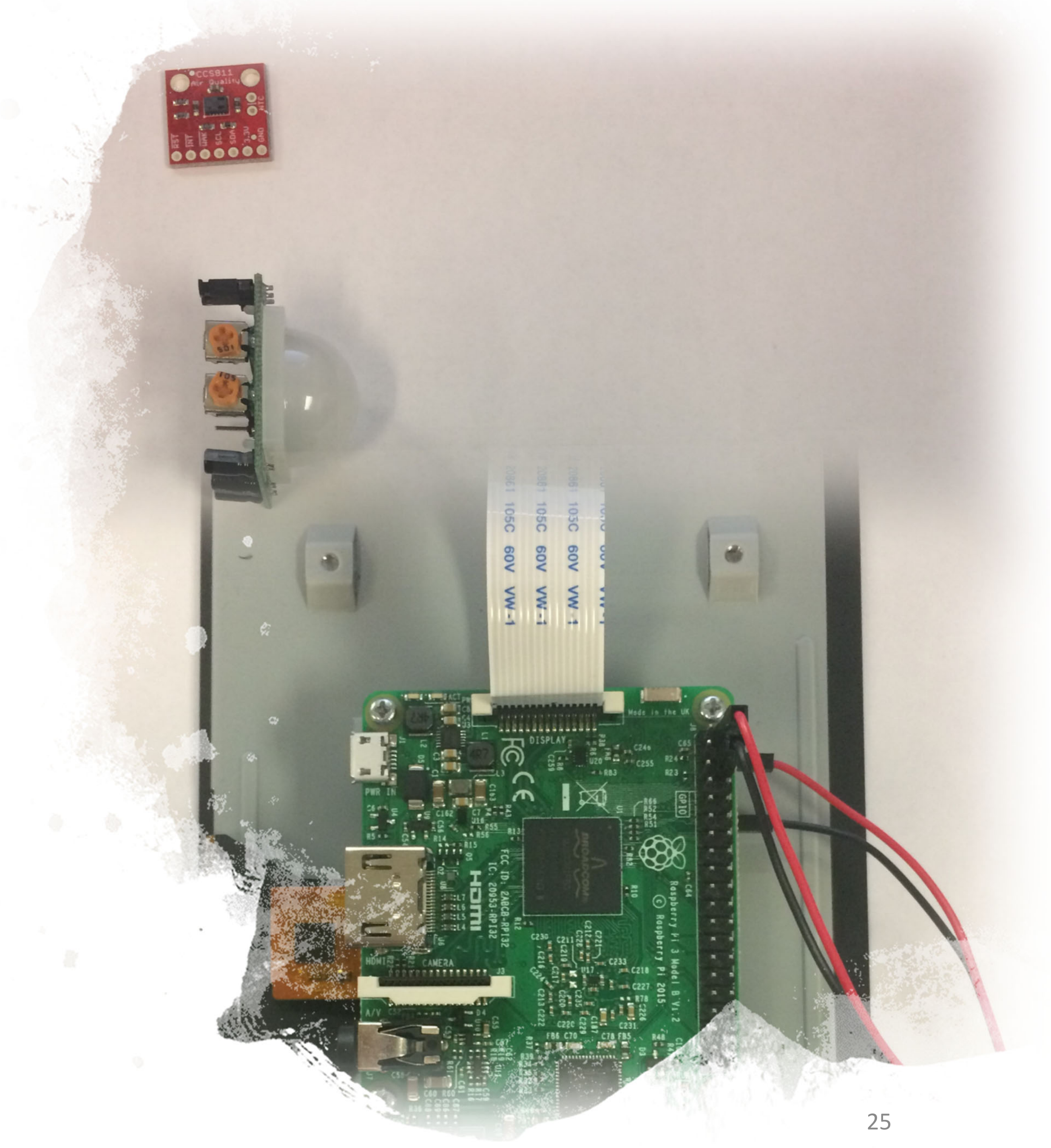
Introduction | Background | System Overview | Field Deployment | Expert Review | Conclusion

TALK OVERVIEW

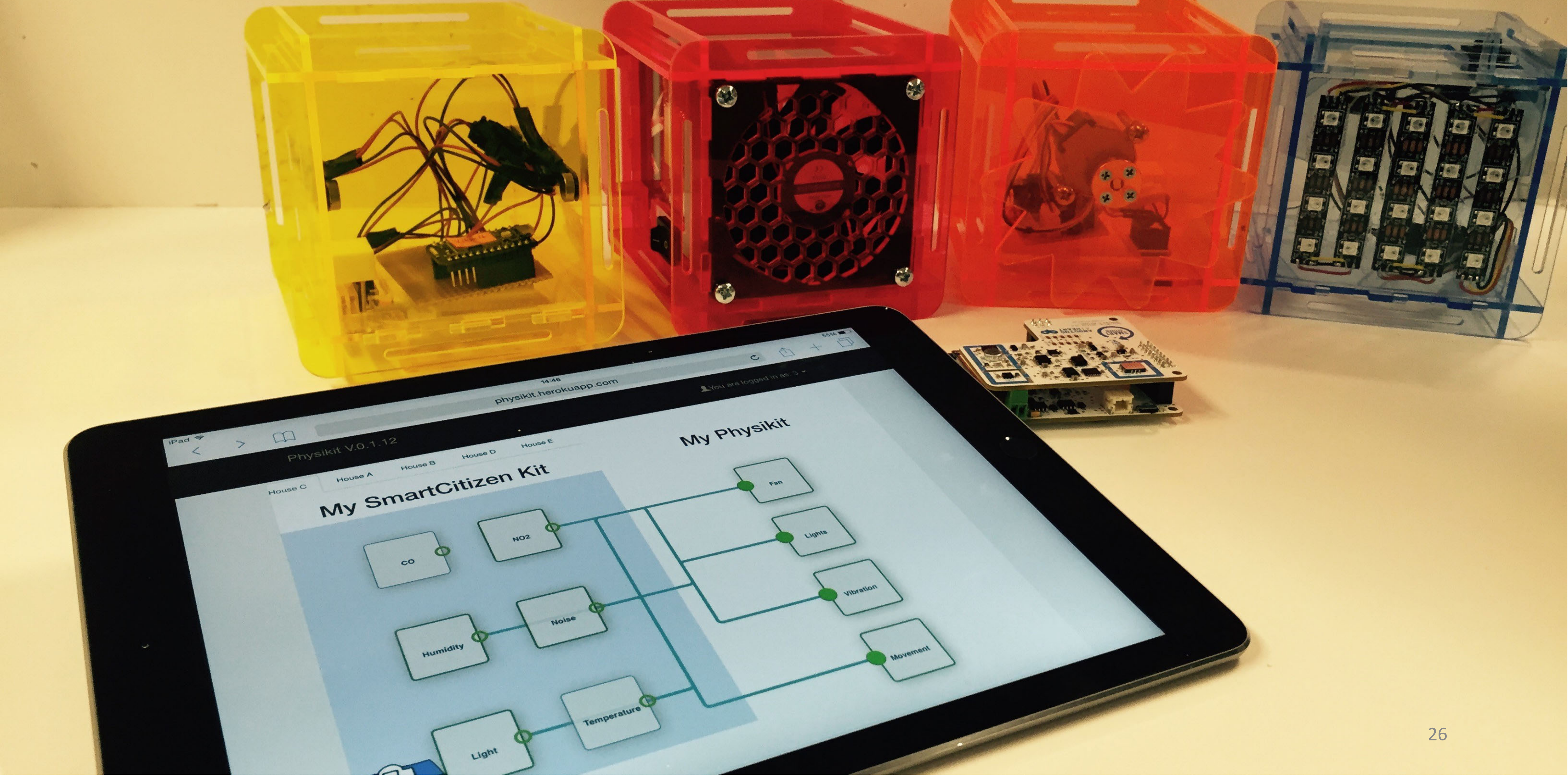


DEVELOPMENT: DESIGN GOALS

- Easy-to-Deploy
- Non-intrusive
- Provide Rapid Analysis
- Help with Severity Estimation
- Holistic Report



