

FROM WARM WALLS TO COOL CITIES

Investigating Insulation and Urban Heat Loss

thematic: energy and energy efficiency



Introduction

The challenge of **reducing energy consumption** and enhancing **thermal comfort** in buildings is central to **global sustainability** and **energy efficiency goals**. Buildings consume a **substantial portion of global energy**, and better **insulation** leads directly to **energy savings**, **reduced greenhouse gas emissions**, and **climate change mitigation**. Well-insulated, energy-efficient buildings also create **healthier living environments** by maintaining **consistent indoor temperatures**.

In this inquiry-based activity, students **design and test insulation solutions**. They explore **heat transfer principles**, **energy conservation** through insulation, and how **material properties** affect thermal performance. Through hands-on experiments, they measure **insulation's effect on temperature stability**, modeling real-world building energy management.

This activity combines **scientific exploration of thermal properties** with **practical applications to global challenges**. Students develop critical thinking skills while connecting classroom concepts to environmental and societal issues, fostering appreciation for sustainable practices in daily life and future engineering.

This activity connects directly to several United Nations Sustainable Development Goals (SDGs):

- **SDG 7: Affordable and Clean Energy**—Students learn how insulation reduces heating and cooling needs, making energy more affordable through simple interventions.
- **SDG 11: Sustainable Cities and Communities**—Energy-efficient building design strengthens urban sustainability and resilience.
- **SDG 13: Climate Action**—Lower building energy consumption reduces carbon footprints and supports climate mitigation.

Interdisciplinarity



physics

engineering

Sustainable Development Goals



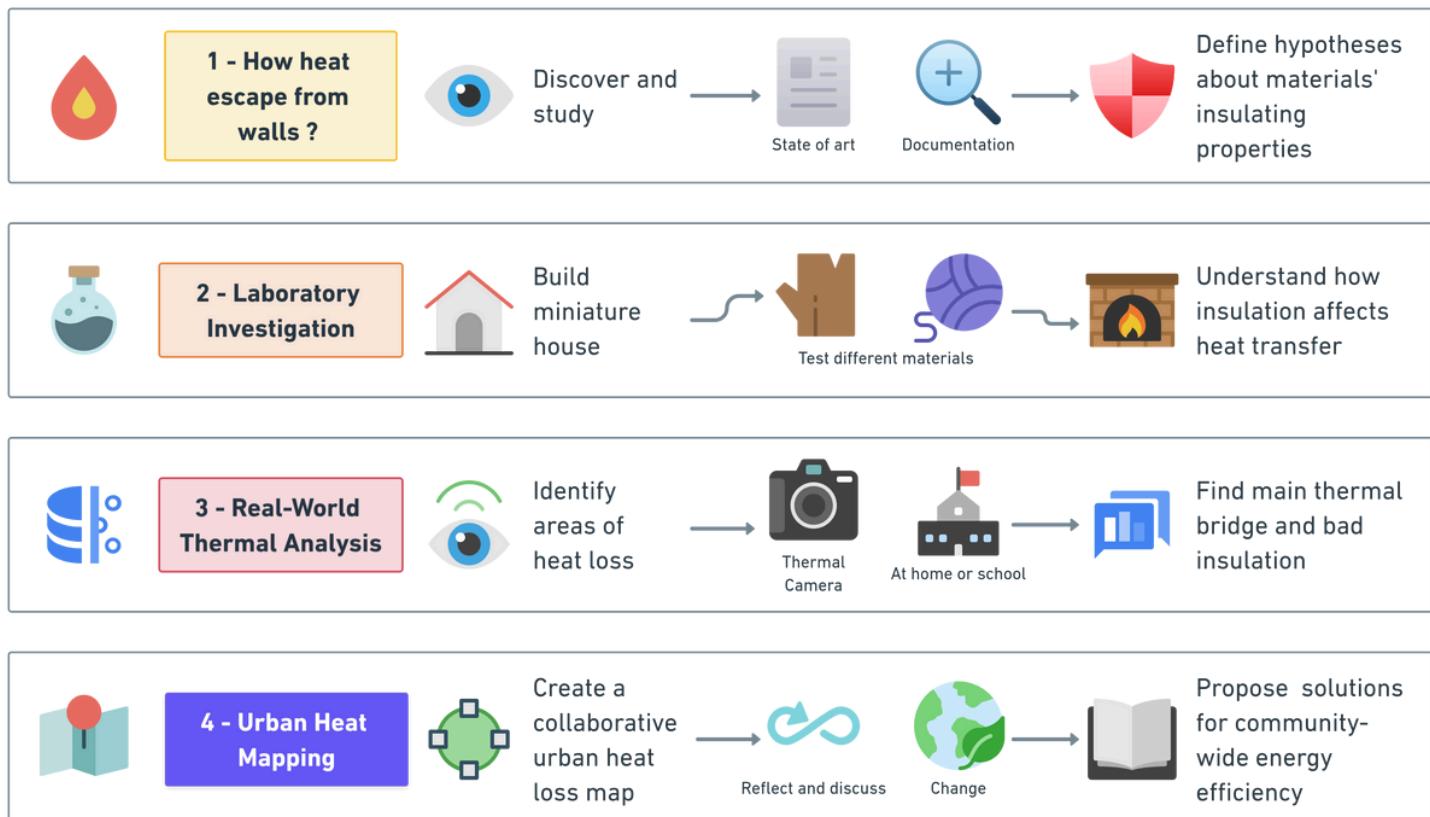


Overview

Protocol Structure

The experiment consists of four key steps that help students progressively understand thermal insulation, from theory to real-world applications. Here is the course outline:

- 1. Step 1 - Investigating the Indoor Climate: Linking Temperature, Humidity, and Comfort - Introduction to Thermal Insulation and Hypothesis Formulation:** Students explore the principles of thermal insulation and learn about factors affecting heat loss, including thermal conductivity, resistance, and building materials. Working together, they form hypotheses about different materials' insulating properties and their real-world performance. This phase includes discussions about heat transfer, insulation, and energy efficiency, along with developing research questions for future investigation.
- 2. Step 2 - Exploring Thermal Insulation Materials - Laboratory Investigation:** In this hands-on phase, students measure and compare the thermal resistance of various insulating materials. Through controlled experiments, they test different materials, thicknesses, and conditions (e.g., dry vs. moist) to understand how each factor affects heat transfer. This work strengthens their skills in experimental design, data collection, and analysis while connecting theory to practice.
- 3. Step 3 - Applying Thermal Insulation Insights to Real-World Contexts:** Students apply their laboratory findings in real settings by using thermal cameras and sensors to study heat loss in their homes or school buildings. They identify and document areas of significant heat loss, such as poorly insulated walls or windows. This practical investigation helps them understand how insulation works in complex, real-world environments.
- 4. Step 4 - Collaborative Mapping of Urban Heat Loss:** In the final phase, students broaden their focus to the community level by conducting a "thermal walk" through their neighborhood or city. Using thermal cameras, they collect data from multiple buildings and create a collaborative urban heat loss map. This phase puts their learning in a broader social context and leads them to propose practical solutions for improving community-wide energy efficiency.



Getting started

Duration: This activity is designed to span four sessions, each session being dedicated to one of the step.

Level of difficulty: *The activity requires students to engage in both theoretical exploration and practical experimentation. It also includes hands-on use of thermal imaging tools and data analysis*



Material needed:

- Thermal cameras or infrared thermometers.
- Insulating materials for laboratory experiments (e.g., foam, cardboard, wool, aluminum foil).
- Temperature sensors or thermometers.
- Access to maps for annotating urban heat loss observations.
- Notebooks or digital tools for data collection and analysis.

Glossary

Keywords & Concepts	Definitions
Thermal Insulation	Materials or techniques used to reduce heat transfer between indoor and outdoor environments.
Thermal Conductivity (λ)	A measure of a material's ability to conduct heat. Lower values indicate better insulation properties.
Thermal Resistance (R)	The ability of a material to resist heat flow, calculated as the material's thickness divided by its thermal conductivity.
Thermal Bridge	Areas in a building where insulation is interrupted, causing higher rates of heat transfer.
Urban Heat Island	A phenomenon where urban areas are warmer than surrounding rural areas due to heat absorption and retention by buildings and infrastructure.
Heat Loss	The transfer of heat from inside a building to the outside environment, typically through walls, windows, doors, and roofs.
Thermal Imaging	The use of infrared cameras to detect temperature variations and visualize heat loss in buildings.
Air Infiltration	The uncontrolled flow of outside air into a building through gaps, cracks, or poorly sealed openings.
R-Value	A measure of an insulating material's effectiveness. Higher R-values indicate better insulation.
Moisture Resistance	The ability of a material to maintain its insulating properties when exposed to humidity or water.
Energy Efficiency	The use of technology or practices to reduce energy consumption while maintaining desired performance levels.
Sustainability	Practices that meet current needs without compromising the ability of future generations to meet their own needs, often linked to environmental stewardship.
Heat Transfer	The movement of heat energy through conduction, convection, or radiation.
Insulation Retrofit	The process of adding or upgrading insulation in an existing building to improve energy efficiency.
Aerial Thermal Imaging	A technique using drones or aircraft to capture thermal data of large areas, such as neighborhoods or cities, to identify heat loss trends.



Protocol

Step 1 - Investigating the Indoor Climate: Linking Temperature, Humidity, and Comfort

Background and description of the problem to be solved in this step: Indoor climate refers to the physical and environmental conditions inside a building that affect occupants' comfort, health, and well-being. Temperature, humidity, air quality, and ventilation are the key measurable factors, though their perception varies among individuals based on preferences, clothing, activity levels, and health status. A well-regulated indoor climate promotes comfort and health. However, poor indoor environments can trigger significant health issues. High humidity encourages mold growth and dust mites—common triggers for asthma and allergies. Conversely, dry conditions can irritate respiratory systems and skin. Long-term exposure to suboptimal conditions—whether too cold, hot, dry, or humid—can lead to chronic issues like cardiovascular strain, respiratory infections, and mental fatigue. Indoor climate consists of these interrelated components:

- **Temperature:** The primary factor in thermal comfort. Indoor temperatures outside 20–25°C can cause discomfort, lower productivity, and strain the body's heat regulation.
- **Humidity:** Air moisture affects both comfort and health. The ideal relative humidity range is 40–60%. Outside this range, **high humidity** promotes mold growth, worsens allergies, and amplifies heat perception and **low humidity** causes skin, eye, and mucous membrane dryness, increasing respiratory infection risk.
- **Air Quality:** Involves pollutants like particulate matter, volatile organic compounds (VOCs), and carbon dioxide. Poor air quality, often from inadequate ventilation, can cause "sick building syndrome" with symptoms like headaches, fatigue, and respiratory irritation.
- **Ventilation:** Enables fresh air exchange, removing pollutants and maintaining oxygen levels.



These elements work together. For instance, high humidity can degrade air quality through mold growth, while poor ventilation can trap heat and pollutants, worsening indoor conditions. Indoor climate extends beyond comfort to affect public health, energy use, and environmental sustainability:

1. **Health Impacts:** Poor indoor conditions particularly affect vulnerable groups—children, elderly, and those with pre-existing conditions. Cold environments increase cardiovascular and respiratory disease risks, while heat can cause dehydration and heatstroke. Poor ventilation and high humidity worsen allergies, asthma, and other chronic conditions.
2. **Energy Use and Environmental Implications:** Poorly insulated buildings require excessive heating or cooling, increasing energy consumption and greenhouse gas emissions. Better insulation and climate optimization support sustainable development and climate action goals.
3. **Economic and Productivity Considerations:** Suboptimal indoor environments reduce worker and student productivity, causing fatigue and concentration problems. In homes, inefficient climate control creates financial strain through high energy costs and health-related expenses, especially in poorly insulated buildings.