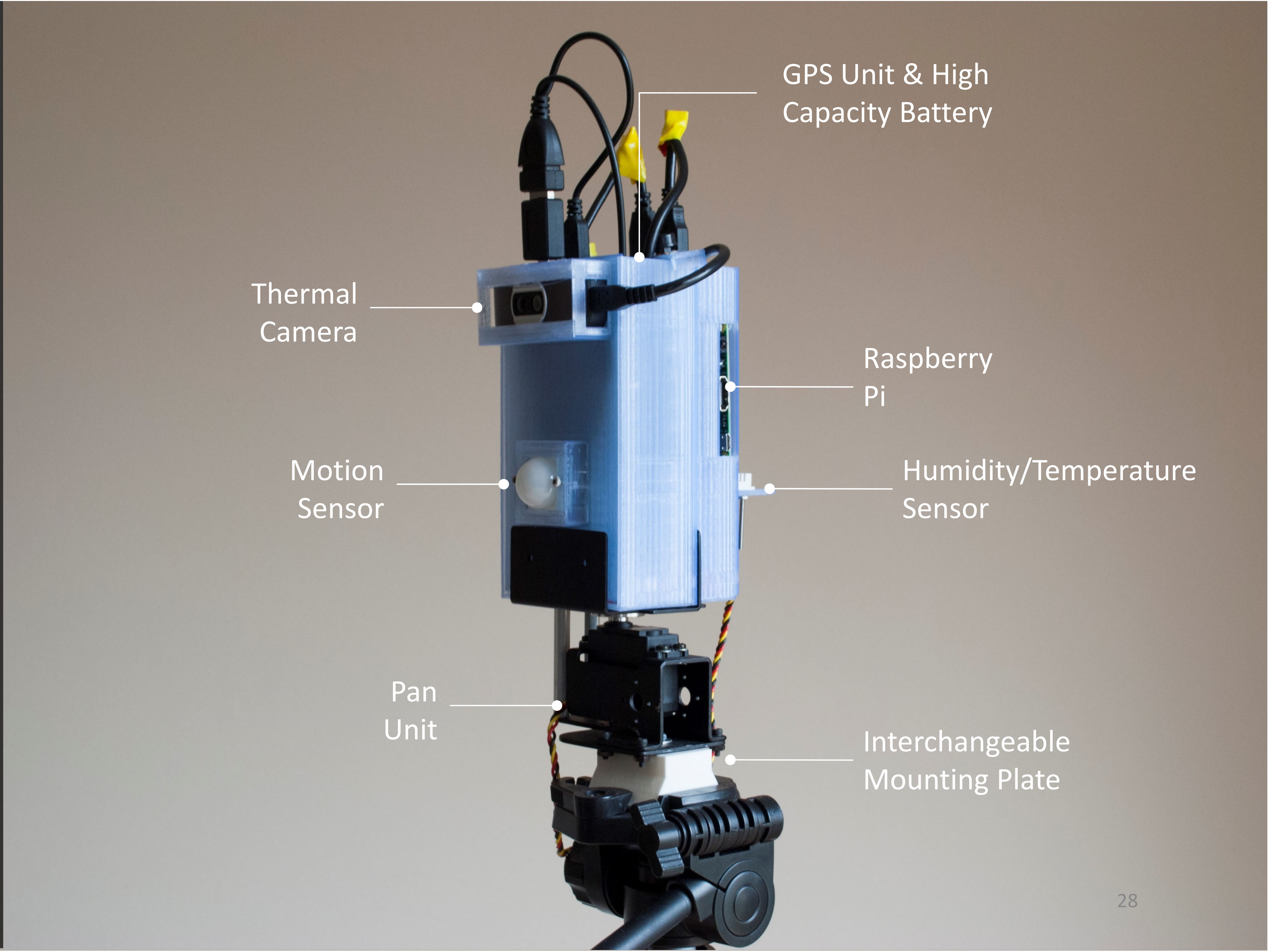
PHYSIKIT
HOUBEN *ET AL.*, 2016

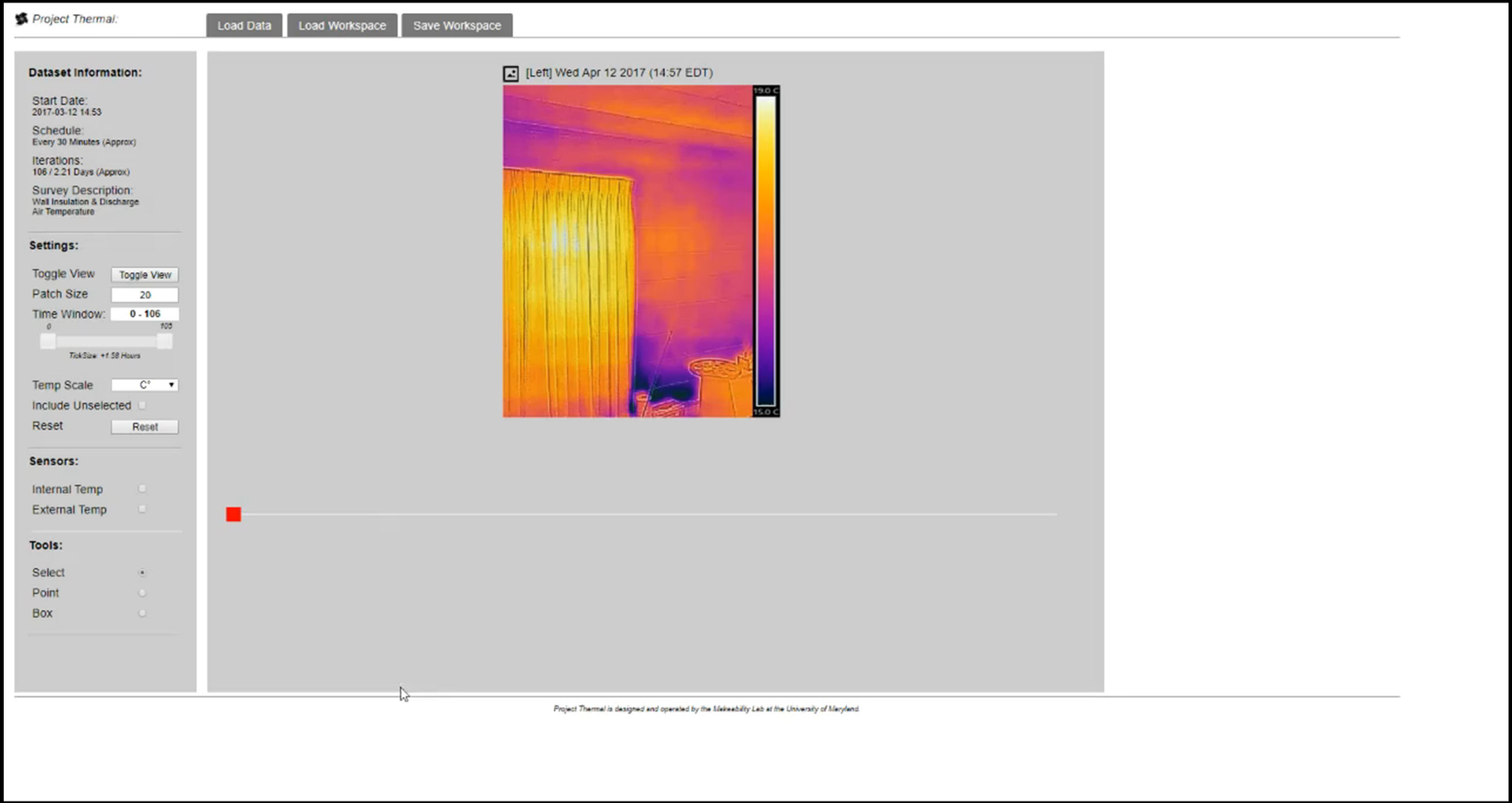


PHYSIKIT
HOUBEN *ET AL.*, 2016

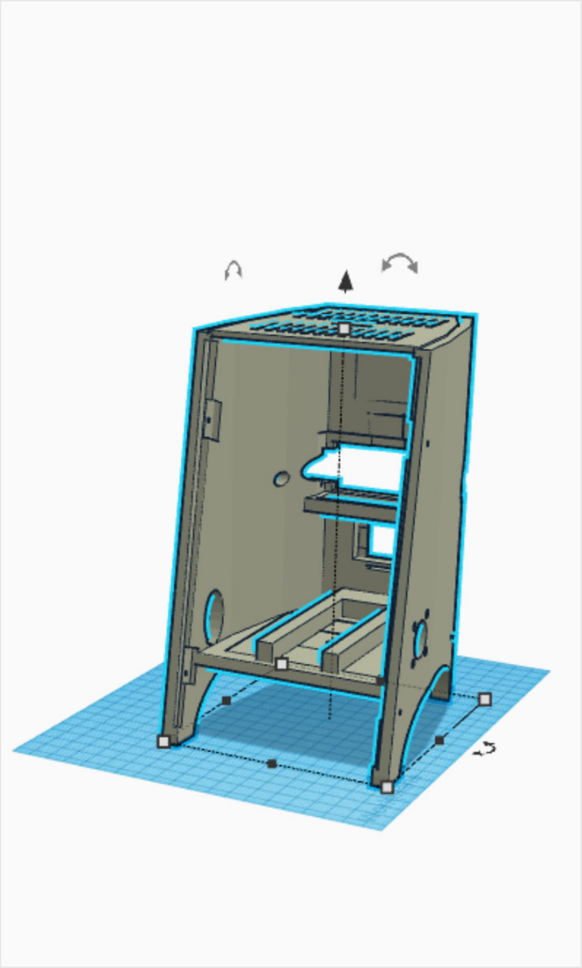
BuildAX Environmental Sensor Toolkit
Finnigan *et al.* 2017

Easy-to-Deploy Thermographic Sensor System
(v3.0)

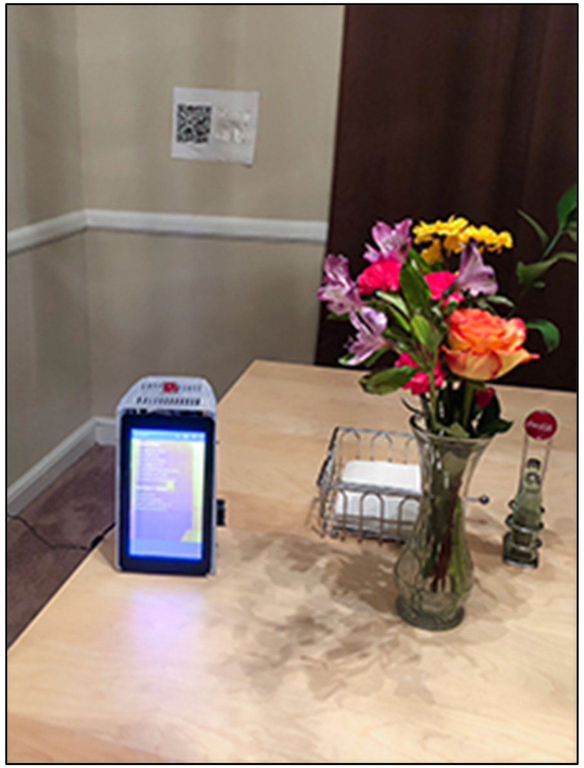



Project Thermal:
Load Data
Load Workspace
Save Workspace
Dataset Information:
Start Date:
2017-03-12 14:53
Schedule:
Every 30 Minutes (Approx)
Iterations:
106 / 2.21 Days (Approx)
Survey Description:
Wall Insulation & Discharge Air Temperature
Settings:
Toggle View
Toggle View
Patch Size
20
Time Window:
0 - 106
Temp Scale
C°
Include Unselected
Reset
Reset
Sensors:
Internal Temp
External Temp
Tools:
Select
Point
Box
[Left] Wed Apr 12 2017 (14:57 EDT)
Project Thermal is designed and operated by the Makeability Lab at the University of Maryland.

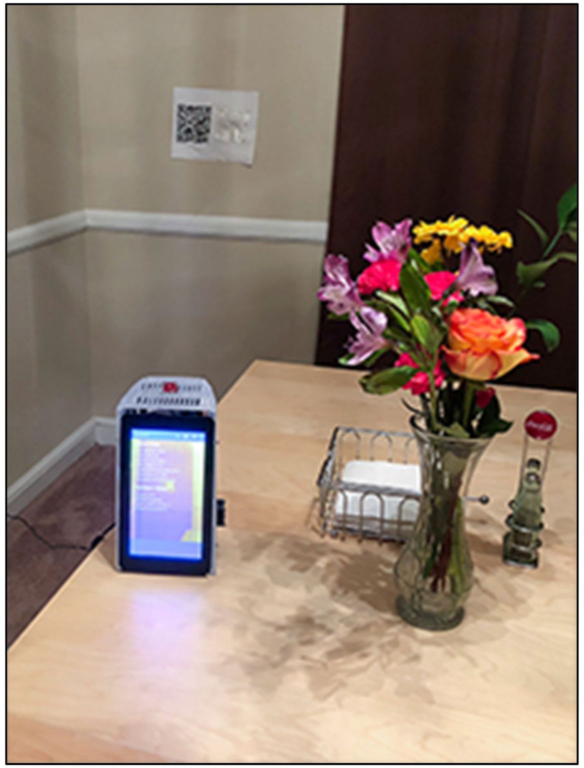
DEVELOPMENT: EASY-TO-DEPLOY THERMOGRAPHIC SENSOR KIT (V4.0)