Learning Objectives: Explore the interplay between physical parameters (temperature, humidity) and subjective comfort levels. Understand the scientific process of gathering and interpreting environmental data.

Initial Questions to Spark Interest

To connect the topic to students' daily experiences, the teacher can ask:

- **Have you ever noticed that some rooms feel "stuffy" or uncomfortable even when the temperature seems fine? What might be causing that?**

- **How does the indoor environment affect your mood or ability to focus?**
- **Why do you think some houses need a lot of heating or cooling to stay comfortable, while others don't?**

These questions encourage students to draw on their own observations and experiences, setting the stage for an inquiry-driven exploration of indoor climate dynamics.

Conceptualisation

In this phase, students will explore key concepts about indoor climate and its effects on comfort and health. To develop meaningful hypotheses, they must understand the basics of thermal comfort, humidity, ventilation, and how these factors interact. Clear explanations will provide students with the necessary vocabulary and framework for their investigation. Students will examine these core concepts of indoor climate and comfort:

1. **Thermal Comfort:** The balance between environmental factors (temperature, humidity, air movement) and personal factors (clothing, activity level), and how they work together to affect comfort.
2. **Humidity Levels:** Understanding how different humidity levels affect comfort and health:
 - Low humidity: Causes dry skin, respiratory problems, and discomfort.
 - High humidity: Promotes mold and dust mites, leading to allergies and stuffiness.
3. **Ventilation:** How air circulation maintains stable temperature and humidity while removing pollutants.
4. **Health Impacts:** Understanding how poor indoor climate can lead to respiratory issues, heart strain, and decreased mental performance.

Teachers should connect these concepts to students' daily experiences, such as seasonal changes in home comfort or variations between rooms.

Research Questions and Hypotheses: Students will develop specific research questions. A well-crafted research question clearly defines the study's purpose and guides the subsequent hypothesis formation. Sample research questions can be:



- How do temperature and humidity levels differ between various rooms in a home?
- How does ventilation affect temperature and humidity stability over time?
- What factors influence comfort levels across rooms in the same household?

Through guided discussions, students will share observations and develop questions that spark their curiosity. After selecting a research question, students will collaborate to create testable hypotheses. A good hypothesis makes a clear, testable prediction. The teacher should emphasize that hypotheses must use measurable variables. Each hypothesis addresses the research question, and testing may lead to refinements of the original question such as:



1. For "How do temperature and humidity levels differ between various rooms in a home?"
Hypothesis: Rooms with more sunlight exposure will have higher temperatures and lower humidity levels than shaded rooms.
2. For "How does ventilation affect temperature and humidity stability over time?"
Hypothesis: Rooms with better ventilation will show more stable temperature and humidity levels than poorly ventilated spaces.
3. For "What factors influence comfort levels across rooms in the same household?"
Hypothesis: Rooms with higher humidity levels will feel less comfortable, regardless of temperature.

For each hypothesis, students should identify these key variables:

- **Independent Variables:** Factors to change or compare (ventilation status, sunlight exposure, insulation quality)
- **Dependent Variables:** Outcomes to measure (e.g., temperature, humidity, perceived comfort)
- **Controlled Variables:** Factors to keep constant (e.g., time of day, sensor placement)



Encouraging Critical Thinking and Debate: Students should explore different perspectives and question their assumptions: Could building materials or furniture placement affect temperature or humidity? Why might different people experience comfort differently? Are our temperature and humidity measurements capturing all important variations? Students should connect their research to broader challenges: *How can better indoor climate control reduce energy use and improve sustainability? What solutions could create healthier environments in poorly insulated homes? How should these findings shape energy-efficient building design?* These connections show students how their work relates to real-world problems and encourage deeper analysis of their hypotheses.

Guide students in understanding core concepts, developing clear research questions, and creating testable hypotheses. Through collaborative discussion and debate, they prepare students for investigation. This groundwork ensures students are ready to test their hypotheses and explore indoor climate dynamics in the next phase

Students Investigation

In this phase, students will **design and set up experiments to test their hypotheses about how temperature, humidity, and other indoor climate factors affect comfort levels in different areas of their homes**. The teacher will help students develop a clear and practical protocol while encouraging critical thinking and scientific rigor. Before starting the experiments, students will review relevant literature to better understand indoor climate and comfort factors. Key resources will include **scientific articles on thermal comfort standards, technical guides on temperature and humidity measurement and case studies and infographics showing indoor climate's effects on health and energy use**. This background research will strengthen their investigation and help them contextualize their findings within established scientific knowledge.

Define the Experimental Protocol: A well-designed experimental protocol is essential for reliable and reproducible results. Here are key elements to consider through two example experimentation protocols:



Protocol 1 - Study Objective: Investigate how temperature and humidity variations across different rooms affect perceived comfort levels.

Hypothesis: Rooms with higher humidity levels will be perceived as less comfortable, regardless of temperature.

Study Duration: One week of data collection, with three daily measurements (morning, afternoon, and evening).

Data Collection Method:

- **Quantitative Measurements:** Place temperature and humidity sensors in three locations: bedroom, bathroom, and living space. Maintain consistent sensor placement to avoid bias. Record measurements at fixed times to track daily patterns.
Qualitative Observations: Record comfort levels using simple descriptors: "comfortable," "too dry," or "too humid." Document environmental conditions (window status, heating status, sunlight exposure).

Data Usage:

- **Data Storage:** Record all measurements in a structured table:

Date/Time	Room	Temperature (°C)	Humidity (%)	Perceived Comfort	Environmental Notes
07/01 - 8 AM	Bedroom	18°C	55%	Comfortable	Heating on, curtains closed
07/01 - 8 PM	Bathroom	22°C	70%	Too Humid	Window closed, no ventilation

- Data Analysis: Compare temperature and humidity across rooms, correlating them with comfort ratings. Use statistical tools to identify patterns (averages, ranges, correlations).

Interpretation and Evaluation:

- Evaluate whether the data supports the hypothesis by examining the relationship between humidity and comfort levels.
- Identify patterns related to ventilation and insulation effects on indoor climate.

Presentation of Results:

- Generate visual representations (bar graphs, line charts) showing temperature and humidity patterns with comfort ratings.
- Create a concise presentation highlighting key findings and their implications for indoor climate improvement.



Protocol 2 - Study Objective: Investigate how ventilation influences temperature and humidity stability in different rooms.

Hypothesis: Ventilated rooms will exhibit less fluctuations in temperature and humidity than non-ventilated rooms.

Study duration: A two-week period, with data collected every ten minutes.

Data collection method:

- Quantitative measurements: Use a humidity/temperature sensor at each chosen location. Keep numerical value for humidity and temperature.
- Environmental observations: Record relevant environmental factors, such as the type of wall, location of the windows, ventilation activity,
- Qualitative Measurements: Observe and note comfort feeling.

Data usage:

- Data storage: Store quantitative data in a CSV file, including information about the date, time, location, and environmental conditions.
- Data analysis: Calculate averages and medians temperature and humidity in different locations. Create graphs to visualize the comfort level and the link with environmental factors. Identify trends and discuss any notable differences.
- Comparison of factors: Visually compare comfort level with temperature and humidity, and other recorded factors. Use simple graphs to highlight general trends between these indicators. Discuss any deviations from these trends.
- Correlation analysis: Calculate correlation coefficients between comfort level and temperature/humidity. Interpret these coefficients to determine how strongly comfort level is related to each axis of analysis. Discuss which factors may be the most influential.

Presentation of results: Present the findings in the form of graphs showing the correlation between variables. Document the entire protocol in an infographic that can be shared with the class, the school, or on social media.

Prepare Experimental Setup

Students will collaborate in small groups to define their protocol's practical details. Careful setup preparation is essential for reliable data collection. Here are the key considerations:

- **Sensor Placement:**
 - Optimal height: Position sensors 1.5m above the floor to match a seated person's height
 - Distance from heat sources: Keep at least 1m away from radiators, windows, and electronic devices
 - Central position: Select open areas away from corners where air might stagnate

- **Control Variables:**

- Measurement period: Set consistent time slots (e.g., 8am, 2pm, 8pm)
- Weather conditions: Document outdoor conditions with each measurement
- Room occupancy: Take measurements during similar occupancy patterns

- **Data Integrity:**

- Calibration: Check sensor accuracy before starting measurement series
- Double verification: Deploy multiple sensors to cross-validate readings
- Detailed log: Record any unusual events or anomalies



To help you program the appropriate sensor, refer to **Practical Implementation 1 - Collect Data with the Temperature Sensor**.

The teacher's role is to support this process by encouraging students to think critically about potential sources of error and ways to improve measurement reliability. They also guide discussions on the importance of rigorous methodology in science.



Active Learning Approach: While students are encouraged to design the protocol themselves, the teacher plays a crucial role as a guide:

- Ensuring that the protocol aligns with scientific standards for data collection and analysis.
- Prompting students to consider how their hypotheses shape their experimental design.
- Helping groups address logistical challenges, such as sensor availability or time constraints.

At the end of this step, students will have a well-developed experimental protocol that they can use to conduct their investigation.

Conclusion & Further Reflexion



- **Knowledge Mobilized:** By completing this phase, students will understand how temperature, humidity, and other factors shape indoor climate and affect comfort and health. They will learn to measure environmental parameters and connect these measurements with personal observations to build a complete picture of indoor spaces. Students will also grasp how these elements work together to influence energy efficiency and sustainable living.
- **Classroom Implementation Reflection:** During this phase, students develop essential scientific skills by formulating hypotheses, designing protocols, and conducting systematic data collection and analysis. The activity emphasizes collaborative learning as students work together to refine research questions and adapt their methods to real-world constraints. Students also strengthen their decision-making abilities through managing variables, maintaining experimental consistency, and solving practical challenges that arise during their investigation.
- **Learning Outcomes:** Students will refine their ability to formulate clear research questions and testable hypotheses, design and execute systematic experiments, gather and interpret both quantitative and qualitative data. Through identifying variables, testing hypotheses, and analyzing results, students will strengthen their ability to evaluate evidence and form reasoned conclusions. Students will apply their findings to real-world challenges, including indoor comfort optimization, energy efficiency, and health improvement. By examining the intersection of thermodynamics and health sciences, students will gain a comprehensive understanding of indoor climate as a complex system.

To conclude this phase, students will explore key questions that encourage deeper reflection on their study and its broader implications:

1. How can we apply these experimental findings to enhance building energy efficiency, and what role do construction materials and insulation play in creating indoor climate variations across different homes?

2. Which other environmental factors—like air quality and natural light—merit investigation for understanding indoor climate, and how will climate change affect indoor environments and our strategies for maintaining comfort and health?
3. How might our improved understanding of indoor climate shape future urban planning and building design, and how can these principles guide the design of environments in extreme conditions, like space stations or arctic bases?
4. What health advantages could better indoor climates offer, especially for vulnerable groups like children and the elderly, and how do cultural and regional differences in living habits—such as window use and heating preferences—shape comfort perception?

Through this reflective process, students will think critically about their findings and connect them to broader challenges. This helps them grasp how scientific inquiry can address both individual and societal needs.

Step 2 - Exploring Thermal Insulation Materials

Background and description of the problem to be solved in this step: Thermal insulation is essential for maintaining stable, comfortable indoor environments while reducing energy consumption and costs. Materials vary in their insulating effectiveness based on four key properties: thermal conductivity, thickness, air permeability, and resistance to moisture. Understanding these characteristics helps us choose the most effective materials for improving building energy efficiency and comfort. Poorly insulated buildings face two major challenges: in cold weather, heat escapes through walls, roofs, and floors, forcing heating systems to work harder; in warm weather, excess heat enters, increasing cooling needs. These inefficiencies result in higher energy bills and increased greenhouse gas emissions, making proper insulation crucial for environmental and economic sustainability.



- What physical properties make a material an effective thermal insulator?
- How can insulation improve temperature regulation and energy efficiency?
- What trade-offs exist when choosing between different insulation materials?
- How does material thickness influence heat transfer reduction?
- How do external factors like moisture and air infiltration affect insulation performance?

Learning Objectives: Examine and comprehend the fundamental physical properties of insulating materials, including thermal conductivity, resistance, and their behavior in various conditions (such as moisture exposure). Create and perform experiments to evaluate and contrast the effectiveness of different materials. Evaluate how material choices affect performance, environmental impact, and cost considerations.

This phase introduces students to the science of thermal insulation and encourages them to think critically about how material properties affect real-world performance. Through hands-on investigation, students will discover the direct connection between theoretical concepts and practical applications.

Conceptualisation

In this phase, students will explore the fundamental properties that characterize effective insulation materials and examine how these properties contribute to enhanced thermal performance in real-world applications. Through systematic investigation and analysis, they will study the relationships between material composition, structure, and insulating capabilities. This thorough understanding of insulation principles will enable students to formulate well-reasoned hypotheses and design rigorous experimental protocols that test their predictions about thermal behavior and energy efficiency. These foundational concepts serve as essential building blocks for developing sophisticated experimental methodologies and interpreting results within a broader scientific context.

Thermal Conductivity (λ): This fundamental property measures the rate at which heat energy flows through a material under specific temperature conditions. Materials with lower thermal conductivity create more effective barriers against heat transfer, making them superior insulators. For example, still air has a very low thermal conductivity of about $0.024 \text{ W}/(\text{m}\cdot\text{K})$, which explains why many effective insulation materials incorporate trapped air pockets.

Thermal Resistance (R): This critical parameter quantifies a material's capacity to impede heat flow across its entire thickness. The relationship between thermal resistance, material thickness, and thermal conductivity is expressed through the following equation, where higher R-values indicate greater insulating effectiveness:

$$R = \frac{\text{Thickness (m)}}{\lambda}$$

Specific Heat Capacity (c): The specific heat capacity (c) of a substance is the amount of heat that must be added to one unit of mass of the substance in order to cause an increase of one unit in temperature. The SI unit of specific heat capacity is joule per kelvin per kilogram, $J \cdot kg^{-1} \cdot K^{-1}$.

Density (ρ): Density is a substance's mass per unit of volume. Mathematically, density is defined as mass divided by volume.

$$\rho = \frac{m}{V}$$

Volumetric Heat Capacity (VHC): The volumetric heat capacity c of a material is the heat capacity of a sample of the substance divided by the volume of the sample. It is the amount of energy that must be added, in the form of heat, to one unit of volume of the material in order to cause an increase of one unit in its temperature. The SI unit of volumetric heat capacity is joule per kelvin per cubic meter, $J \cdot K^{-1} \cdot m^{-3}$.

$$VHC = \rho c$$

Thermal Mass: Thermal mass, or the ability to store heat, is also known as volumetric heat capacity (VHC). VHC is calculated by multiplying the specific heat capacity by the density of a material:

- Specific heat capacity is the amount of energy required to raise the temperature of 1kg of a material by $1^{\circ}C$.
- Density is the weight per unit volume of a material (ie how much a cubic metre the material weighs).

The higher the VHC, the higher the thermal mass.

Thermal effusivity (e): Material's thermal effusivity, also known as thermal responsivity, is a measure of its ability to exchange thermal energy with its surroundings. It is defined as the square root of the product of the material's thermal conductivity (λ) and its volumetric heat capacity (VHC).

$$e = \sqrt{\lambda \rho c}$$

Thermal effusivity is a good approximation for the material's thermal inertia.

Air Permeability: This characteristic describes how readily air can penetrate through a material's structure. While some degree of breathability can be beneficial for moisture management, excessive air permeability can significantly compromise a material's insulating performance by creating thermal bridges and allowing unwanted heat exchange through convection currents.

Moisture Resistance: This crucial property determines how well an insulating material maintains its thermal performance when exposed to varying humidity levels and water exposure. Materials with poor moisture resistance can experience significant degradation in their insulating capabilities, as water has much higher thermal conductivity than air and can displace the trapped air that provides insulation.

Environmental Impact: This comprehensive assessment encompasses the material's entire lifecycle, from raw material extraction through manufacturing, installation, use, and eventual disposal. Key considerations include embodied energy, carbon footprint, potential for recycling or biodegradation, and overall contribution to sustainable construction practices and building energy efficiency.

Through class discussions and guided explanations, **students will connect theoretical concepts to real-world applications**. They'll explore **everyday scenarios** like **why some buildings stay comfortable more easily than others**, **how weather affects indoor climate**, and **how moisture gradually reduces insulation effectiveness** over time. Working in small groups, students will develop **specific, measurable research questions** that match both their interests and available resources. Example questions include:

- How do different insulation materials perform under controlled conditions, and how do they respond to temperature changes?
- How does varying insulation thickness affect thermal resistance, and what is its relationship to energy efficiency?
- How do moisture and humidity affect insulation materials' long-term performance?

By crafting these focused research questions, students will build a strong foundation for their experiments. This ensures their investigation remains systematic and yields practical insights into thermal management. Students will then develop hypotheses to predict experimental outcomes. Each hypothesis should establish clear, testable relationships between variables with specific, measurable predictions about thermal behavior, while remaining practical to test with available resources. Here are some examples:

- *Foam-based insulation materials will maintain internal temperatures 20-30% more effectively than natural fiber alternatives when exposed to equivalent heat sources, due to their closed-cell structure and trapped air pockets.*
- *For every 1cm increase in material thickness, the thermal resistance will improve by approximately 0.5 R-value units, following a linear relationship until reaching a plateau.*
- *Materials with high air permeability ($>300 \text{ cm}^3/\text{cm}^2/\text{s}$) will show 40-50% lower thermal resistance than those with low permeability ($<50 \text{ cm}^3/\text{cm}^2/\text{s}$) under identical conditions.*

Students must carefully categorize their variables into these groups:

- **Independent Variables:** The factors researchers will modify throughout the study:
 - Material composition - density (kg/m^3), porosity, and structural characteristics
 - Material thickness - measurements in millimeters with documented tolerances
 - Moisture content - measured as percentage by weight
- **Dependent Variables:** The measurable outcomes:
 - Temperature differential - in degrees Celsius
 - Heat transfer rate - in watts per square meter (W/m^2)
 - Calculated R-values - from experimental measurements
- **Controlled Variables:** Conditions that must remain constant:
 - Heat source intensity - maintained at precise wattage
 - Exposure duration - standardized measurement intervals
 - Ambient room temperature - within $\pm 0.5^\circ\text{C}$

To deepen understanding, students will connect their findings to broader challenges through these questions:

- How do different insulation materials affect building energy use, and how can we measure their impact on carbon emissions and energy costs?
- What factors should we consider when comparing synthetic and natural insulating materials, including manufacturing energy, longevity, disposal, and environmental impact?
- How can we apply insights from these small-scale studies to improve building practices and architectural design?

This reflection helps students place their work within larger sustainability contexts while developing critical thinking skills. By linking lab results to practical applications, students better understand how scientific inquiry advances sustainable building practices.

Role of the Teacher: The teacher acts as a facilitator and mentor throughout this investigative process, guiding students toward deeper understanding while fostering their independence. Their primary responsibilities include:



- Ensuring students grasp fundamental concepts and terminology related to thermal insulation
- Encouraging the development of precise, testable research questions and well-structured hypotheses
- Leading productive group discussions that challenge students to think critically
- Providing relevant examples that bridge theoretical concepts with practical applications
- Offering constructive feedback to help refine experimental designs

Students Investigation

In this phase, students will conduct a controlled experiment to test their hypotheses about the effectiveness of different insulation materials. The teacher will help develop a structured protocol to ensure systematic measurement and comparison of the materials' thermal properties. Before experimenting, students will complete a focused literature review to:

- Study the key physical properties of insulating materials, including thermal conductivity and resistance.
- Examine existing research on insulation effectiveness to strengthen their experimental design.
- Learn how environmental factors like moisture and air infiltration affect material performance.

This foundational research will help students create robust methods that connect to real-world applications.

Example of Protocol Application



Hypothesis: Increasing the thickness of an insulating material will proportionally improve its thermal resistance.

Steps:

Test foam samples at thicknesses of 1 cm, 2 cm, and 3 cm.

Measure temperature differences across each sample using identical conditions.

Plot results to assess the relationship between thickness and resistance.

Prepare Experimental Setup

This experiment will measure how effectively different materials resist heat transfer under controlled conditions.

Objective: Compare the thermal resistance of various insulation materials by examining their material type, thickness, and response to moisture.

Materials Needed:

- Insulation material samples (foam, cardboard, wool, aluminum foil)
- Heat source (desk lamp or electric heating element)
- Temperature sensors or thermometers
- Insulated box or model house
- Stopwatch or timer
- Ruler or caliper

Procedure

- **Baseline Measurements:** Record ambient and heat source temperatures. Allow all materials to reach room temperature.
- **Testing Materials:** Position insulating material between heat source and temperature sensor. Monitor temperatures on both sides for 10 minutes. Test all samples using identical placement and timing.
- **Thickness Variations:** Test each material at 1 cm, 2 cm, and 3 cm thicknesses. Record temperature differences for each thickness.
- **Moisture Exposure (Optional):** Test water-soaked samples to evaluate moisture's effect on insulation.
- **Control Variables:** Maintain constant heat source output. Keep fixed distances between heat source, material, and sensor.
- **Data Collection and Organization:** Record all measurements in a structured table:

Material	Thickness (cm)	Moisture Level	Initial Temp (°C)	Final Temp (°C)	Temp Difference (°C)	Observations
Foam	1	Dry	20	30	10	Lightweight, easy to cut
Wool	2	Wet	20	33	13	Absorbs water quickly

- **Data Analysis and Interpretation:**

1. **Calculating Thermal Resistance (R):** Compare materials to identify top performers

2. **Visualizing Results:**

- Create graphs showing temperature differences and thermal resistance
- Identify patterns in thickness and moisture effects

3. **Interpreting Findings:**

- Identify the most effective heat-transfer barriers
- Compare results against initial hypotheses

Miniature model: To make the experiment more meaningful, students can use a miniature house model. Rather than reinventing the wheel, this model can be based on existing, cost-effective solutions. Given the constraints, a mini-greenhouse serves as the ideal solution. Its transparent walls clearly demonstrate the model's temperature sensitivity when exposed to a simple desk lamp. Since automated mini-greenhouse construction is included in the French technology syllabus, several adaptable examples are available for this protocol:

- [ÅKERBÄR Serre - intérieur/extérieur/anthracite 65 cm](#)
- [Pack Serre Autonome sans interface de programmation](#)
- [Maquette mini-serre en kit](#)
- [Projet de Sciences et Technologie cycle 3](#)



For this project, a simple and cost-effective model is ideal. Basic kits are available for around 10€ that meet all protocol requirements: [Maquette la Serre à assembler complètement](#)

You can build the kit at an even lower cost using readily available materials from DIY stores. The manufacturing instructions are available here:

https://technologieservices.fr/media/akeneo_connector/asset_files/N/o/Notice_TS_dossier_technique_KT5016_270203_FR_bb92.pdf

The design makes insulation straightforward, with simple triangular and rectangular shapes. Thanks to the full-width opening, insulation materials can be easily installed on both interior and exterior surfaces.