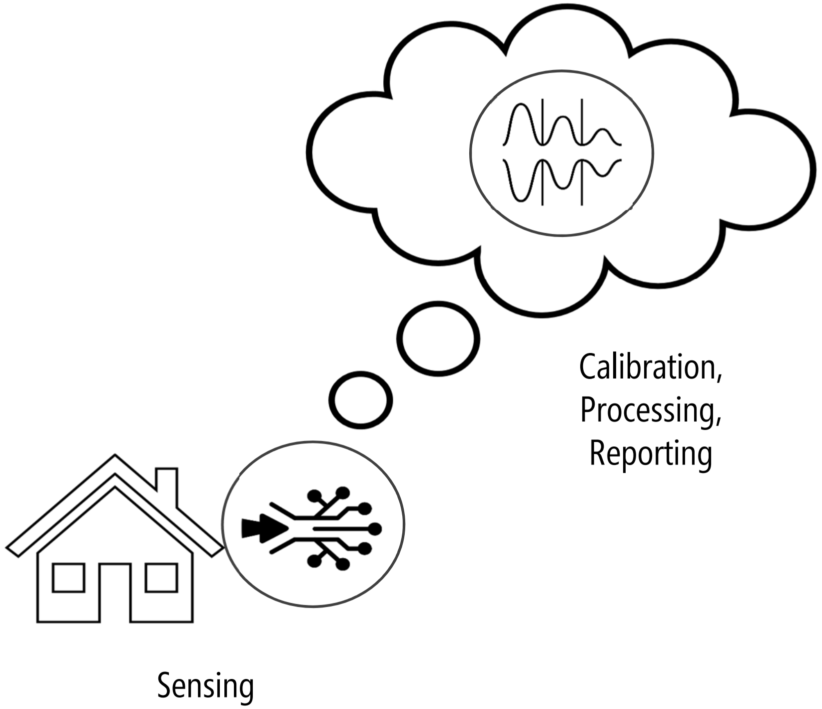


DEVELOPMENT: SYSTEM OVERVIEW



DEVELOPMENT: SYSTEM OVERVIEW





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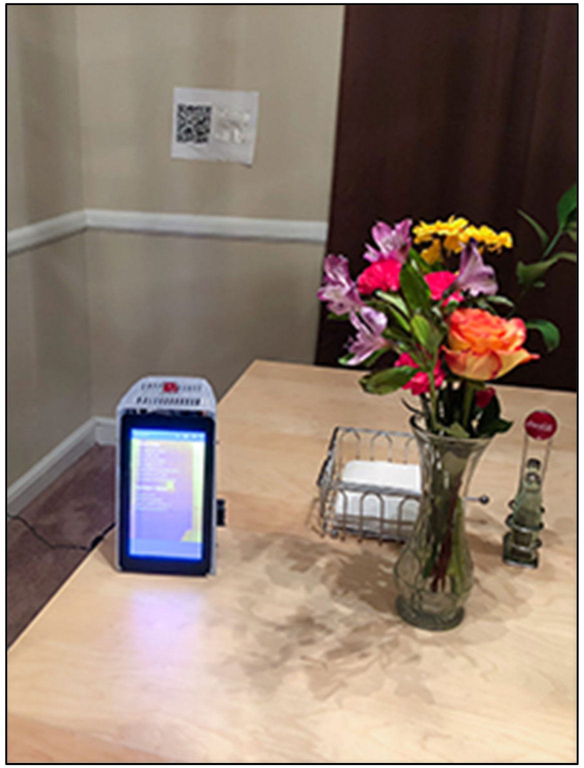
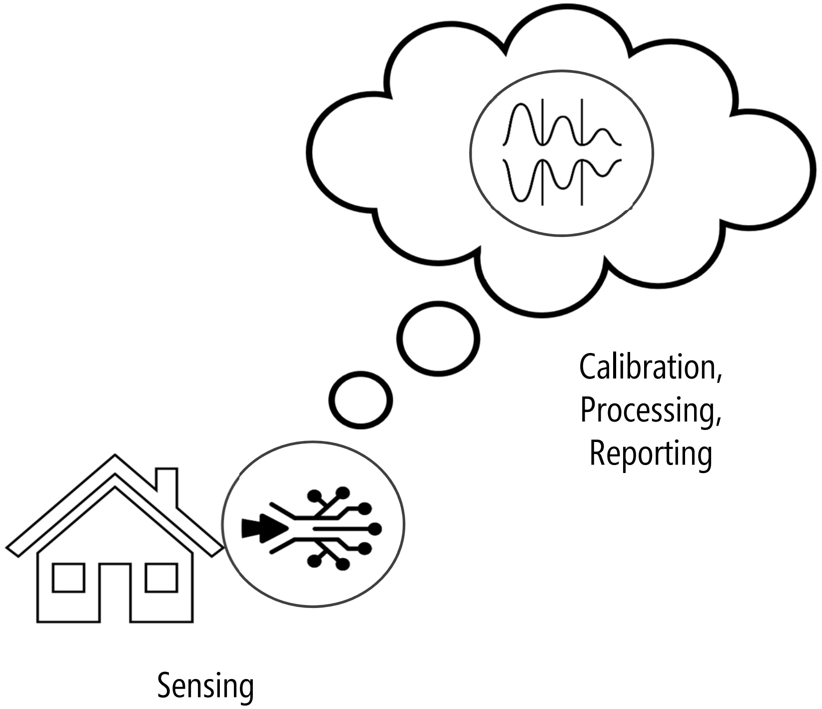
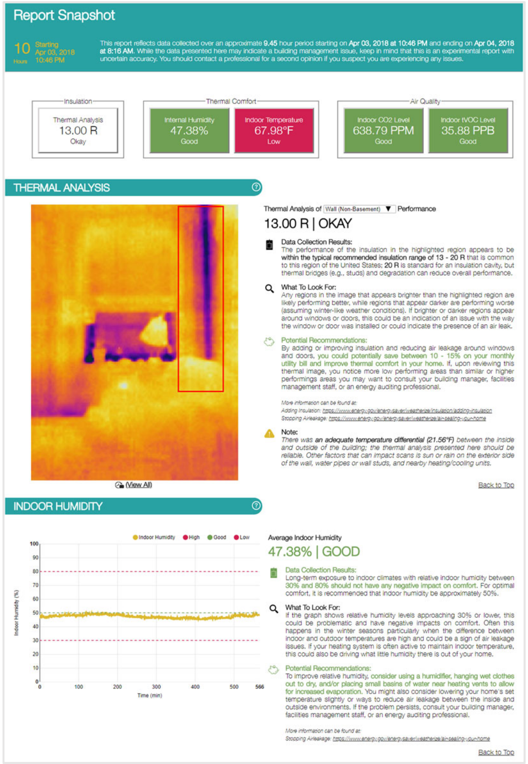
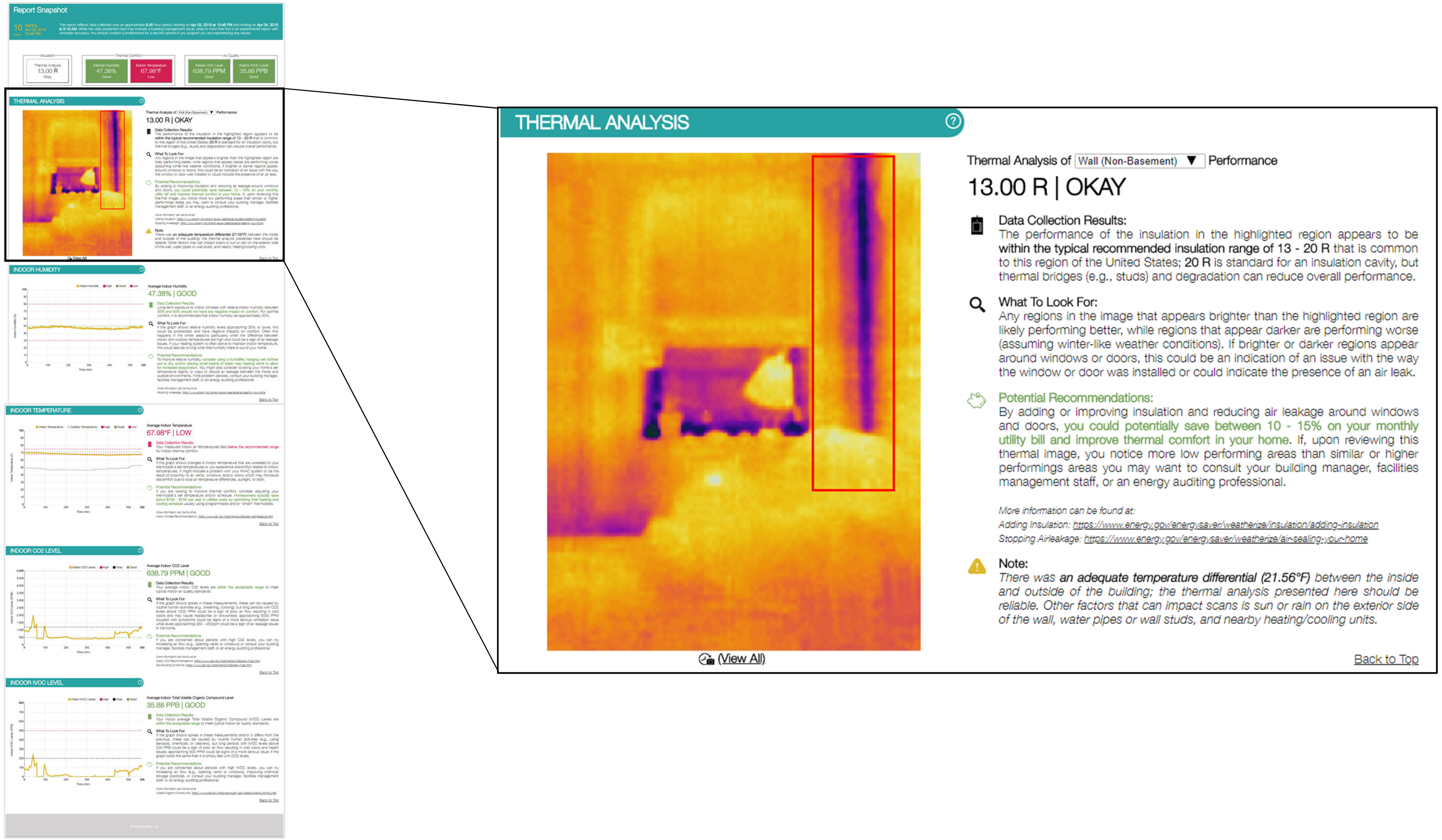


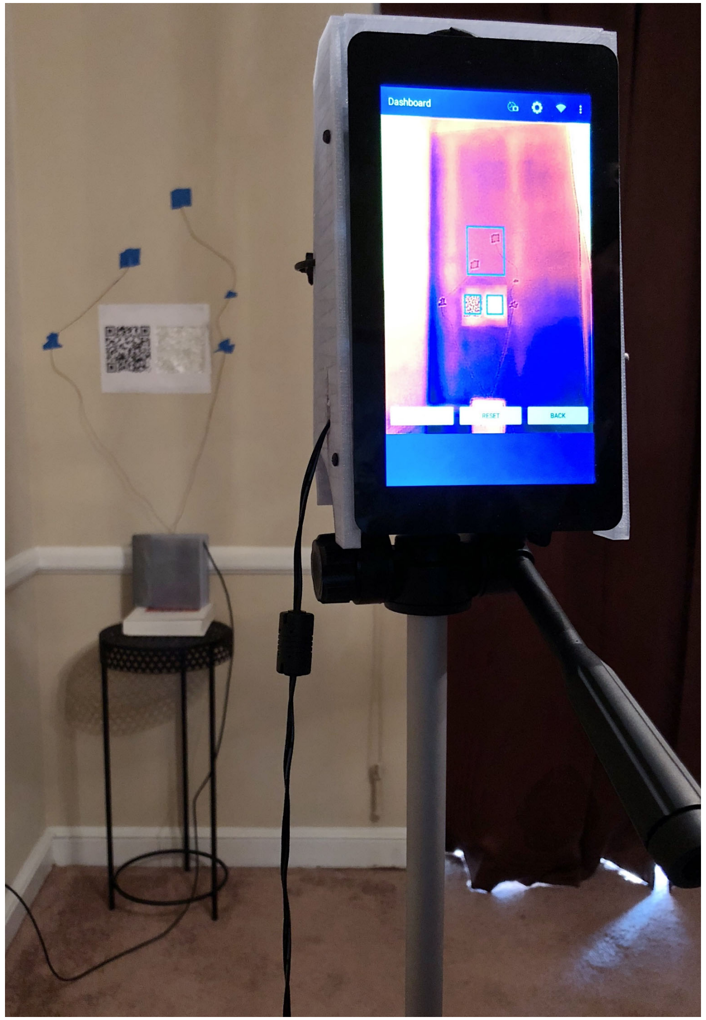




DEVELOPMENT: REVISED VISUALIZATION



Development: Validation Experiments



Development: Validation Results

Data Segment	Notional	THM (deviation)	IRT (deviation)	Average Temp. Delta
Day 1	R-6.50	R-7.54 (16.00%)	R-7.67 (18.00%)	27.47°C
Day 2	R-6.50	R-6.67 (2.61%)	R-6.29 (3.23%)	20.96°C
Full Campaign	R-6.50	R-6.30 (3.07%)	R-6.39 (1.69%)	22.85°C

TALK OVERVIEW

Introduction

Background

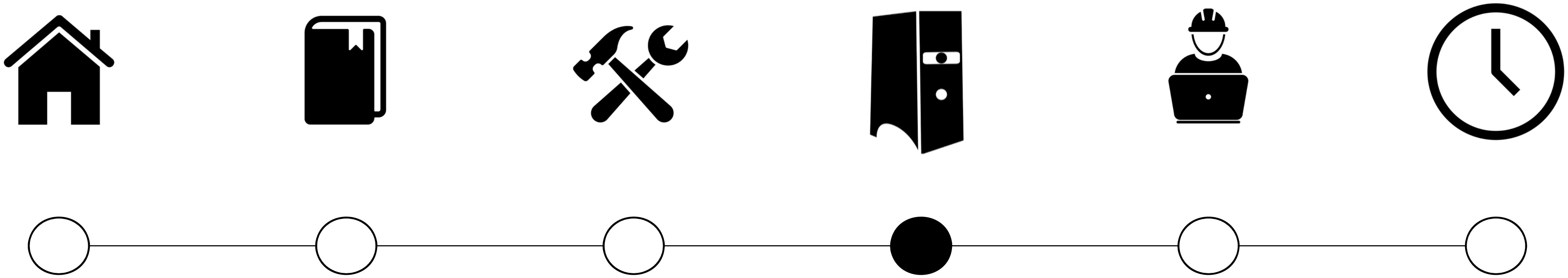
System Overview

Field Deployment

Expert Review

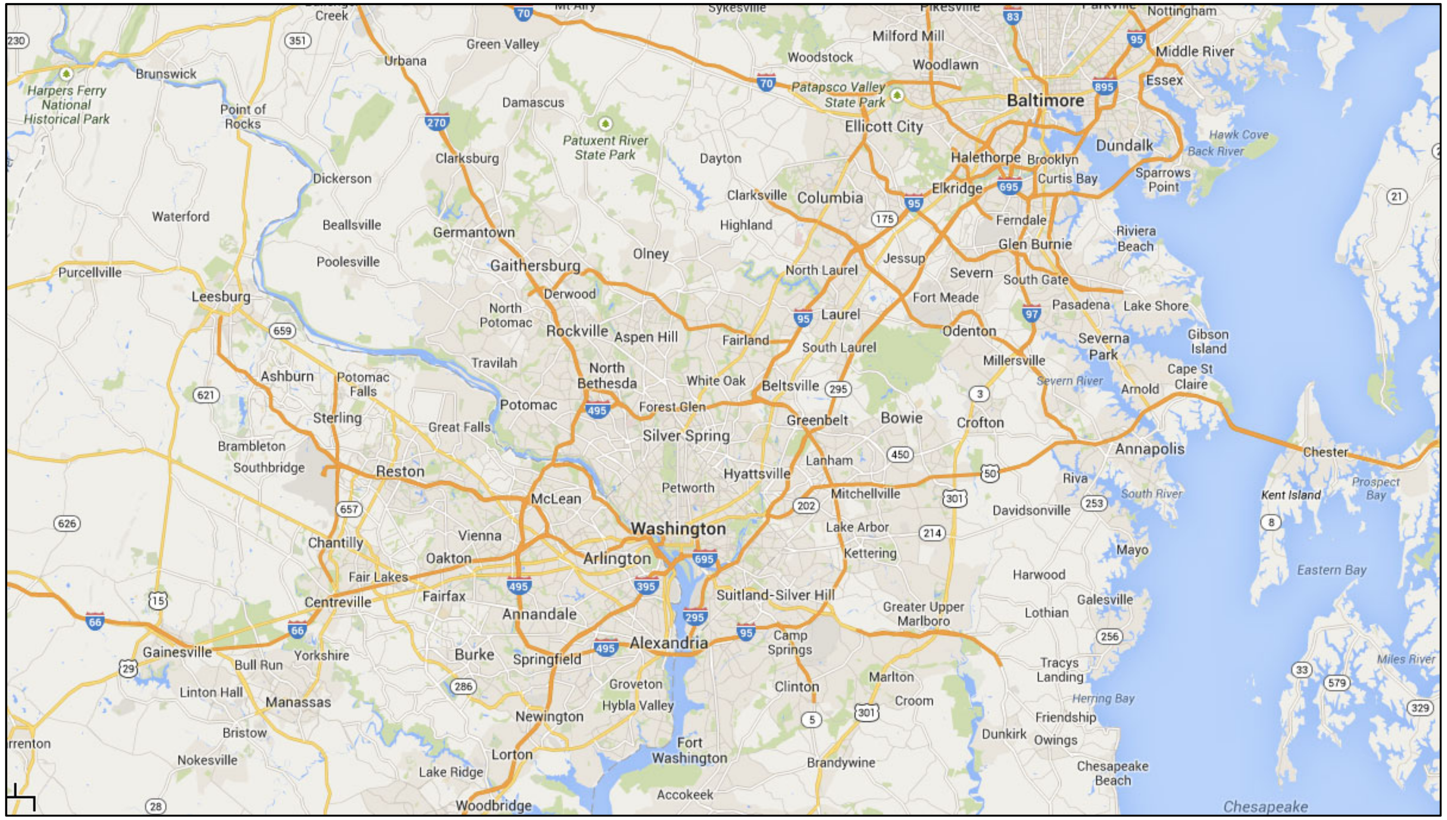
Conclusion

TALK OVERVIEW



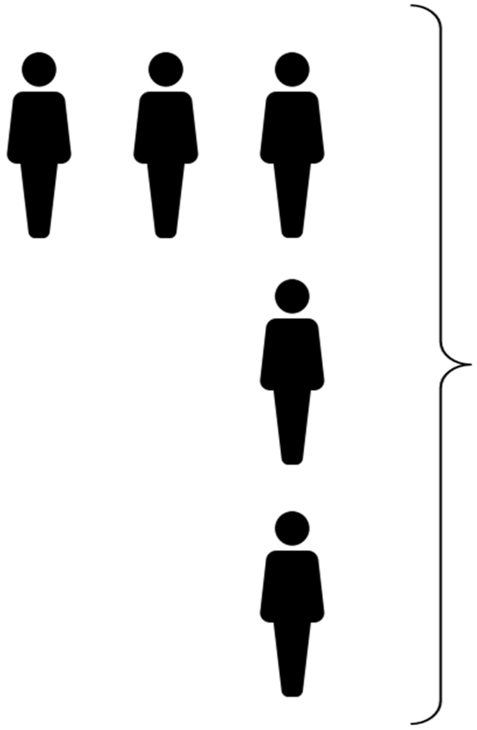
Introduction | Background | System Overview | Field Deployment | Expert Review | Conclusion

FIELD DEPLOYMENT: RECRUITMENT



We recruited local participants using listserv, community message boards, and word-of-mouth in the Washington D.C. metro area.