Evaluate the scientific validity of the experiments

Ensuring scientific validity is a central aspect to discuss with students. They need to understand the limitations of their experiments and how to address them. For example, the teacher can ask each student group questions to examine common issues affecting scientific validity:

- **Comprehensive Troubleshooting Protocol:**

- Systematically evaluate and adjust sensor placement when encountering measurement inconsistencies, documenting each adjustment and its impact on readings
- Implement a structured series of repeated measurements at regular intervals to establish measurement reliability and identify potential systematic errors
- Document environmental conditions that might affect readings, including ambient temperature fluctuations and air currents

- **Rigorous Reliability Measures:**

- Execute a minimum of five trials for each material configuration to establish statistical significance and calculate standard deviation
- Utilize multiple sample sets from different batches of the same material to account for manufacturing variations
- Maintain detailed documentation of any deviations from standard protocol and their potential impact on results

- **Quality Control Procedures:**

- Calibrate all measurement instruments before each testing session
- Implement cross-validation methods by having different team members independently verify measurements
- Establish clear criteria for identifying and handling outlier data points

Teacher's Role: The teacher serves as a facilitator by:



- Guiding students to refine their experimental protocols for maximum consistency and scientific rigor
- Fostering critical thinking through questions about potential sources of error
- Facilitating collaborative discussions to help students visualize and interpret their data

By the end of this phase, students will have conducted a hands-on experiment, analyzed their data, and gained insights into the factors that make materials effective thermal insulators. This investigation prepares them to apply their findings to practical contexts, such as designing energy-efficient solutions or improving insulation in real-world settings.

Conclusion & Further Reflexion



- **Knowledge Mobilized:** Students will develop a clear understanding of how insulation materials work, focusing on key properties like thermal conductivity, resistance, thickness, and moisture effects. They will see how these properties work together to improve energy efficiency, comfort, and environmental impact. Through hands-on experiments, students will learn to measure thermal performance and test their predictions. This practical experience shows them how scientific methods can solve real-world problems.
- **Classroom Implementation Reflection:** Through hands-on experimentation and collaborative analysis, students strengthen their ability to: design and refine precise, consistent experimental protocols, systematically collect and organize quantitative data, and analyze and visualize results to uncover meaningful patterns. This phase emphasizes the collaborative nature of scientific investigation, with students working together to share responsibilities, compare observations, and reach conclusions. As they tackle challenges like measurement variability and environmental factors, students develop stronger problem-solving abilities and scientific discipline.
- **Learning Outcomes:** Students will enhance their ability to design and conduct experiments by controlling variables and measuring results, apply mathematical formulas to calculate thermal resistance and other material properties, and analyze data rigorously to reach evidence-based conclusions. Students will evaluate trade-offs between material performance, cost, and environmental impact. Students will apply their findings to real-world challenges like home energy efficiency and sustainable building design. Students will understand how materials science advances global sustainability, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action)

To conclude this phase, students will participate in a reflective discussion guided by open-ended questions that explore the study's deeper implications:

1. How do your experimental results support or challenge your initial hypotheses?
2. Beyond thermal performance, what factors—like durability and environmental impact—should guide insulation material selection?
3. How can we apply these findings to enhance building energy efficiency?
4. What are the key performance, cost, and sustainability trade-offs between natural and synthetic insulation materials?
5. How do different climates and building types affect insulation requirements?
6. Which emerging insulation technologies might solve current challenges with moisture and cost?
7. In what ways does effective insulation help reduce energy consumption and combat climate change?
8. What additional material properties should we evaluate when choosing sustainable construction materials?

This phase provides students with the scientific understanding and analytical skills to tackle real-world applications, from assessing their homes' insulation to designing energy-efficient structures. These practical insights help students view insulation as part of an integrated system that balances comfort, sustainability, and environmental stewardship.

Step 3 - Applying Thermal Insulation Insights to Real-World Contexts



Background and description of the problem to be solved in this step: In this phase, students will apply their understanding of insulation to real-world scenarios. This step connects their experimental findings from Step 2 with practical applications, enabling them to analyze, evaluate, and propose solutions to improve building energy efficiency. Buildings are among the world's largest energy consumers, with heating and cooling systems using a major portion of this energy. Poor insulation exacerbates this problem—heat escapes in winter and enters in summer. This inefficiency increases both energy consumption and utility costs while generating more greenhouse gas emissions. Proper insulation is therefore crucial for sustainable construction and energy-efficient living. Inadequate insulation affects not just the environment but also occupant health and comfort. Poorly insulated buildings suffer from uneven temperatures, drafts, and condensation. These issues create discomfort and can trigger health problems, particularly respiratory issues from dampness and mold. Understanding where and why buildings lose heat is essential to addressing these challenges. Students will apply their laboratory findings to real-world situations. By analyzing the thermal performance of their homes and school buildings, they'll identify insulation weaknesses and develop practical solutions. This hands-on approach shows how scientific principles solve real problems while giving students the knowledge to make informed recommendations about energy efficiency.

Learning Objectives: Use tools such as thermal cameras and sensors to identify and analyze heat loss in real-world settings. Evaluate the effectiveness of existing insulation in homes or schools by comparing observed data to experimental results. Propose realistic, cost-effective strategies to enhance insulation and improve energy efficiency.

Conceptualisation

This step invites students to think critically about how their experimental findings relate to real-world challenges:

- **Which areas of my home or school are most prone to heat loss, and what causes these weaknesses?**
- **How does the effectiveness of the insulation I observe compare to the materials tested in the lab?**
- **What practical solutions can enhance insulation performance and reduce energy demand?**

Students will undertake an in-depth exploration of insulation principles through hands-on analysis of real-world thermal performance in buildings. This practical investigation allows them to bridge theoretical knowledge with tangible applications. To conduct this analysis effectively and draw meaningful conclusions, students will need to thoroughly explore and develop a detailed understanding of several interconnected concepts:

1. **Thermal Imaging and Heat Loss Analysis:** Through the application of sophisticated thermal imaging cameras and precise infrared thermometers, students will learn to detect and analyze temperature variations across building surfaces. These advanced tools reveal critical areas of heat loss, particularly in commonly vulnerable locations such as poorly insulated walls, inadequately sealed roofs, aging windows, and improperly fitted doors. Students will develop expertise in interpreting complex thermal patterns and temperature gradients, enabling them to accurately identify and assess specific areas of insulation inefficiency in building envelopes.
2. **Thermal Bridges and Structural Considerations:** Students will examine the significant impact of thermal bridges - specialized zones in building construction where heat transfer occurs at an accelerated rate due to breaks in insulation continuity or the presence of highly conductive structural elements. These can include metal window frames, steel building supports, concrete floor-wall junctions, and other architectural features. Understanding the mechanics and implications of these thermal bridges becomes crucial for developing comprehensive improvement strategies.
3. **Energy Efficiency and Heat Transfer Mechanisms:** Through detailed comparative analysis, students will establish connections between their laboratory findings from Step 2 and real-world thermal behavior. This involves examining how different heat transfer mechanisms - conduction, convection, and radiation - manifest in actual buildings. Students will learn to correlate measured thermal properties like conductivity and resistance with observable heat loss patterns, developing a more nuanced understanding of building thermal dynamics.

4. Comprehensive Cost-Benefit Analysis: Students will conduct thorough evaluations of potential insulation improvements, considering multiple factors beyond simple thermal performance. This includes analyzing initial material and installation costs, projected long-term energy savings, environmental impact reduction through decreased carbon emissions, and potential improvements in occupant comfort. They will learn to calculate payback periods and return on investment while also considering factors such as material durability, maintenance requirements, and local climate conditions in their assessment of various upgrade options.

Research Questions and Investigative Framework: Through collaborative discussions and careful analysis, students will develop comprehensive, empirically-testable research questions that will serve as the foundation for their investigation. These questions should encompass both a thorough assessment of current insulation effectiveness and a detailed exploration of potential enhancement strategies. The questions should be specifically crafted to generate quantifiable data and meaningful insights:

- What are the primary zones of thermal energy loss within residential and educational buildings, and what specific structural, material, or environmental factors contribute to these inefficiencies?
- How do the thermal performance characteristics of existing building insulation systems compare with the laboratory-tested materials from our previous experimental phase, particularly in terms of heat retention and transfer rates?
- Which evidence-based, cost-effective interventions could be implemented to enhance thermal efficiency in identified problem areas, considering both immediate and long-term performance metrics?



Fostering Critical Thinking and Broader Connections: To deepen their understanding, students will explore how their findings connect to broader societal challenges: *How do insulation improvements affect both a building's carbon footprint and energy costs? What are the key trade-offs between natural and synthetic insulation materials regarding cost, performance, and environmental impact? In what ways does climate and geographic location shape the selection of insulation strategies?* These focused questions push students to think beyond their immediate context to understand insulation's role in sustainable development and climate action.



These carefully formulated questions establish a robust framework for systematic investigation, enabling students to create meaningful connections between their experimental findings and practical applications while developing critical analytical skills. Building upon these research questions, students will formulate detailed hypotheses that make specific, testable predictions grounded in their preliminary observations and experimental data. Here are some representative examples:

- Areas featuring visible thermal bridges will demonstrate heat loss rates approximately 40-60% higher than adjacent sections with continuous insulation, particularly during peak temperature differentials.
- Building sections constructed prior to modern insulation standards will show thermal efficiency ratings 30-50% lower than newer additions, primarily due to degradation of materials and outdated installation techniques.
- Strategic implementation of supplementary insulation layers will yield measurable improvements in thermal retention, with an anticipated reduction in heat loss ranging from 20-35%, depending on material selection and installation methods.

Each hypothesis should establish clear relationships between carefully defined independent variables (such as insulation materials, building construction periods, and material thickness), measurable dependent variables (including quantifiable heat loss patterns and temperature differentials), while maintaining rigorous control over external variables (environmental conditions, measurement duration, and ambient temperature fluctuations).



Role of the Teacher: The teacher will guide students by helping students craft precise, measurable research questions that align with their investigation goals, supporting the development of testable hypotheses that clearly connect variables to thermal performance and facilitating meaningful discussions that link the investigation to real-world scientific and social implications.

Students Investigation

In this comprehensive investigative phase, students will conduct a thorough examination of their home or school building's **thermal performance** through the strategic deployment of **sophisticated diagnostic tools** including **thermal imaging cameras**, **environmental sensors**, and **precision infrared thermometers**. This hands-on investigation enables students to systematically evaluate their carefully formulated hypotheses by methodically identifying and documenting areas of **significant heat loss**, while conducting detailed analysis of how various **insulation configurations** and **materials** contribute to the overall **energy efficiency** of the structure. Through this process, students will gain practical experience in real-world thermal assessment techniques while developing a deeper understanding of how theoretical principles of **heat transfer** manifest in actual building environments.



Example of Protocol Application: **Hypothesis:** Walls with visible thermal bridges will exhibit higher heat loss compared to uniformly insulated walls. **Steps:** Use a thermal camera to scan walls, focusing on potential bridge locations. Measure temperature differences at these points. Compare findings with uniformly insulated sections. Calculate the relative heat loss and suggest improvements.

Preparing for the Investigation

1. Tools and Materials Needed:

- Thermal imaging camera or infrared thermometer.
- Temperature and humidity sensors
- Access to the building's floor plan or a simple sketch for mapping findings.
- Notebook or digital device for recording observations.

2. Pre-Investigation Setup:

- Ensure students understand how to operate thermal tools safely and accurately.
- Introduce a calibration activity where students measure the temperature of known surfaces (e.g., a wall in direct sunlight versus one in shade).



To help you to use the appropriate sensor, refer to the section "**Practical Implementation 2 - Using Thermal Cameras for Insulation Analysis**".

Steps to Conduct the Investigation

- **Identify Testing Locations:** Students will determine key areas to analyze, focusing on common sources of heat loss such as windows, doors, external walls, roofs, and floors.
- **Capture Thermal Data:** Using thermal cameras or thermometers, students will record temperature variations at each location. Highlight thermal bridges, drafts, or poorly insulated areas by capturing detailed images or readings.
- **Measure Environmental Conditions:** Record outdoor temperature, wind conditions, and sunlight exposure during the investigation. Note any HVAC system activity (e.g., heating or cooling) that might influence indoor temperatures.
- **Document Observations:** Use a table or annotated floor plan to log findings.