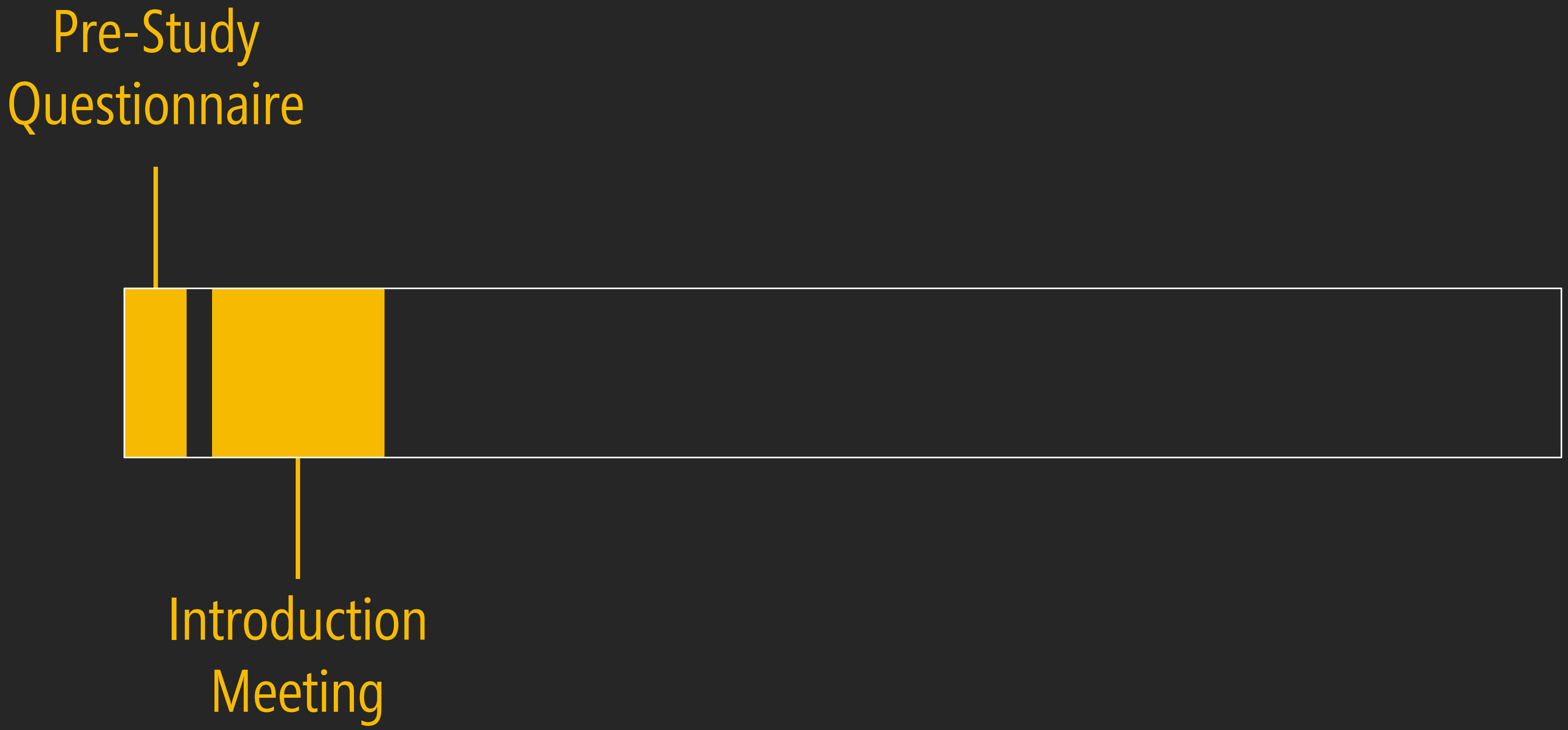
FIELD DEPLOYMENT: PARTICIPANTS



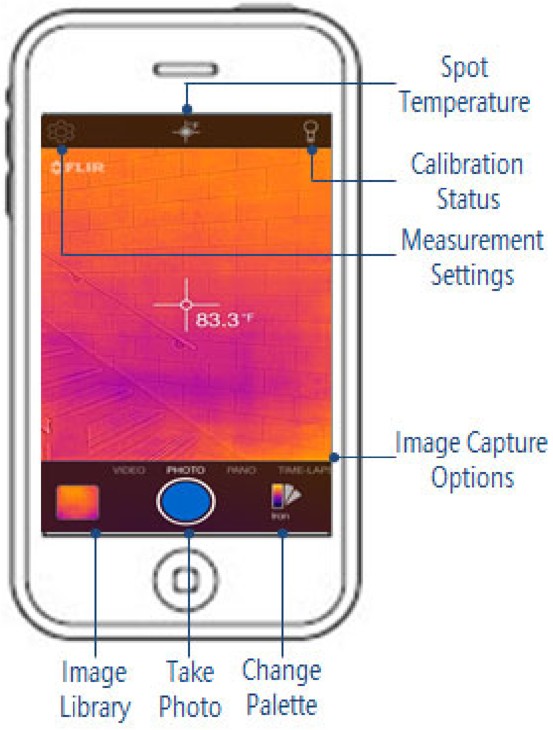
5 Participants

(3 Male, 1 Female, 1 Prefer Not to Answer)

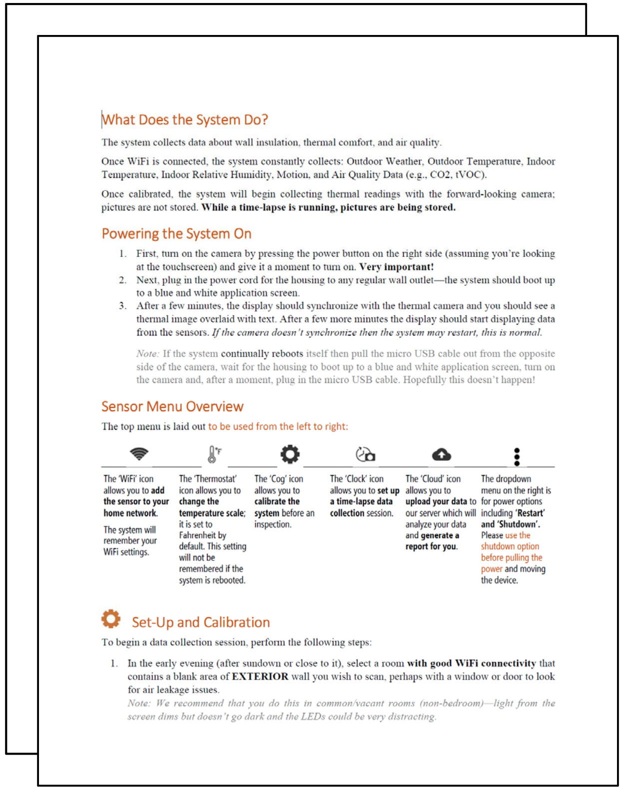
FIELD DEPLOYMENT: PROCEDURE



FIELD DEPLOYMENT: TRAINING



Hardware/Software Overview



What Does the System Do?

The system collects data about wall insulation, thermal comfort, and air quality.

Once WiFi is connected, the system constantly collects: Outdoor Weather, Outdoor Temperature, Indoor Temperature, Indoor Relative Humidity, Motion, and Air Quality Data (e.g., CO2, tVOC).

Once calibrated, the system will begin collecting thermal readings with the forward-looking camera; pictures are not stored. **While a time-lapse is running, pictures are being stored.**

Powering the System On

1. First, turn on the camera by pressing the power button on the right side (assuming you're looking at the touchscreen) and give it a moment to turn on. **Very important!**
2. Next, plug in the power cord for the housing to any regular wall outlet—the system should boot up to a blue and white application screen.
3. After a few minutes, the display should synchronize with the thermal camera and you should see a thermal image overlaid with text. After a few more minutes the display should start displaying data from the sensors. *If the camera doesn't synchronize then the system may restart, this is normal.*

Note: If the system **continually reboots** itself then pull the micro USB cable out from the opposite side of the camera, wait for the housing to boot up to a blue and white application screen, turn on the camera and, after a moment, plug in the micro USB cable. Hopefully this doesn't happen!

Sensor Menu Overview

The top menu is laid out to be used from the left to right:

The 'WiFi' icon allows you to **add the sensor to your home network.** The system will remember your WiFi settings.

The 'Thermostat' icon allows you to **change the temperature scale**; it is set to Fahrenheit by default. This setting will not be remembered if the system is rebooted.

The 'Cog' icon allows you to **calibrate the system** before an inspection.

The 'Clock' icon allows you to **set up a time-lapse data collection** session.

The 'Cloud' icon allows you to **upload your data** to our server which will analyze your data and **generate a report for you.**

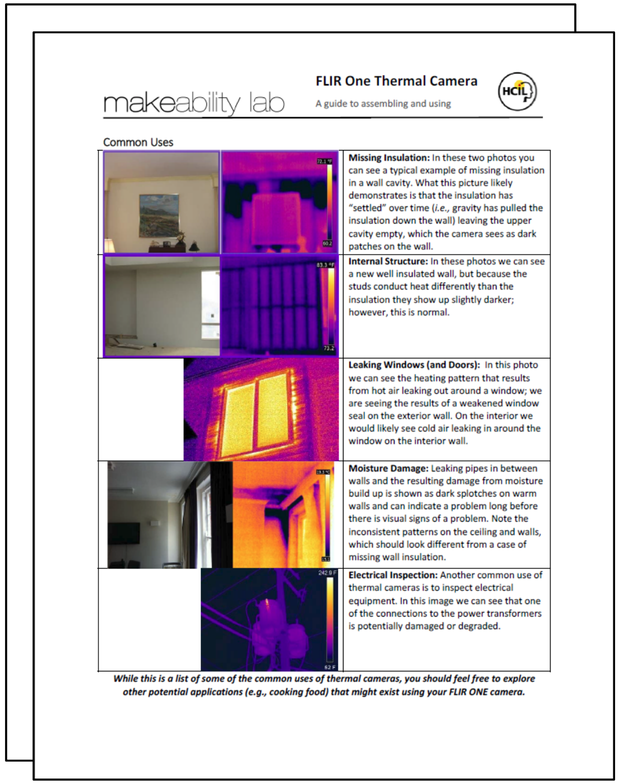
The dropdown menu on the right is for power options including **'Restart' and 'Shutdown'.** Please use the shutdown option before pulling the power and moving the device.

Set-Up and Calibration

To begin a data collection session, perform the following steps:

1. In the early evening (after sundown or close to it), select a room **with good WiFi connectivity** that contains a blank area of **EXTERIOR** wall you wish to scan, perhaps with a window or door to look for air leakage issues.
   Note: We recommend that you do this in common/vacant rooms (non-bedroom)—light from the screen dims but doesn't go dark and the LEDs could be very distracting.

How-to Thermporal Guide



makeability lab

FLIR One Thermal Camera

A guide to assembling and using

HCIL

Common Uses

Missing Insulation: In these two photos you can see a typical example of missing insulation in a wall cavity. What this picture likely demonstrates is that the insulation has "settled" over time (*i.e.*, gravity has pulled the insulation down the wall) leaving the upper cavity empty, which the camera sees as dark patches on the wall.

Internal Structure: In these photos we can see a new well insulated wall, but because the studs conduct heat differently than the insulation they show up slightly darker; however, this is normal.

Leaking Windows (and Doors): In this photo we can see the heating pattern that results from hot air leaking out around a window; we are seeing the results of a weakened window seal on the exterior wall. On the interior we would likely see cold air leaking in around the window on the interior wall.