Location	Temp. Inside (°C)	Temp. Outside (°C)	Temp. Difference (°C)	Observations
Living Room Wall	18	5	13	Visible heat loss through thermal bridge
Window Frame	15	5	10	Drafts detected, poor insulation observed

- **Relate to Experimental Findings:** Compare the observed performance of the building's insulation to the materials tested in Step 2. Discuss how material properties like thickness, thermal conductivity, and moisture resistance may explain the observed variations.

Analysis and Interpretation

- **Evaluate Thermal Performance:** Identify the areas of greatest heat loss and the factors contributing to it (e.g., poor insulation, thermal bridges). Determine whether the findings align with experimental results from Step 2.
- **Propose Improvements:** Students will brainstorm and recommend specific actions to reduce heat loss. These could include adding insulation layers to walls, floors, or roofs, sealing gaps around windows and doors and upgrading to double-glazed or energy-efficient windows.
- **Visualize Results:** Create thermal maps or annotated images to present findings. Use graphs to compare the effectiveness of different areas (e.g., insulated vs. non-insulated walls).

Challenges and Validity Considerations in Thermal Assessment

- **Measurement Challenges and Environmental Variables:** Address the complex interplay of factors affecting thermal readings, including daily temperature fluctuations, seasonal weather patterns, varying solar exposure throughout the day, and the dynamic impact of HVAC systems on internal temperature distribution. These variables can significantly influence measurement accuracy and must be carefully controlled or accounted for in the analysis.
- **Ensuring Experimental Consistency and Data Reliability:** Emphasize the implementation of standardized measurement protocols, including conducting readings at consistent times of day, maintaining uniform environmental conditions where possible, and establishing clear measurement intervals. This systematic approach helps minimize variability and ensures the collection of reliable, comparable data across different testing periods and locations.
- **Acknowledging Technical and Practical Limitations:** Discuss the various constraints that may impact the investigation's comprehensiveness, such as restricted access to certain building areas, limitations in measurement tool precision and calibration, potential interference from building materials, and the challenges of maintaining consistent environmental conditions throughout the study period. Understanding these limitations helps in developing more robust experimental designs and interpreting results with appropriate consideration for uncertainty.



By the end of this investigation, students will have a detailed understanding of their building's insulation performance and actionable ideas for improvement. This hands-on activity reinforces the connection between theoretical knowledge and practical applications, preparing students to make informed recommendations for energy efficiency and sustainability.

Conclusion & Further Reflexion



- **Knowledge Mobilized:** By the end of this phase, students will have gained a deeper understanding of how theoretical principles of insulation apply to real-world contexts. They will have learned to identify and analyze thermal inefficiencies in buildings, interpret data collected from thermal imaging or temperature sensors, and relate their findings to broader energy efficiency goals. Students will also recognize the practical limitations and challenges of applying insulation principles in diverse environments, considering factors such as material availability, structural constraints, and budget.
- **Classroom Implementation Reflection:** By engaging in hands-on investigations, students enhance their critical thinking and ability to connect scientific principles with tangible improvements in their everyday environments. This phase reinforces students' ability to bridge the gap between experimental findings from Step 2 and real-world observations, use tools like thermal cameras to conduct meaningful analyses of insulation performance and work in teams to propose realistic, cost-effective solutions to improve insulation.
- **Learning Outcomes:** Students will refine their ability to collect, analyze, and interpret real-world data. Through identifying weaknesses in insulation and proposing improvements, students will evaluate trade-offs between effectiveness, cost, and environmental impact. Students will connect their findings to larger societal goals, such as reducing energy consumption and addressing climate change. Reflecting on how local improvements contribute to global sustainability efforts, students will appreciate the role of science in promoting SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action).

To conclude this phase, students will engage in a discussion centered on open-ended questions. These questions are designed to encourage deeper reflection on the study and its broader implications. Several questions can be opened for discussion:

1. How do the areas of greatest heat loss in your home or school align with your initial hypotheses?
2. What surprised you about the thermal performance of your building?
3. How do the materials and conditions you observed compare to the results from Step 2?
4. What cost-effective improvements could significantly reduce heat loss and improve energy efficiency?
5. How do regional climates and building codes influence insulation needs and strategies?
6. What role can innovations in insulation technology play in addressing global energy challenges?
7. How can your findings be scaled to inform sustainable construction practices in your community?

This phase provides a platform for students to think critically about how science, engineering, and policy intersect to solve real-world problems. By understanding the importance of insulation in reducing energy waste and improving comfort, students will be equipped to engage with larger discussions about sustainability, urban planning, and climate resilience. Students could use their findings to develop actionable projects, such as:

- Creating an insulation improvement plan for their school or home.
- Designing energy-efficient buildings as part of a collaborative class project.
- Presenting their findings in a public awareness campaign about insulation and energy efficiency.

Step 4 - Collaborative Mapping of Urban Heat Loss

Background and description of the problem to be solved in this step: In this final phase, students will extend their learning beyond individual buildings to a larger community context. By conducting a collaborative thermal mapping project, they will analyze heat loss patterns in their local neighborhood or city. This activity fosters an understanding of the broader implications of insulation and energy efficiency, while empowering students to contribute to community awareness and potential policy recommendations. Heat loss from buildings extends beyond individual concerns to become a collective challenge affecting energy consumption, environmental sustainability, and urban living conditions. In cities, poorly insulated buildings increase energy demands for heating and cooling, leading to higher greenhouse gas emissions. This issue intensifies the urban heat island effect, where cities retain more heat than rural areas due to heat-emitting infrastructure and inadequate insulation. A community-level understanding of heat loss is crucial for developing targeted energy efficiency solutions. By identifying high-heat-loss areas, communities can prioritize improvements—from retrofitting old buildings and upgrading windows to implementing city-wide sustainable construction policies. This approach addresses both energy waste and social equity, as inadequate insulation often affects vulnerable populations who face higher energy costs and thermal discomfort. In this phase, students will broaden their investigation from single buildings to the urban landscape. Through organized "thermal walks," they will gather temperature data from multiple buildings using thermal cameras. This data will form a collaborative heat loss map showing the area's thermal performance. Where possible, students will compare their ground-level observations with aerial thermal imaging to understand city-wide patterns. This process will demonstrate how collective action and informed decisions can tackle heat loss at a community scale, deepening students' understanding of the connections between science, policy, and environmental sustainability.



Learning Objectives: Guide students in developing sophisticated analytical approaches to urban heat loss assessment, enabling them to draw meaningful connections between local thermal patterns and larger environmental challenges while considering social and economic implications. Foster the development of advanced collaborative research skills through the systematic creation and interpretation of comprehensive thermal mapping data, emphasizing the importance of detailed documentation and clear visualization techniques in understanding urban heat distribution. Strengthen students' capacity for nuanced critical analysis when evaluating and proposing community-scale solutions that balance immediate energy efficiency needs with long-term environmental sustainability goals.

Conceptualisation

In this phase, students will investigate heat loss patterns at a community level, linking their observations to broader urban and environmental dynamics and exploring the key following questions:

- Which buildings or areas in our neighborhood demonstrate significant thermal energy loss patterns, and what specific architectural, structural, or environmental factors contribute to these heat loss variations across different locations?
- In what ways do architectural elements, construction periods, renovation history, and insulation technologies interact to create distinct thermal performance profiles throughout our community's built environment?
- What comprehensive, scalable, and economically viable solutions could our community implement to systematically address heat loss challenges while promoting long-term energy sustainability?

To ensure a structured and meaningful analysis, students must understand the following concepts:

- **Urban Heat Loss Dynamics:** Heat loss from buildings varies depending on factors such as construction materials, insulation quality, building age, and usage patterns (e.g., residential vs. commercial). Poorly insulated

structures and thermal bridges contribute to localized heat loss, which can have a ripple effect on energy demand and greenhouse gas emissions.

- **Thermal Mapping and Visualization:** Mapping heat loss involves capturing thermal images of buildings and annotating them with temperature data to identify patterns and hotspots of inefficiency. Collaborative mapping allows for a comprehensive view of a neighborhood's thermal performance, enabling the identification of trends across building types and locations.
- **Comparative Analysis with Public Data:** Where available, students can compare their findings with aerial thermal imaging data provided by local governments or environmental organizations to assess how ground-level observations align with city-wide heat loss patterns.
- **Collective Energy Efficiency Strategies:** Urban heat loss mitigation requires collaborative action, from individual building retrofits to policy measures promoting sustainable construction practices. Understanding the economic, environmental, and social implications of these strategies is key to making informed recommendations.

Research Questions and Investigative Framework: Students will develop research questions to guide their analysis. These questions should explore the causes and implications of urban heat loss and identify potential solutions.



- Which types of buildings (e.g., residential, commercial, older, newer) exhibit the most significant heat loss in our community, and why?
- How do local weather conditions (e.g., wind, humidity) influence observed heat loss patterns?
- What specific interventions could reduce heat loss in the areas identified as most inefficient?

After formulating their research questions, students will propose hypotheses that link their observations to expected outcomes. Examples include:



- Older buildings will exhibit higher levels of heat loss compared to newer constructions due to less efficient insulation materials and outdated building codes.
- Commercial buildings will show more heat loss than residential structures due to larger windows and higher occupancy rates.
- Buildings exposed to higher wind speeds will exhibit greater heat loss due to increased air infiltration through poorly sealed structures.

Hypotheses should clearly define:

- **Independent Variables:** Building type, age, materials, or exposure to external conditions.
- **Dependent Variables:** Heat loss levels (e.g., temperature differences, thermal hotspots).
- **Controlled Variables:** Environmental conditions during data collection (e.g., outdoor temperature, time of day).



Encouraging Critical Thinking and Broader Connections: To deepen their understanding, students will reflect on how their investigation relates to larger societal challenges. Key discussion points include: How does urban planning influence heat loss and energy efficiency at a community scale? What role do economic factors, such as income disparities, play in determining which buildings receive insulation upgrades? How can thermal mapping data inform policy decisions or community awareness campaigns? These discussions encourage students to connect their local observations to global sustainability efforts, emphasizing the need for collective action to address climate change and energy inefficiency. The teachers will facilitate discussions to ensure research questions and hypotheses are clear, measurable, and focused. They should provide examples of how similar mapping projects have informed real-world energy efficiency strategies. This will encourage students to think critically about the societal and environmental implications of their findings.

Students Investigation

In this comprehensive phase of investigation, students will embark on an organized "**thermal walk**" throughout their neighborhood or city to systematically identify and document patterns of **heat loss** across diverse building types and

architectural styles. Armed with sophisticated tools such as **thermal imaging cameras** or precise **infrared thermometers**, they will methodically collect temperature readings at strategic points, carefully document their detailed observations of building characteristics and environmental conditions, and collaborate to develop an extensive **heat loss map**. This detailed visualization tool will enable them to analyze emerging patterns, identify **critical areas of energy inefficiency**, and formulate evidence-based solutions for improving **thermal performance** across the community. Through this hands-on data collection process, students will gain practical experience in scientific measurement while contributing to a broader understanding of **urban energy dynamics**.

Before beginning the thermal mapping investigation, careful preparation is essential to ensure accurate data collection and meaningful results. This preparation phase involves gathering necessary equipment, establishing protocols, and ensuring all participants understand their roles and responsibilities. **A well-organized preparation will lead to more reliable data and a smoother investigation process.**

Preparing for the Investigation

1. Tools and Materials Needed:

- Thermal cameras, infrared thermometers, or other heat-measuring devices.
- Maps of the target area (digital or printed) for annotation.
- Notebook or digital device for data recording.
- Weather app or data to document outdoor conditions (temperature, wind speed, humidity).