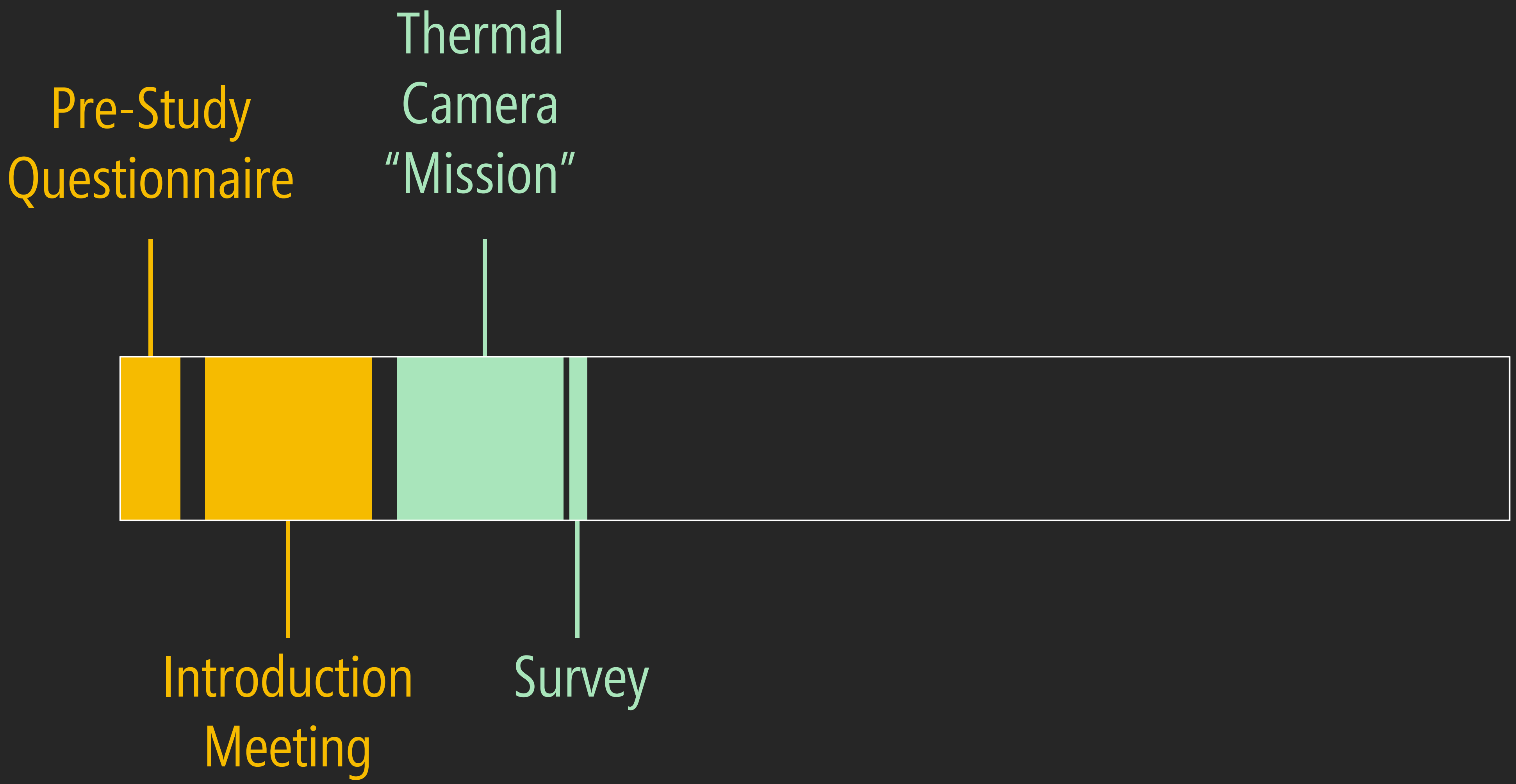
Moisture Damage: Leaking pipes in between walls and the resulting damage from moisture build up is shown as dark splotches on warm walls and can indicate a problem long before there is visual signs of a problem. Note the inconsistent patterns on the ceiling and walls, which should look different from a case of missing wall insulation.

Electrical Inspection: Another common use of thermal cameras is to inspect electrical equipment. In this image we can see that one of the connections to the power transformers is potentially damaged or degraded.

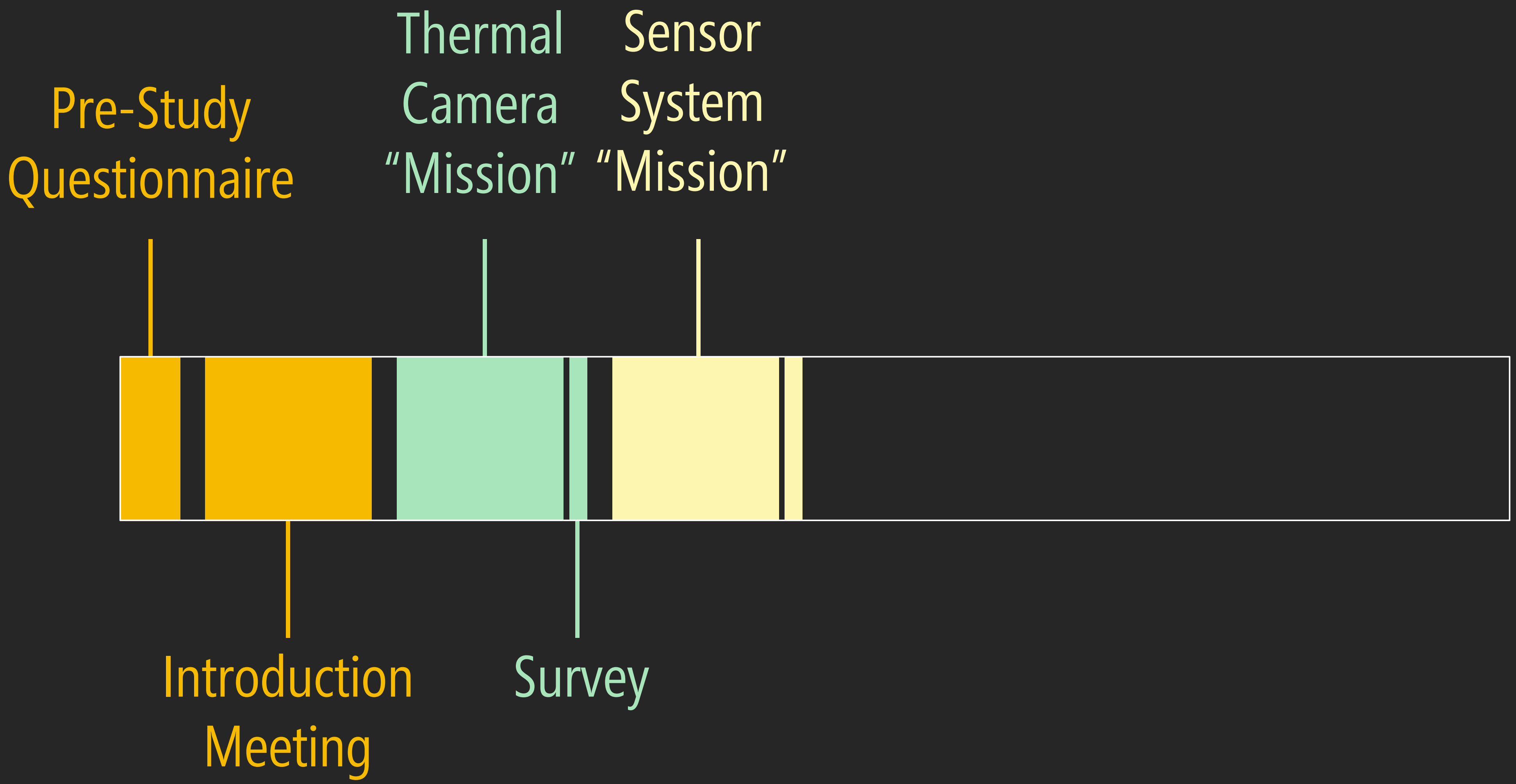
While this is a list of some of the common uses of thermal cameras, you should feel free to explore other potential applications (e.g., cooking food) that might exist using your FLIR ONE camera.

Thermographic Inspection Guide

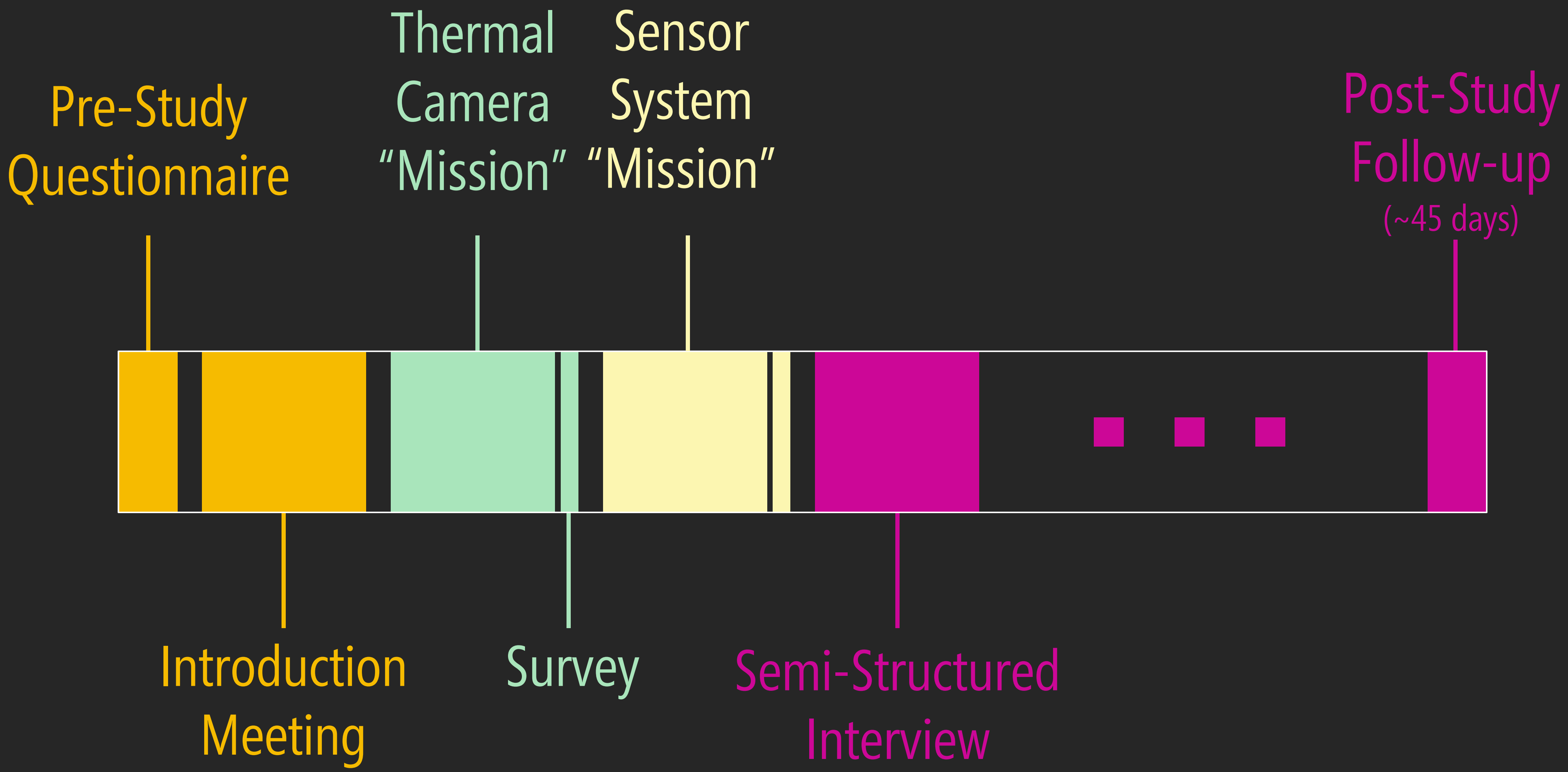
FIELD DEPLOYMENT: PROCEDURE



FIELD DEPLOYMENT: PROCEDURE



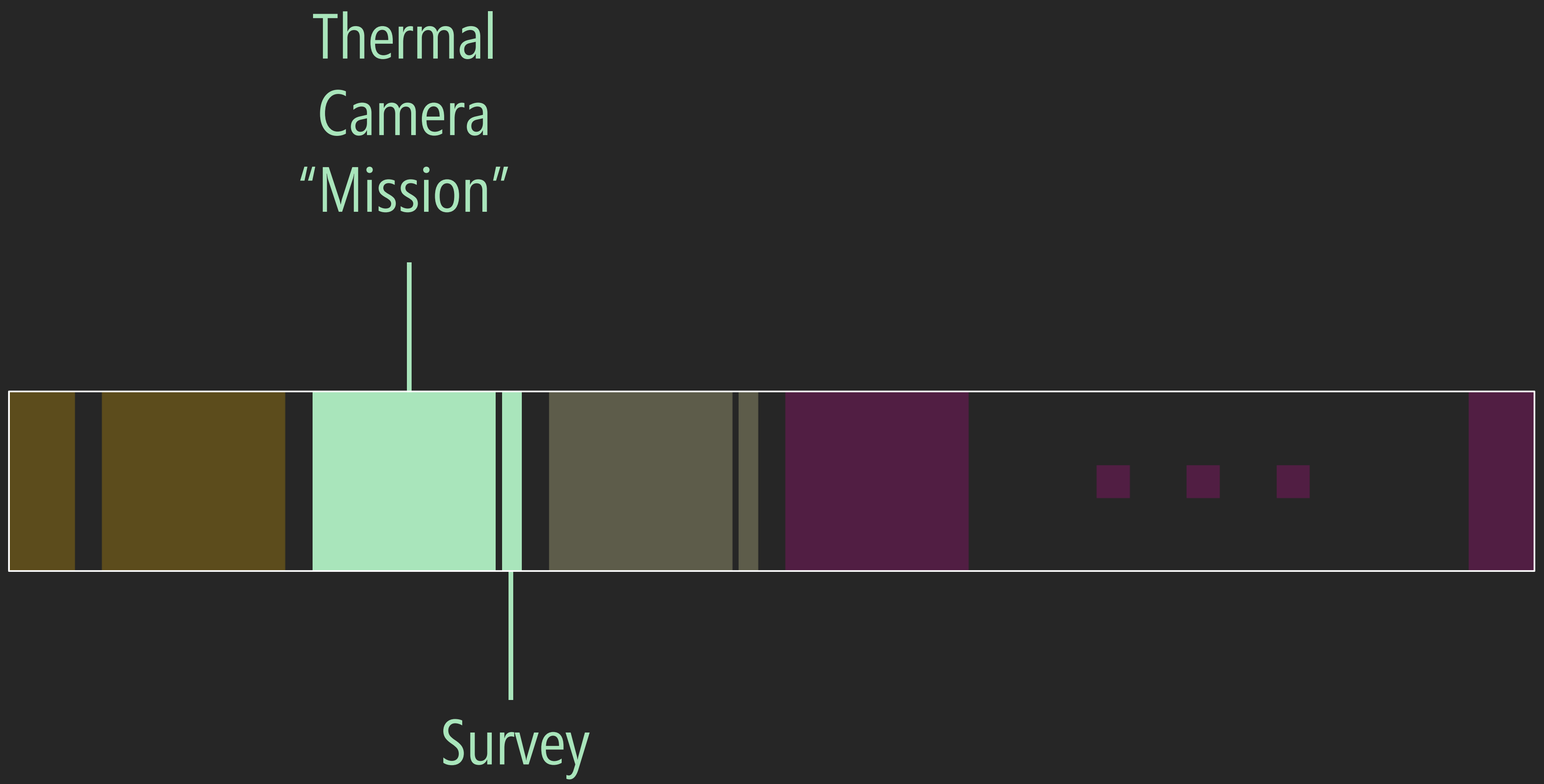
Field Deployment: Procedure



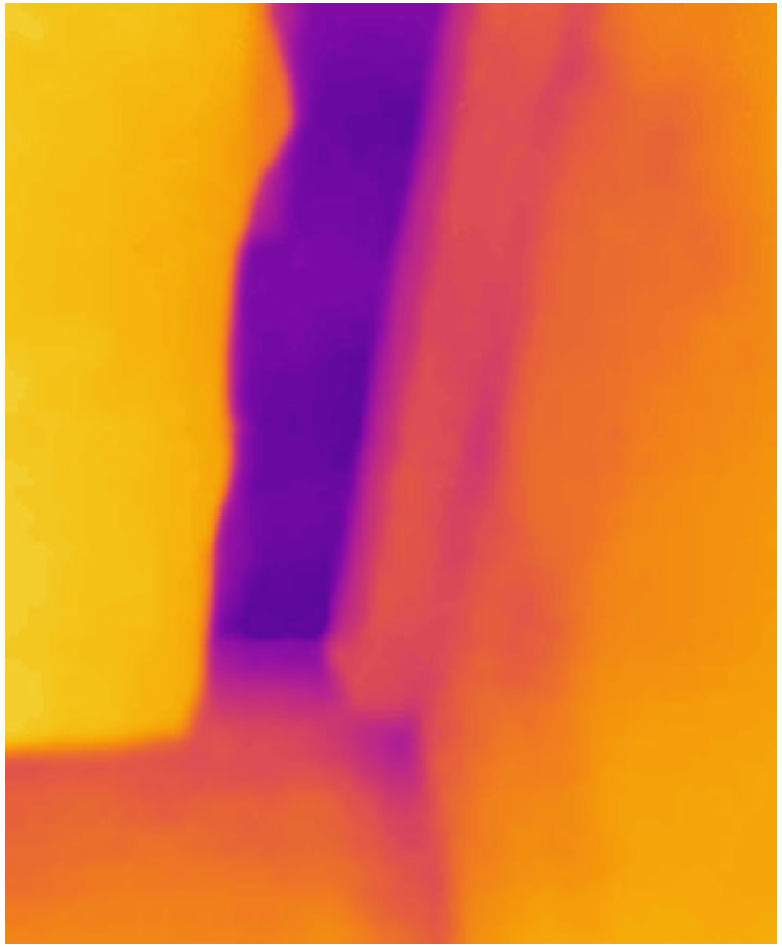
Field Deployment: Analysis

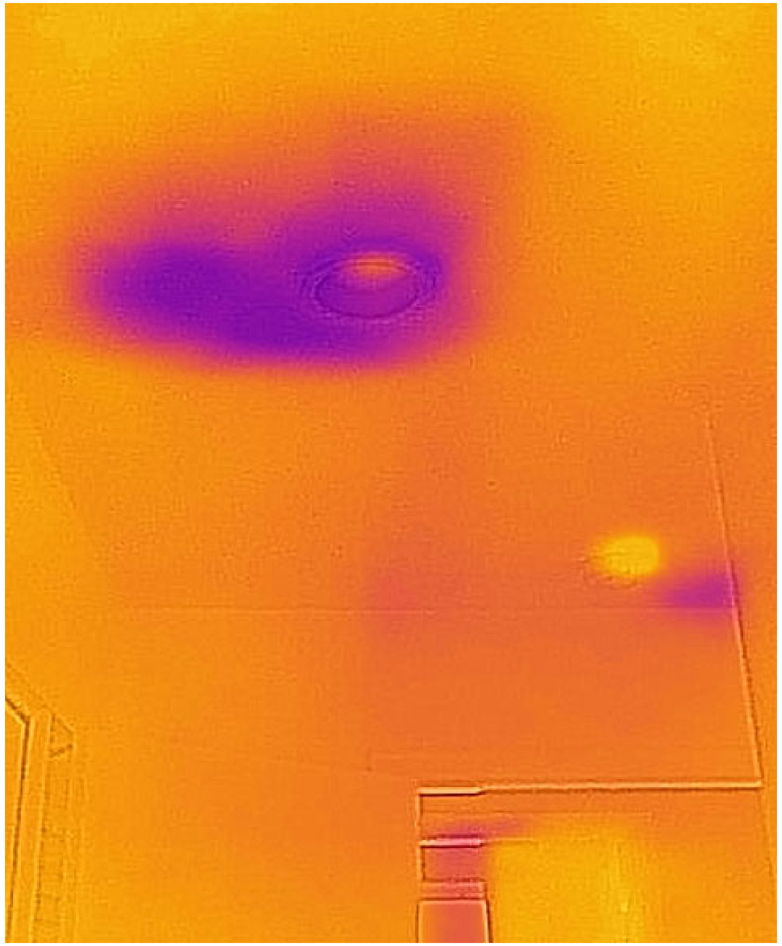
We qualitatively coded the survey and interview data to uncover themes.

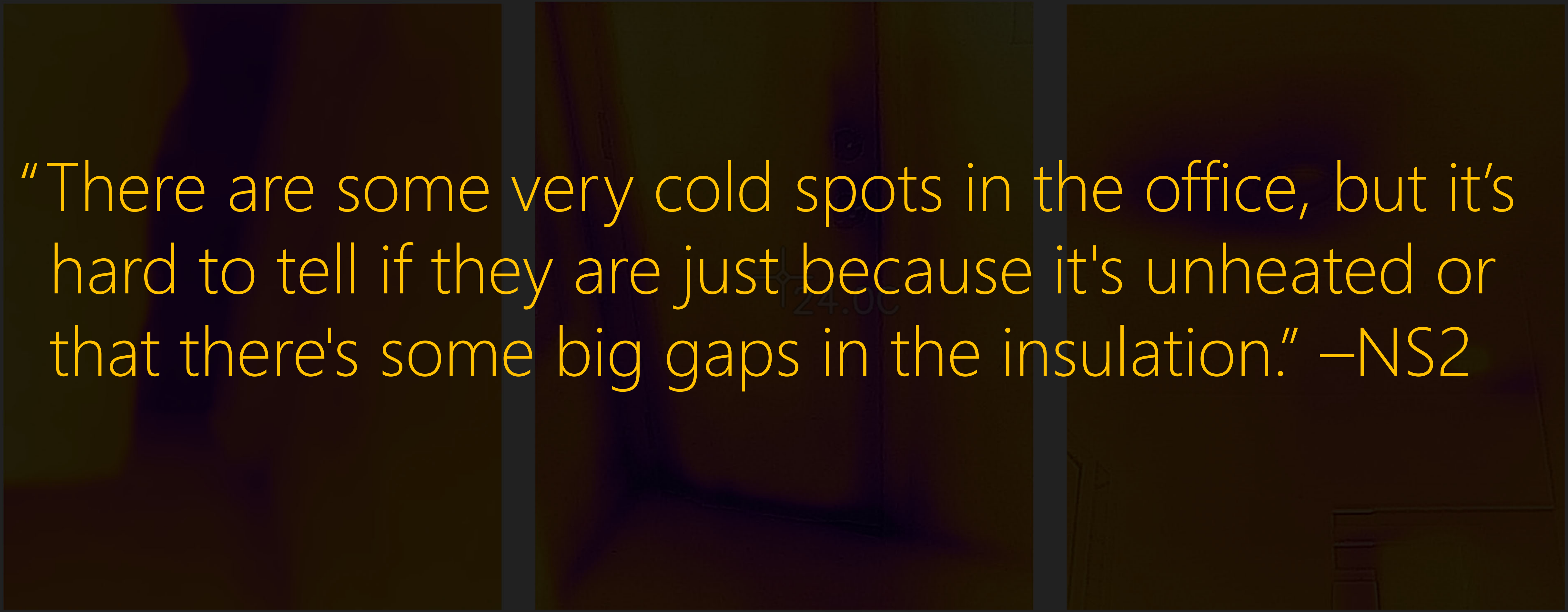
FIELD DEPLOYMENT: RESULTS



FIELD DEPLOYMENT: THERMAL CAMERA RESULTS

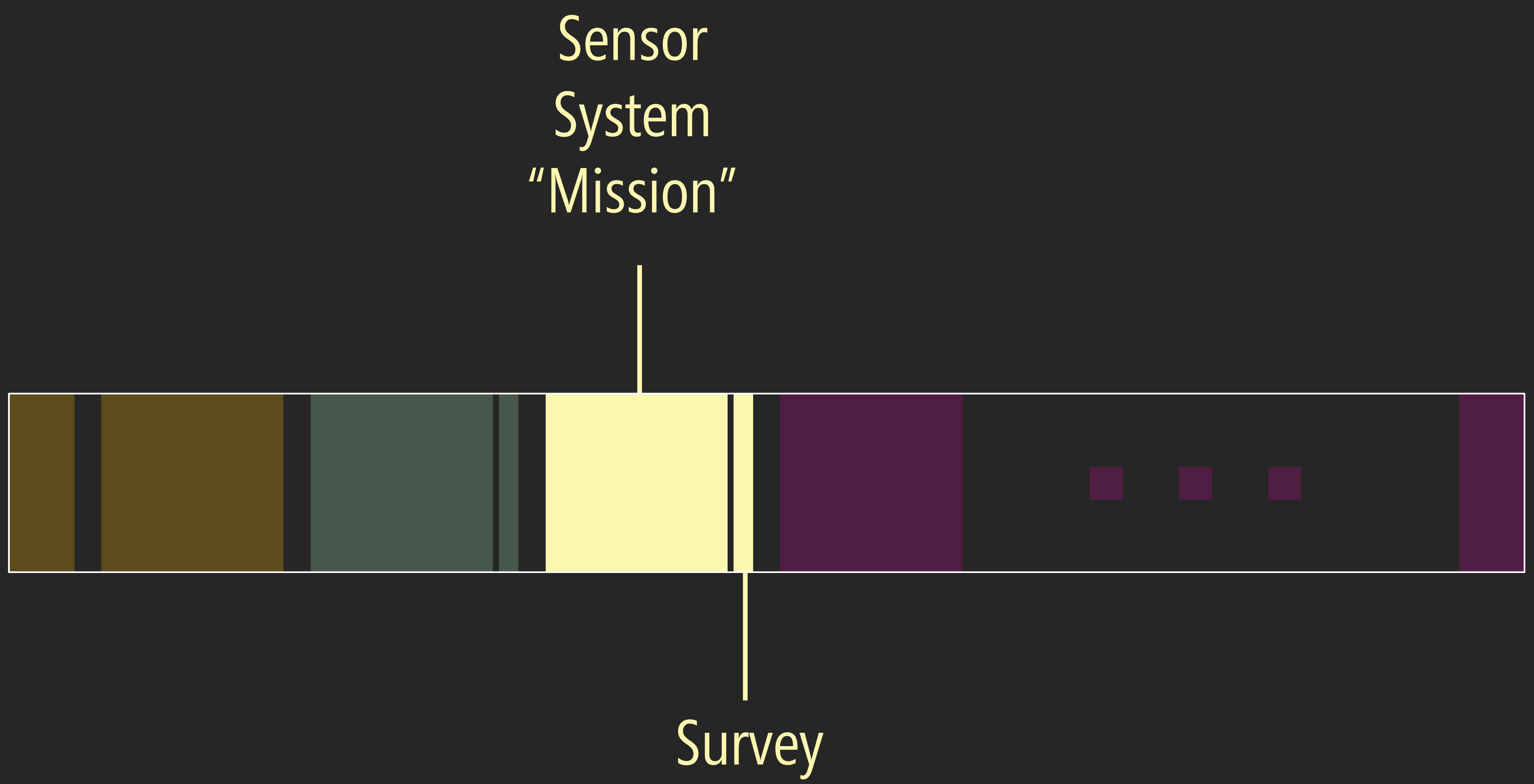






"There are some very cold spots in the office, but it's hard to tell if they are just because it's unheated or that there's some big gaps in the insulation." –NS2

FIELD DEPLOYMENT: RESULTS



Field Deployment: Sensor System Results

Participant ID	Sensor Kit Aimed at Suspected Issue	Issue was Found
P1	No	No
P2	Yes	Yes *Less severe than anticipated*
P3	Yes	Yes
P4	No	Yes
P5	Yes *Based on intuition, not thermal camera mission*	No

FIELD DEPLOYMENT: SENSOR SYSTEM RESULTS

Participant ID	**Sensor Kit Aimed at Suspected Issue**	**Issue was Found**
P1	No	No
P2	Yes	Yes *Less severe than anticipated*
P3	Yes	Yes
P4	No	Yes
P5	Yes *Based on intuition, not thermal camera mission*	No

Field Deployment: Sensor System Results

"It kind of gave me a why. **It's real cold here and it is below code.** Here's some further information you can look at. That was super helpful. **I can decide if I agree that this is a problem,** and it's telling me something I can do."
–NI2