2. Pre-Investigation Setup:

- Ensure students are familiar with using thermal cameras, including calibration and safe handling.
- Discuss data collection ethics, such as respecting privacy when capturing images of residential buildings.

Steps for Conducting the Investigation

- **Define the Study Area:** Select a specific neighborhood or cluster of buildings to analyze. Include a mix of building types (e.g., residential, commercial, older, newer) for comparative analysis.
- **Plan the Thermal Walk:** Divide students into small groups, assigning each group a section of the area to survey. Establish consistent times for data collection (e.g., early morning or late evening) to ensure meaningful temperature differences between indoors and outdoors.
- **Collect Thermal Data:** Capture thermal images or temperature readings for each building surface (e.g., walls, windows, roofs). Note visible signs of inefficiencies, such as thermal bridges, air leaks, or inadequate insulation. Record environmental conditions, including outdoor temperature, wind speed, and sunlight exposure.
- **Document Observations:** Use a standardized table to log findings, such as:

Building ID	Type (Residential/Commercial)	Age	Heat Loss Area	Temperature Difference (°C)	Observations
Building A	Residential	1970s	Roof	15	Insufficient insulation visible
Building B	Commercial	2000s	Windows	10	Drafts detected near frames

- **Integrate Public Data (if available):** Compare on-the-ground findings with aerial thermal imaging data or other public records to validate observations and identify larger trends.

Challenges and Validity Considerations



- **Data Variability:** Discuss how outdoor conditions (e.g., wind, sunlight) may affect measurements and emphasize the importance of consistent timing and controlled methods.
- **Ethical Considerations:** Ensure students respect privacy and obtain permission if capturing images of private properties.
- **Measurement Accuracy:** Encourage repeated measurements for consistency and use calibration techniques to ensure reliable data.

Collaborative Mapping and Analysis: After data collection, students will proceed with a comprehensive and collaborative analysis of the results. They will begin by creating a detailed heat loss map using mapping tools like Google My Maps or ArcGIS. This map will serve as a visual support to represent the collected thermal data, including building types and observed inefficiencies. Trend analysis will constitute the second crucial step. Students will compare different heat loss patterns based on building characteristics (type, age, location). They will seek to identify significant correlations between observed thermal losses and various factors such as insulation quality, construction materials, or exposure to environmental conditions.

Based on this thorough analysis, students will develop concrete proposals to reduce heat loss. These solutions may include modernizing insulation in older buildings, improving the sealing of windows and doors, or implementing community programs aimed at enhancing insulation in the most vulnerable areas.

- **Create a Heat Loss Map:** Use mapping tools (e.g., Google My Maps, ArcGIS, or printed maps) to visually represent the collected data. Annotate maps with thermal data, building types, and observed inefficiencies.
- **Analyze Trends:** Compare heat loss patterns across building types, ages, and locations. Identify correlations between observed heat loss and factors like insulation quality, building materials, or exposure to environmental conditions.
- **Develop Proposals:** Based on their analysis, students will brainstorm actionable strategies to reduce heat loss, such as retrofitting older buildings with modern insulation, sealing air leaks around windows and doors and advocating for community-wide programs to upgrade insulation in vulnerable areas.

Teacher's Role



- Guide students in developing a clear and systematic protocol for data collection and mapping.
- Support the use of mapping tools and ensure data visualization is accurate and meaningful.
- Facilitate discussions on the findings, encouraging students to connect their observations to broader community and environmental challenges.

Upon completing this comprehensive investigation phase, students will have achieved several significant milestones in their understanding of urban thermal dynamics and community-level energy efficiency:

1. **Successfully executed an extensive collaborative thermal survey** of their local community, meticulously documenting **temperature variations and heat loss patterns** across diverse building types and architectural styles.
Developed and implemented a detailed visual heat loss map that systematically identifies and highlights **critical areas of thermal inefficiency**, incorporating multiple data points and environmental factors to create a comprehensive overview of community energy patterns.
Conducted thorough **trend analysis** to identify **recurring patterns, correlations, and potential causative factors**, leading to the formulation of **evidence-based, practical solutions tailored to specific community needs**.

This rigorous investigative process not only strengthens the fundamental connection between localized observations and broader global sustainability objectives but also empowers students to develop critical thinking skills essential for understanding how scientific methodology can be effectively applied to create meaningful, lasting change at the community level. Through this hands-on experience, students gain valuable insights into the practical applications of thermal science while contributing to the larger dialogue on environmental sustainability and energy conservation.

Conclusion & Further Reflexion

- **Knowledge Mobilized:** By completing this phase, students will have gained a deeper understanding of how thermal inefficiencies manifest at a community scale. They will have applied their knowledge of insulation, heat transfer, and thermal imaging to real-world scenarios, connecting their observations to larger urban and environmental dynamics. Additionally, students will recognize the value of collaborative mapping in identifying systemic inefficiencies and prioritizing targeted interventions. Students will also understand how factors such as building age, type, materials, and environmental conditions contribute to urban heat loss patterns. This knowledge highlights the interplay between science, urban planning, and social responsibility in addressing energy inefficiency and sustainability challenges.
- **Classroom Implementation Reflection:** This phase emphasizes collaborative, hands-on learning and critical analysis. Students will have developed expertise in using thermal imaging tools and interpreting data to identify heat loss patterns. They will have compared findings across buildings, identified trends, and proposed evidence-based solutions. They will have worked collaboratively to create a comprehensive heat loss map and share insights with peers. The activity also fosters an appreciation for the societal and environmental impact of their findings, encouraging students to think beyond the classroom.
- **Learning Outcomes:** Students will refine their ability to collect, analyze, and visualize real-world thermal data. By identifying inefficiencies and proposing solutions, students will evaluate trade-offs and prioritize effective interventions. Students will connect their findings to actionable solutions that address community-scale energy inefficiency. Students will appreciate the role of collective action in addressing global sustainability challenges, including SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action).



To conclude this phase, students will engage in a discussion centered on open-ended questions. These questions are designed to encourage deeper reflection on the study and its broader implications. Several questions can be opened for discussion:

- What patterns did you observe in heat loss across different buildings, and how did these align with your hypotheses?
- What factors (e.g., building type, age, location) contributed most to the inefficiencies you identified?
- What solutions would you prioritize for reducing heat loss in your community, and why?
- How can the data you collected inform local policy or awareness campaigns about energy efficiency?
- What are the potential barriers to implementing insulation improvements at a community scale?
- How does addressing urban heat loss contribute to global efforts to combat climate change and promote sustainability?



Connecting to Broader Themes: This phase highlights the power of collective action and evidence-based decision-making in addressing urban energy inefficiency. By linking their findings to broader societal and environmental challenges, students will understand the importance of science in shaping policy and driving change. They will also recognize the role of their own community in contributing to global sustainability goals.

Students can use their findings to create impactful projects, such as:

- Designing a public awareness campaign on the importance of insulation and energy efficiency.
- Proposing a community action plan to retrofit older buildings or improve insulation in vulnerable areas.
- Presenting their findings to local authorities or organizations to advocate for energy-efficient building policies.

This final phase concludes the investigation with a call to action, empowering students to use their scientific insights to make meaningful contributions to their communities and the planet.

Practical Implementation 1



Collect Data with the Humidity and Temperature Sensor



Material and tools needed

To program a micro:bit board to collect humidity and temperature , you will need the following materials:

- **Micro:bit V2 Board and its built-in sensors:** The main programmable board including a built-in light sensor through its LED display, a built-in sound level sensor and a built-in temperature sensor - Around 19 EUR per micro:bit ([check prices here](#))
- **Micro-USB Cable:** For powering and programming the micro:bit
- **Battery Pack (optional):** For portable operation if the micro:bit needs to be untethered - You can check the official micro:bit battery pack available for purchasing around 2,20 EUR per pack [here](#)

You can also purchase Micro:bit V2 kit including the USB cable and battery pack for 21 EUR per kit ([check here](#)) or 177 EUR for 10 kits ([check here](#))

- **DHT22 sensor (or DHT11):** DHT11 and DHT22 are two popular sensors among microcontroller users, especially the cheap DHT11s. DHT22s cost more but have better data resolution.
- **Computer or Tablet:** To write and upload code.
- **Programming Environment:** [MakeCode Online Editor](#)



We recommend for this step to program at least 3 to 6 micro:bit boards for sharing them among students and gather more information and data. You can do it with only 1 board, but you will need either to expand the overall duration of the collection period or reduce the duration of the collection period per student from 7 to 3 days.



Instructions for wiring and using the micro:bit board

Follow these steps to program, place, record, and retrieve environmental data using the micro:bit.

Step 1: Wiring Temperature/Humidity sensor to the Micro:bit board:

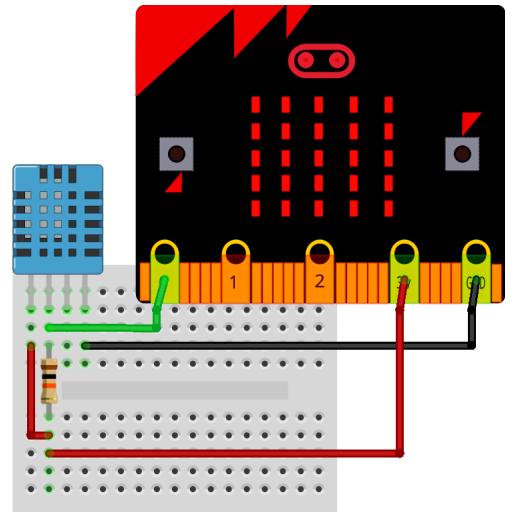
There are two types of DHT11/DHT22s, one without PCB boards and have 4 pins; another have PCB boards, built-in pull up resistors and only 3 pins.

Personally I would recommend you to use PCB versions. For the PCB version it's easy: Vcc (+) to 3.3V or 5V (both works), GND (-) to GND, Data (out) to any GPIO pins you like.

If you are using the 4-pin version, you'll need to add a resistor (in my test 220 Ω - 10 K Ω works under 3.3V; above that the sensor won't response) between Vcc and Data to pull up the voltage of the data pin.

Or you can simply use the pull up option in the query block - the micro:bit has internal resistors about 12-13 K Ω .

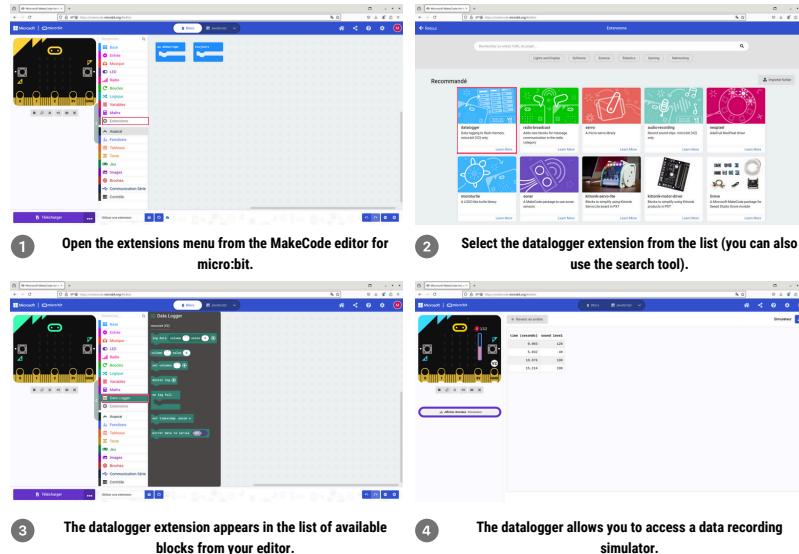
The third pin on the 4-pin sensor from the left is not used.