Field Deployment: Sensor System Results

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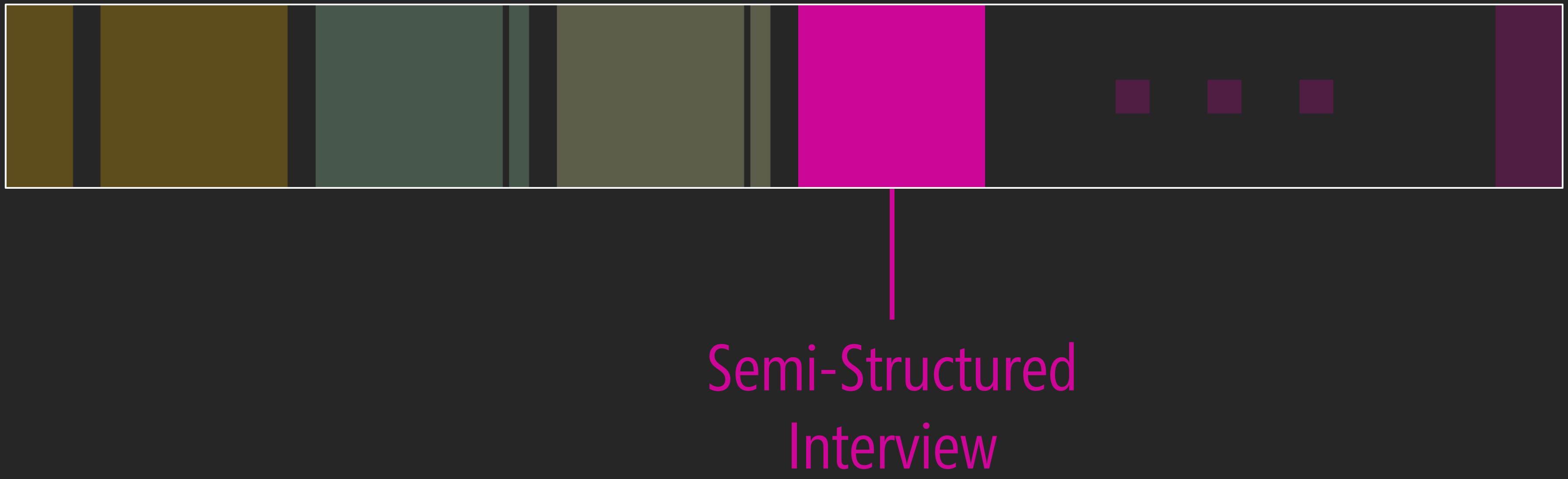
"My reports were negative, so I am not sure what else to glean from them." –NS5

Field Deployment: Results



FIELD DEPLOYMENT: SEMI-STRUCTURED INTERVIEW RESULTS

Interactive Reporting

Data Privacy

Personal Confidence

Post-Mission Attitudes

Interactive Reporting

Data Privacy

Personal Confidence

Post-Mission Attitudes

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Interactive Reporting

Participants described the interactive report in several ways:

- 4 of 5 were positive about receiving the easy-to-read, automatically generated report.

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- 4 of 5 were positive about receiving the easy-to-read, automatically generated report.
- 4 of 5 liked having longitudinal data and the additional depth the report provided by comparison to thermograms alone.

"I like the idea of having a report that I can refer to again afterward. You get that with pictures too, obviously. But the reporting aspect gives you more detail, [...] the fact that you had the environmental and air quality readings also gave you something more to look at." –NI3

Interactive Reporting

Participants described the interactive report in several ways:

- 4 of 5 were positive about receiving the easy-to-read, automatically generated report.
- 4 of 5 liked having longitudinal data and the additional depth the report provided by comparison to thermograms alone.
- 3 of 5 envisioned using this data as a tool to communicate with professionals

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- 4 of 5 liked having longitudinal data and the additional depth the report provided by comparison to thermograms alone.
- 3 of 5 envisioned using this data as a tool to communicate with professionals

"If there's a big problem, that's the thing I want to fix, but I don't trust that some guy is coming in and not trying to sell me." –NI2

Field Deployment: Semi-structured Interview Results

Interactive Reporting

Data Privacy

Personal Confidence

Post-Mission Attitudes

Data Privacy

Participants were largely homogenous when it came to the privacy of their data:

- 4 of 5 desired explicit control over all data collected about/in their home.

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- 4 of 5 desired explicit control over all data collected about/in their home.

"If it were not an internet connected device, if it were just a local network thing that I used in my house, that would be fine. If information is going out, then I have a big problem with technology like that." –NI2

Data Privacy

Participants were largely homogenous when it came to the privacy of their data:

- 4 of 5 desired explicit control over all data collected about/in their home.
- 1 of 5 desired aggregated data about their neighborhood and advocated that local policy makers should have access.

Interactive Reporting

Data Privacy

Personal Confidence

Post-Mission Attitudes

FIELD DEPLOYMENT: SENSOR SYSTEM RESULTS

Participant ID	Sensor Kit Aimed at Suspected Issue	Issue was Found
P1	No	No
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P3	Yes	Yes
P4	No	Yes
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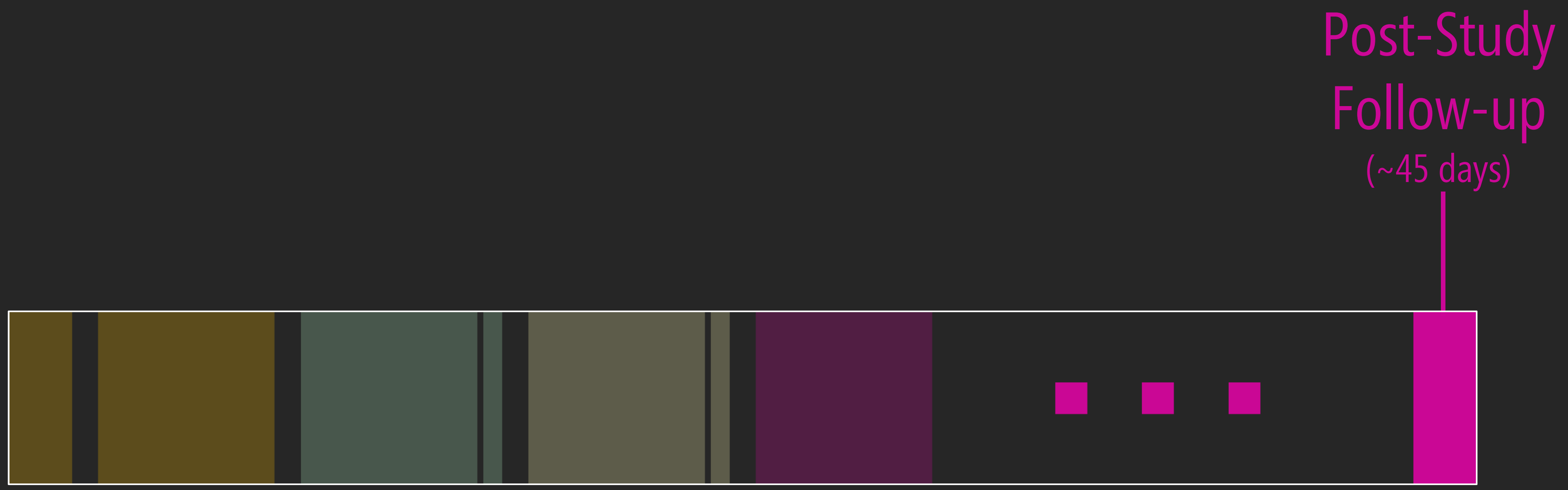
Field Deployment: Results



Follow-up Findings

- 5 of 5 reported thinking more about energy efficiency issues in their home since participation had ended.

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- 5 of 5 reported thinking more about energy efficiency issues in their home since participation had ended.

"It has made me generally more aware of where there might be issues and why." –NS3

Follow-up Findings

Participants were largely homogenous when it came to the privacy of their data:

- 5 of 5 reported thinking more about energy efficiency issues in their home since participation had ended.
- 2 of 5 reported making some repairs for air leakage issues; however, all reported that insulation issues required more savings and planning.

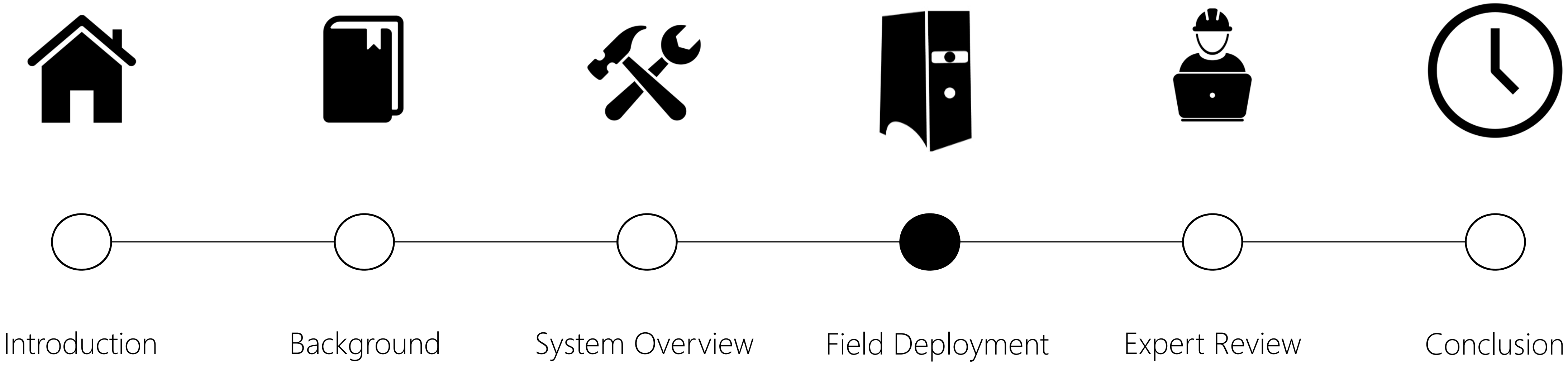
Follow-up Findings

Participants were largely homogenous when it came to the privacy of their data:

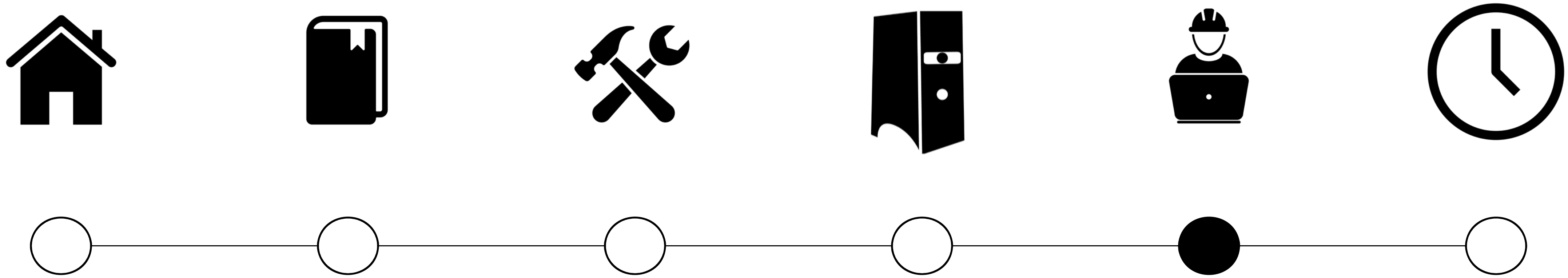
- 5 of 5 reported thinking more about energy efficiency issues in their home since participation had ended.
- 2 of 5 reported making some repairs for air leakage issues; however, all reported that insulation issues required more savings and planning.

"I'd say it's kind of too late for a homeowner, unless you're about to do a renovation." –NI3

Talk Overview



Talk Overview



Introduction — Background — System Overview — Field Deployment — Expert Review — Conclusion

EXPERT REVIEW: PARTICIPANTS

5 Participants
(All male)

EXPERT REVIEW: PRESENTATION OF DESIGN PROBES

Scenario 1
(Text)

Interactive
Demo

Scenario 3
(Text)

EXPERT REVIEW: PRESENTATION OF DESIGN PROBES

Scenario 1
(Text)

Interactive
Demo

Scenario 3
(Text)

→ **Residential Audit**

EXPERT REVIEW: PRESENTATION OF DESIGN PROBES

Scenario 1
(Text)

Interactive
Demo

Scenario 3
(Text)

- **Hardware & Procedure**
- **Study Data & Reports**

EXPERT REVIEW: PRESENTATION OF DESIGN PROBES

Scenario 1
(Text)

Interactive
Demo

Scenario 3
(Text)

Audits-at-Scale

Expert Review: Design Probe Results

Raising Awareness

EXPERT REVIEW: DESIGN PROBE RESULTS

Raising Awareness

Providing Reliable Data

EXPERT REVIEW: DESIGN PROBE RESULTS

Raising Awareness

Providing Reliable Data

Relationship Building

Expert Review: Design Probe Results

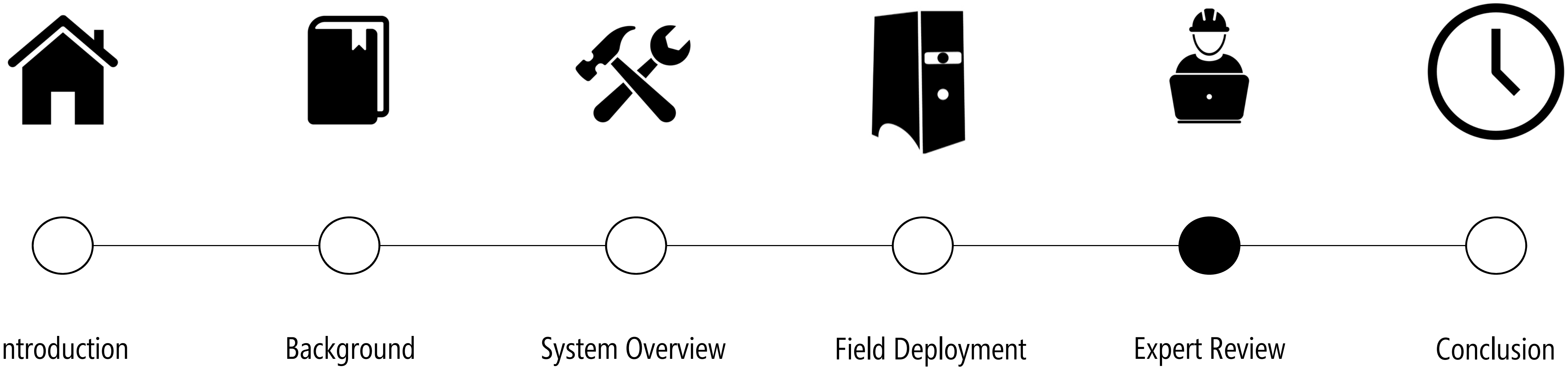
Installation and Coverage

Expert Review: Design Probe Results

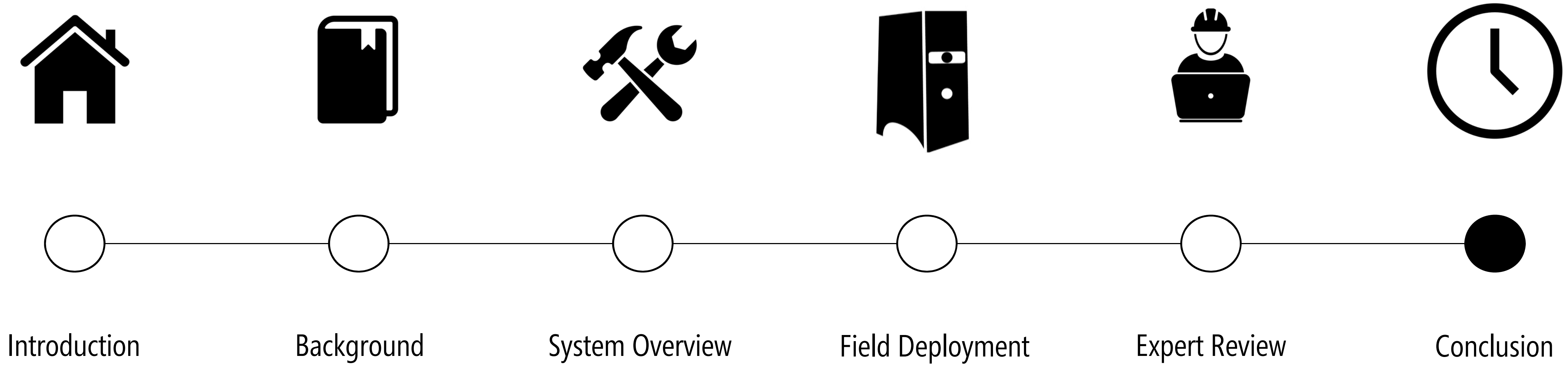
Installation and Coverage

Motivating Action

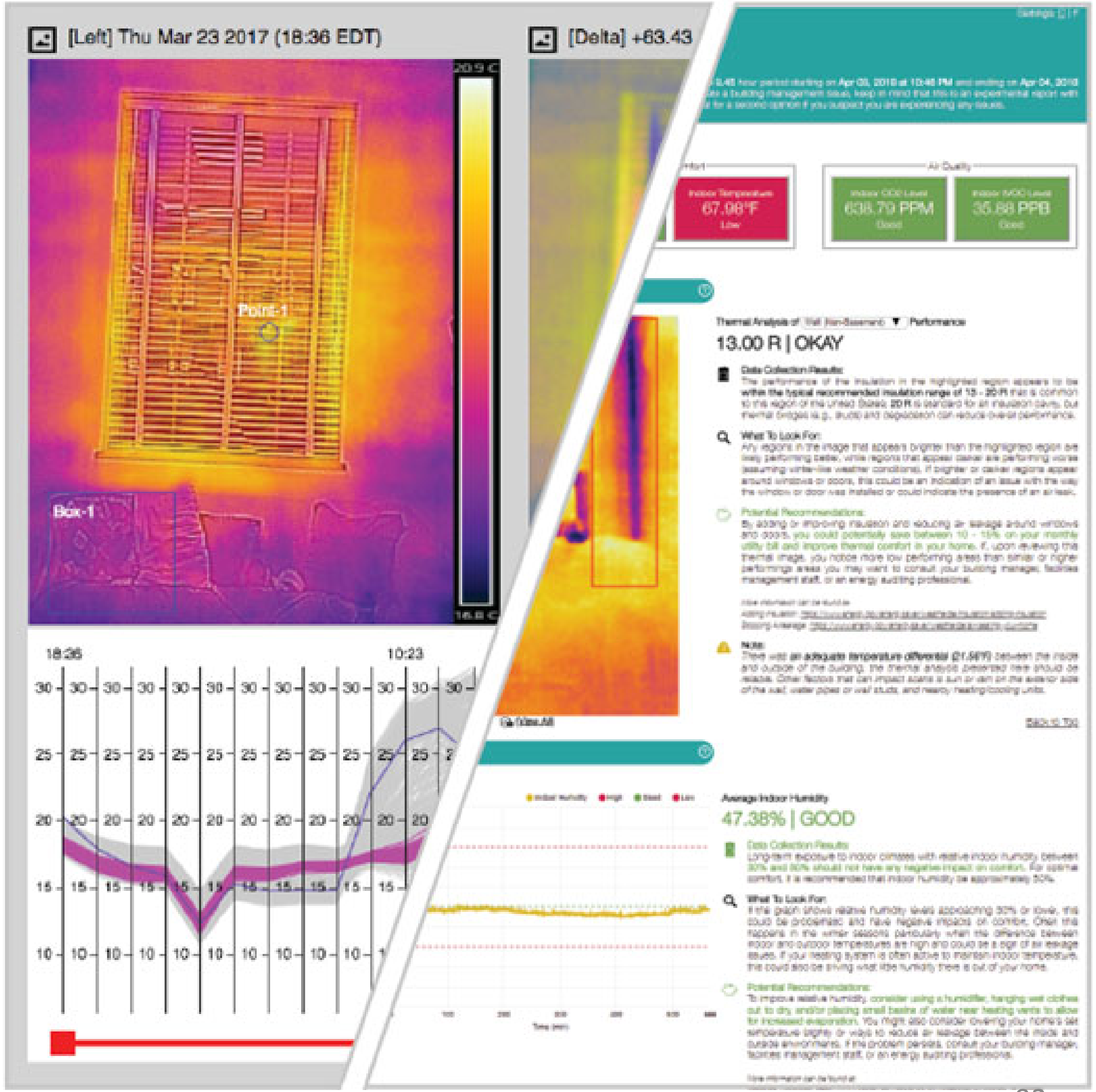
TALK OVERVIEW



TALK OVERVIEW



Conclusion


[Left] Thu Mar 23 2017 (18:36 EDT)
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20.9 C
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Point-1
Box-1
18:36
10:23
67.98°F
638.79 PPM
35.88 PPB
13.00 R | OKAY
47.38% | GOOD

CONCLUSION: DESIGN RECOMMENDATIONS

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Framing efficiency recommendations with the right motivations and delivering them with the right timing is critical.

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Permanently deployed sensor system that provide increased coverage are preferred to overnight scanning

CONCLUSION: LIMITATIONS

Small N for both studies

Homogeneous weather conditions and construction types

Professional participants only evaluated the results of deployments

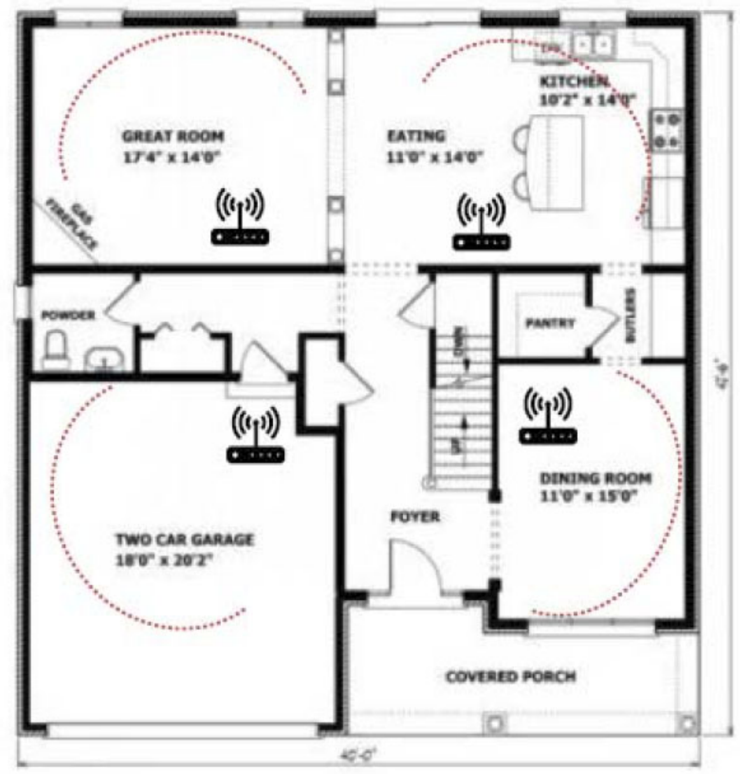
CONCLUSION: SUMMARY

Temporal/Quantitative analysis provides more specific insights in the case of insulation performance.

Increasing homeowner agency opens new opportunities for professional auditor and homeowner relations.

While we saw DIY solutions enacted, motivating larger-scale structural changes remains challenging.

CONCLUSION: FUTURE WORK



Multi-Sensor Deployments

Designation: C 177 – 04

Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus[1]

This standard is issued under the fixed designation C 177; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method establishes the criteria for the laboratory measurement of the steady-state heat flux through flat, homogeneous specimen(s) when their surfaces are in contact with solid, parallel boundaries held at constant temperatures using the guarded-hot-plate apparatus.

1.2 The test apparatus designed for this purpose is known as a guarded-hot-plate apparatus and is a primary (or absolute) method. This test method is comparable, but not identical, to ISO 8302.

1.3 This test method sets forth the general design requirements necessary to construct and operate a satisfactory guarded-hot-plate apparatus. It covers a wide variety of apparatus constructions, test conditions, and operating conditions. Detailed designs conforming to this test method are not given but must be developed within the constraints of the general requirements. Examples of analysis tools, concepts and procedures used in the design, construction, calibration and operation of a guarded-hot-plate apparatus are given in Refs **(1-41)**.[2]

1.4 This test method encompasses both the single-sided and the double-sided modes of measurement. Both distributed and line source guarded heating plate designs are permitted. The user should consult the standard practices on the single-sided mode of operation, Practice C 1044, and on the line source apparatus, Practice C 1043, for further details on these heater designs.

1.5 The guarded-hot-plate apparatus can be operated with either vertical or horizontal heat flow. The user is cautioned however, since the test results from the two orientations may be different if convective heat flow occurs within the specimens.

1.6 Although no definitive upper limit can be given for the magnitude of specimen conductance that is measurable on a guarded-hot-plate, for practical reasons the specimen conductance should be less than 16 W/(m ^{2}K).

1.7 This test method is applicable to the measurement of a wide variety of specimens, ranging from opaque solids to porous or transparent materials, and a wide range of environmental conditions including measurements conducted at extremes of temperature and with various gases and pressures.

1.8 Inhomogeneities normal to the heat flux direction, such as layered structures, can be successfully evaluated using this test method. However, testing specimens with inhomogeneities in the heat flux direction, such as an insulation system with thermal bridges, can yield results that are location specific and shall not be attempted with this type of apparatus. See Test Methods C 976 or C 236 for guidance in testing these systems.

1.9 Calculations of thermal transmission properties based upon measurements using this method shall be performed in conformance with Practice C 1045.

1.10 In order to ensure the level of precision and accuracy expected, persons applying this standard must possess a knowledge of the requirements of thermal measurements and testing practice and of the practical application of heat transfer theory relating to thermal insulation materials and systems. Detailed operating procedures, including design schematics and electrical drawings, should be available for each apparatus to ensure that tests are in accordance with this test method. In addition, automated data collecting and handling systems connected to the apparatus must be verified as to their accuracy. This can be done by calibration and inputting data sets, which have known results associated with them, into computer programs.

1.11 It is not practical for a test method of this type to establish details of design and construction and the procedures to cover all contingencies that might offer difficulties to a person without technical knowledge concerning theory of heat flow, temperature measurements and general testing practices. The user may also find it necessary, when repairing or modifying the apparatus, to become a designer or builder, or both, on whom the demands for fundamental understanding

[1] This test method is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

Current edition approved Nov. 1, 2004. Published November 2004. Originally approved in 1942. Last previous edition approved in 1997 as C 177 – 97.

[2] The boldface numbers given in parentheses refer to the list of references at the end of this standard.

Provläsningsexemplar / Preview

INTERNATIONAL STANDARD

ISO 9869-1

First edition 2014-08-01

ermal insulation — Building ments — *In-situ* measurement hermal resistance and thermal smittance —

flow meter method

Standard for Temporal Thermography

Conclusion: Future Work

GitHub

instructables.com

THE WORLD'S BIGGEST SHOW & TELL

CONCLUSION: ACKNOWLEDGEMENTS

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Erica Brown

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University of Maryland's Office of Sustainability

Thermporal: An Easy-to-Deploy Temporal Thermographic Sensor System to Support Residential Energy Audits

CHI 2019 | May 9th
Session on Sustainable HCI

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