Connect your DHT by following this diagram [Body here aside](#):

Step 2: Programming the Micro:bit: Connect the Micro:bit board: With your USB Cable, connect the board to your computer by using the **micro-USB connector**. Once connected, the micro:bit board will appear on the computer as a removable drive (e.g. "MICROBIT").

Write the Program: Open the [MakeCode editor](#) to create a program that collects light, noise, and temperature data using the built-in sensors of the Micro:bit V2 programming board. Give a clear name to your project before starting.



Once on the editor, and after creating your new project, you will get the default "ready to go" screen shown here and will need to install an **extension**.

Extensions in MakeCode are groups of code blocks that are not directly included in the basic code blocks found in MakeCode.

Extensions, like the name implies, add blocks for specific functionalities. There are extensions for a wide array of very useful features, adding gamepad, keyboard, mouse, servo and robotics capabilities and much more. In the block display columns, click on the **EXTENSIONS** button.

In the list of extensions available, search for the **Datalogger extension** that will be used for this activity. Click on the extension you want to use and a new block group will appear on the main screen. Do the same for the temperature/humidity sensor by searching **DHT11/DHT22 extention**.

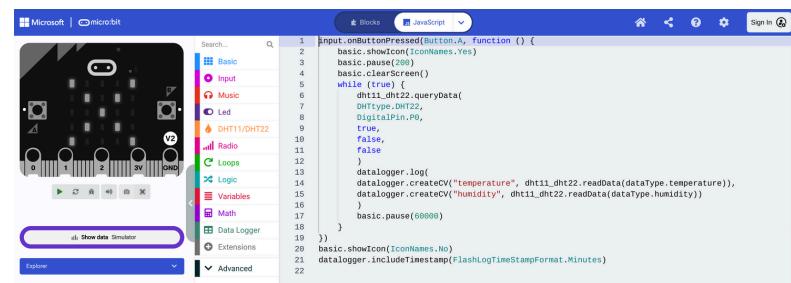
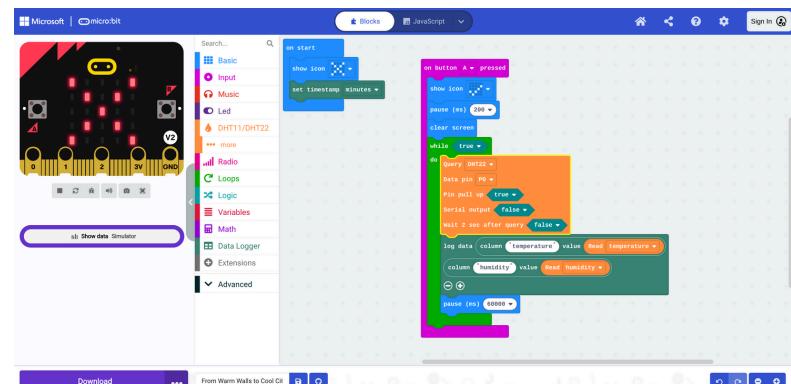
Then, you can start arranging your block following the code provided aside (add an infinity loop, record data in the datalogger ...).

You can also copy paste the code in the Javascript editor available.

Once your program is working properly on the simulator, transfer it to your Micro:bit: click **"Download"** in MakeCode to generate a .hex file.

This file contains the compiled program that will allow the board to function. Copy the .hex file from your download folder to the "**MICROBIT**" removable drive.

Once the file is copied, the board automatically restarts and executes the code.



Step 3: Placing the Micro:bit and start recording data

Once programmed, place the micro:bit for collecting the data you need in an area where it can accurately humidity and temperature without obstruction.

Use a computer or external battery pack to power the micro:bit continuously during the recording.

Before going to bed, press button "A" on the MicroBit to start data recording via the program.

Step 4: Retrieving data and cleaning up the board for the next recording session

Each morning, to avoid data loss, we recommend to disconnect the micro:bit from its power source to stop data recording and **connect the micro:bit to your computer to access the file compiled over the night by the datalogger (which will be called “MY_DATA.HTM, available on the micro:bit drive).**

Copy this file to your computer and rename it with the current date (e.g., BOARD1_NAME_YYYY-MM-DD.HTM).

After copying and renaming the file, delete the **MY_DATA.HTM** file from the MicroBit board to free up space and allow for new data recording.

Repeat the process for the next session.

At the end of the collection period, you can retrieve all the files collected from the different micro:bit boards.

Once opened, the data log pages will be accessible. They will provide all collected data and allow you to download it in .csv format.



Code

Here is the Javascript code used to program a micro:bit board in order to regularly collect data on humidity and temperature:

```
input.onButtonPressed(Button.A, function () {
    basic.showIcon(IconNames.Yes)
    basic.pause(200)
    basic.clearScreen()
    while (true) {
        dht11_dht22.queryData(
            DHTtype.DHT22,
            DigitalPin.P0,
            true,
            false,
            false
        )
        datalogger.log(
            datalogger.createCV("temperature",dht11_dht22.readData(dataType.temperature)),
            datalogger.createCV("humidity",dht11_dht22.readData(dataType.humidity))
        )
        basic.pause(60000)
    }
})
basic.showIcon(IconNames.No)
datalogger.includeTimestamp(FlashLogTimeStampFormat.Minutes)
```

How does the code work?

This program measures the humidity and temperature. Every minute (the interval can be modified to correspond to 10 seconds, 5 minutes, twice per hour...) the program compiles the information in a "**datalogger**" from which we can download a .csv file.



A **.csv** file (Comma-Separated Values) is a text file format used to store tabular data (like in a table or spreadsheet). Each line of the file represents a row of data, and each value in a line is separated by a delimiter (often a comma, but sometimes a semicolon or tab). It is possible to retrieve data from a .csv file in spreadsheet software like Excel or LibreOffice Calc. In Excel, open the software, click on **File > Open**, select the .csv file, and configure the delimiters if necessary via the import tool. In LibreOffice Calc, follow a similar process: click on **File > Open**, select the file, and use the import wizard to choose the delimiter (for example, comma or semicolon). In both cases, the data appears in table form, ready to be analyzed.

Initialization of button "A" press event: When the user presses **button "A"** on the MicroBit, the function `input.onButtonPressed(Button.A, function () { ... })` is triggered.

Display of "Yes" icon during execution: Before starting data recording, the program displays the "**Yes**" icon (`basic.showIcon(IconNames.Yes)`) for **200 milliseconds** (0.2 seconds) to indicate that the recording process has started.

200 millisecond pause: After displaying the "Yes" icon, the program waits **200 milliseconds** using `basic.pause(200)`.

Screen clearing: After the 200 millisecond pause, the screen is cleared with `basic.clearScreen()`, which prepares the screen for what follows without being cluttered with images.

Infinite data collection loop: The program enters an infinite loop `while (true)`. This means that data will be collected and recorded endlessly until the MicroBit is turned off or restarted.

Querying the sensor: the block `dht11_dht22.queryData()`, select module type and read data (it is recommended to wait between queries; at least 1 second for DHT11 and 2 seconds for DHT22) from the sensor. The query must be sent before to get the value of the temperature and humidity. It also verifies checksum from sensors. If the checksum is wrong, you'll get -999 for both temperature and humidity readings, and "Last query successful?" block would return false.

Recording data in the datalogger: At each loop iteration, the program records the values from the MicroBit sensors:

- **Temperature:** `dht11_dht22.readData(dataType.temperature)`, which retrieves the current temperature in degrees Celsius.
- **Humidity:** `dht11_dht22.readData(dataType.humidity)`, which measures the current relative humidity.

The temperature is measured in degrees Celsius (**°C**) and relative humidity in percentage.

These values are recorded in the **datalogger** as variables with respective names ("temperature", "humidity"). This is done via the `datalogger.log()` function:

```
datalogger.log(  
    datalogger.createCV("temperature", dht11_dht22.readData(dataType.temperature)),  
    datalogger.createCV("humidity", dht11_dht22.readData(dataType.humidity))  
)
```

The `createCV` function allows creation of a "CV" (context value) for each sensor, and the `datalogger.log` function allows recording these values in a file on the MicroBit.

60,000 millisecond pause before next reading: After each recording, the program waits 60,000 **milliseconds** (1 minute) before reading the sensor values again. This is achieved with `basic.pause(60000)`.

Data timestamping (included via `datalogger.includeTimestamp`): Outside the button-linked function, the command `datalogger.includeTimestamp(FlashLogTimeStampFormat.Minutes)` is used to include a timestamp with each data recording. The timestamp format is in **minutes**, meaning each recording will have a time indicator based on minutes elapsed since program start.

Display of "No" icon before execution: Before the user presses button "A", the program displays a "**No**" icon (`basic.showIcon(IconNames.No)`) to indicate that the MicroBit is waiting for user action.



Practical Implementation 2

Using Thermal Cameras for Insulation Analysis

Why Using a Thermal Camera?

A thermal camera is a powerful tool for identifying areas of heat loss in buildings. By capturing infrared images, it reveals temperature variations on the surfaces of walls, windows, and roofs. This information helps locate insulation weaknesses, such as thermal bridges, air leaks, or degraded materials—problems that are often invisible to the naked eye.

How Does a Thermal Camera Work?

Thermal cameras detect infrared radiation emitted by objects based on their temperature. They convert this radiation into a color-coded image, where each color corresponds to a temperature range:

- **Red/Yellow:** Warmer areas, often indicating heat loss.
- **Blue/Purple:** Cooler areas, possibly indicating air drafts or poor insulation.

Students can interpret these images to understand thermal variations and pinpoint areas for improvement.

Steps for Effective Thermal Camera Use

1. **Preparation:**
 - Ensure the camera is calibrated correctly.
 - Choose a time when there is a significant temperature difference between the inside and outside (e.g., a cold winter morning or a hot summer afternoon).
2. **Capturing Images:**
 - Scan walls, windows, doors, and roofs systematically.
 - Hold the camera steady and maintain a consistent distance from the surfaces.
 - Avoid pointing the camera directly at heat sources like radiators or electronic devices, as these may distort results.
3. **Analyzing Images:**
 - Look for red or yellow zones on exterior walls, often indicating heat loss.
 - Identify blue zones near windows or doors, which may suggest air drafts.
4. **Documenting Observations:**
 - Annotate each image with location, environmental conditions (e.g., outdoor temperature, weather), and observations.
 - Compare images taken before and after any improvements, if applicable.

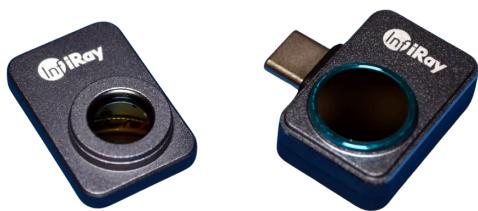
Tips and Precautions:



- **Weather Conditions:** Avoid capturing images in direct sunlight or during strong winds, as these can affect readings.
- **Positioning:** Keep the camera perpendicular to the surface to minimize distortions.
- **Indoor Lighting:** Limit warm light sources that might interfere with measurements.
- **Temperature precision:** A thermal camera is mainly intended (and very suitable) to find hot and cold spots, but to determine the actual temperature of them is difficult and inaccurate. The following factors come into play: - Emissivity, is the correct emission coefficient set depending on the surface being measured? - Distance to the object - Ambient temperature / difference between internal temperature of camera and environment - Quality of the lens - Chosen measurement range (wide range / high res).

Selecting the Right Thermal Camera

The choice of a thermal camera for this activity depends on the resources available to the teacher and school. Thermal cameras vary widely in terms of cost, features, and portability. Teachers are encouraged to explore local options, such as borrowing devices from municipal authorities, environmental organizations, or universities. Many cities have programs to lend thermal imaging equipment, which can significantly reduce costs while providing access to high-quality tools.

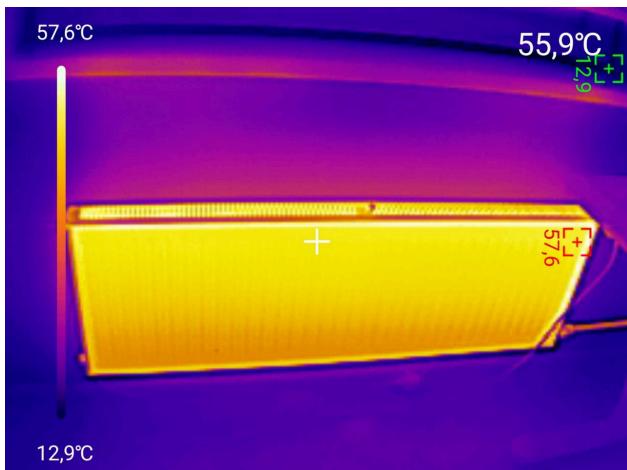


For schools looking for affordable and accessible options, smartphone-compatible thermal cameras like the **Infiray P2 Pro** offer a practical solution. These devices are compact, easy to use, and connect directly to Android smartphones, transforming them into powerful thermal imaging tools. While they may not provide the advanced features of standalone cameras, they are well-suited for educational activities where simplicity and portability are priorities.

Visualizing Thermal Data: Example Images

Below are examples of real thermal images captured during insulation analysis, showcasing common issues such as thermal bridges, drafts, and heat loss through walls or windows.

Radiator and Surrounding Wall



- Description:** This image highlights a radiator as a significant heat source, with temperatures exceeding 55°C, while the surrounding wall remains cooler. This demonstrates localized heat concentration and potential inefficiencies in distributing warmth throughout the room.
- Key Insight:** Such images can help identify whether insulation around radiators is sufficient or if heat loss occurs through nearby walls.

Window Heat Loss



- Description:** A thermal image of a window reveals stark temperature contrasts. The bright areas (above 54°C) indicate significant heat loss through the window frame and corner of the wall.
- Key Insight:** This highlights the importance of well-sealed and double-glazed windows in reducing energy loss.

Stairwell with Thermal Bridges



- **Description:** In this stairwell image, thermal bridges are visible near the ceiling and door frames, where temperatures vary from 22°C to 11°C. This suggests poor insulation at structural junctions. The stairwell is also very cold and is probably a great source of heat loss.
- **Key Insight:** Identifying thermal bridges allows targeted insulation improvements to enhance energy efficiency.

Cold Spots in a Room



- **Description:** This thermal image of a room shows cold spots (15°C) along the corners of the ceiling and warmer zones (19°C) near furniture. This distribution indicates uneven heating, potentially caused by inadequate insulation.
- **Key Insight:** Analyzing such patterns helps pinpoint areas where additional insulation or better ventilation may be required.

Practical Guide: Using the Infiray P2 Pro for Thermal Analysis

The Infiray P2 Pro is a compact and versatile thermal camera designed for Android smartphones. Its user-friendly interface and portability make it an ideal tool for educational activities focused on thermal insulation and energy efficiency. Below is a detailed guide to using the device effectively for thermal analysis.

Getting Started with the Infiray P2 Pro

Before beginning any thermal imaging activity, it is essential to ensure that the Infiray P2 Pro is compatible with the device you plan to use. The camera connects via USB-C, so confirm that the smartphone has a USB-C port and runs on an Android operating system.



Start by downloading the Infiray app from the Google Play Store. This dedicated application enables all the thermal imaging functionalities of the camera. Once installed, plug the Infiray P2 Pro into the USB-C port of the smartphone.

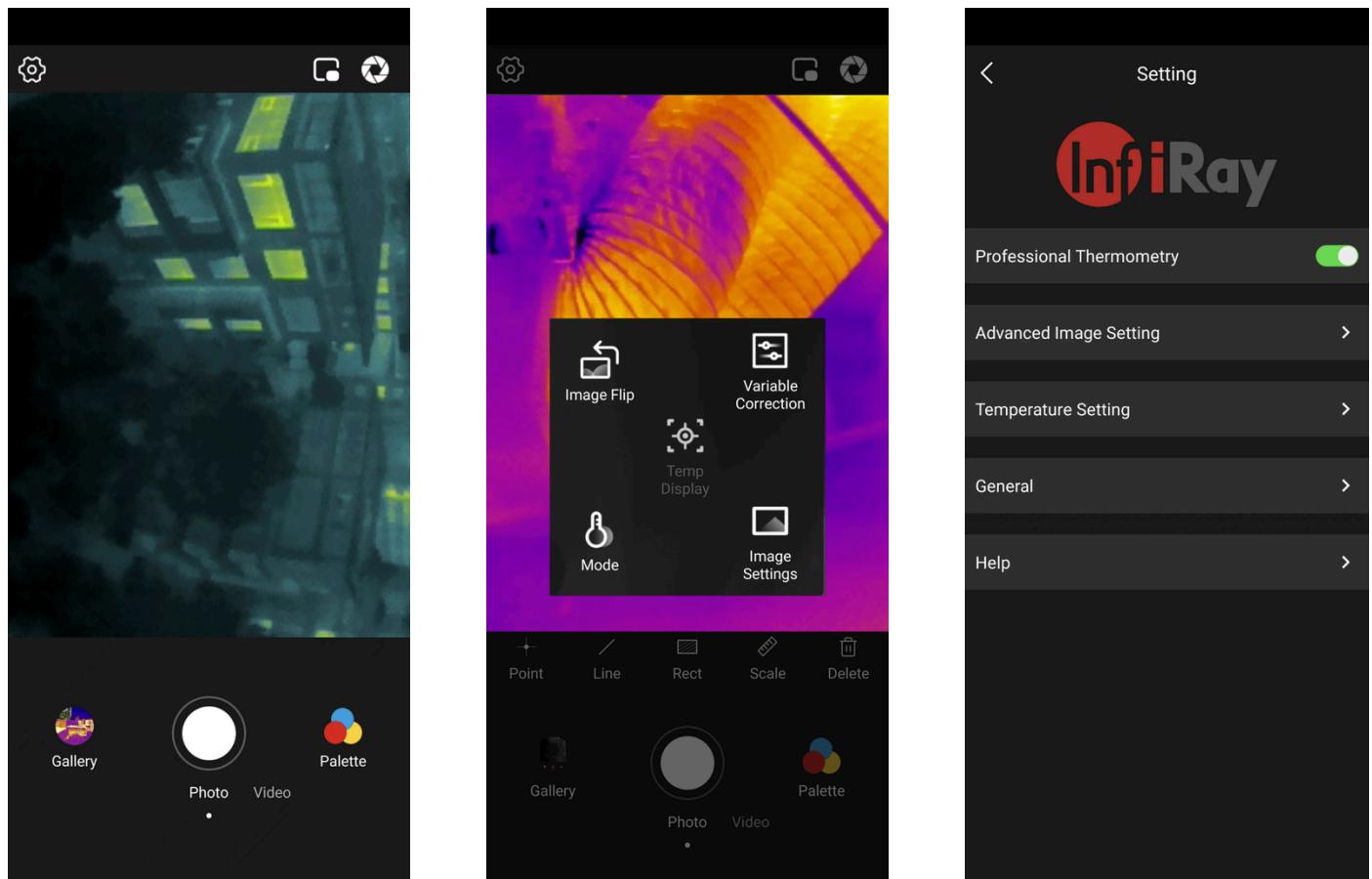
Open the app to activate the camera and follow the on-screen prompts to complete the setup process. At this stage, it's important to calibrate the camera, as accurate temperature readings depend on proper calibration.

Configuring the Camera for Insulation Analysis

Thermal imaging requires precision to highlight temperature differences effectively. Once the camera is activated, configure it to suit the environment you are analyzing:

- **Calibration:** The app will guide you through an initial calibration step. This process aligns the camera's sensors with ambient conditions, ensuring reliable temperature readings.
- **Temperature Range:** Adjust the range to match your environment. For indoor settings, a range of -10°C to 40°C works well, but for outdoor analyses in winter or summer, a broader range may be needed.
- **Color Palette:** Choose a palette that maximizes contrast for easier interpretation of temperature differences. For example, the "Ironbow" palette highlights warmer areas in bright red and cooler areas in blue, making it easy to identify thermal anomalies.

These configurations should be reviewed and adjusted as necessary throughout the analysis, especially if conditions change.



Conducting Thermal Inspections

Once configured, the InfiRay P2 Pro can be used to inspect various parts of a building to identify heat loss:

- **Walls and Windows:** Begin by scanning the walls and windows. Look for warm spots (often red or yellow in the color palette) on walls, indicating heat leakage, or cold spots around windows, which may suggest drafts.
- **Roofs and Doors:** Move to areas like roofs and doors, which are common sources of heat loss. Carefully observe areas where materials meet, such as door frames or roof joints, as these are potential thermal bridges.
- **Taking Measurements:** The app allows you to tap on specific points in the image to display their exact temperature. Use this feature to measure the temperature gradient across surfaces and document heat transfer patterns.

Documenting Observations

Thermal imaging is only as useful as the data collected. After capturing images, it's essential to document them thoroughly for later analysis:

- **Annotating Images:** Save each thermal image with labels specifying the location, environmental conditions (e.g., outdoor temperature, wind speed), and any observations made during the scan.
- **Comparing Conditions:** Capture images of the same location under different conditions (e.g., before and after insulation) to visualize improvements in thermal performance.

The Infiray app allows you to organize captured data systematically, ensuring no critical details are lost.

Analyzing Results

After the inspection, analyze the collected data to draw meaningful conclusions:

- **Identifying Patterns:** Look for consistent heat loss patterns across similar areas, such as windows or uninsulated walls.
- **Correlating with Experimental Data:** Compare your findings to the results from prior insulation experiments conducted in the lab. This can help validate the effectiveness of specific materials.
- **Proposing Solutions:** Based on the analysis, identify practical steps to improve insulation, such as sealing gaps, retrofitting insulation, or replacing windows with energy-efficient alternatives.

Integrating Thermal Camera Use into the Activity

Thermal cameras provide a visually engaging and scientifically rigorous way to explore the principles of heat transfer and insulation. Their integration into the activity transforms theoretical concepts into tangible observations, fostering a deeper understanding of energy efficiency and sustainability. Below are expanded ideas on how to effectively integrate thermal imaging into the activity:

Guided Exploration and Demonstration

- Begin with a classroom demonstration of the thermal camera, allowing students to observe its functionality in a controlled environment. For instance, show how a thermal camera detects heat differences on a cup of hot water versus a cold surface.
- Compare surfaces with varying materials, such as metal, wood, and foam, to illustrate differences in thermal conductivity. This hands-on introduction helps students link thermal imagery to key scientific concepts.

Structured Data Collection

- **Indoor Analysis:** Organize students into small groups to analyze different parts of their school building, such as walls, windows, and doors. Assign specific roles (e.g., camera operator, note-taker, and data analyst) to ensure all students engage with the activity.
- **Outdoor Analysis:** Extend the activity outdoors, where students can compare thermal emissions from sunlit versus shaded walls or identify temperature variations caused by environmental factors like wind or sunlight.

Comparative Analysis

- **Before-and-After Scenarios:** Encourage students to use the camera to document "before" and "after" scenarios, such as placing insulation on a surface or sealing gaps around a window. Compare the thermal images to visualize the effectiveness of their interventions.
- **Material Comparisons:** Conduct controlled experiments to compare the insulating properties of materials tested in the lab with observations of real-world insulation. For example, students could evaluate the performance of a school wall versus a wall insulated with foam or wool.

Integration with Other Tools

- Combine thermal imaging with other measurement tools, such as temperature and humidity sensors. This allows students to compare temperature gradients captured by the thermal camera with point-specific readings from sensors, providing a more comprehensive analysis.

Encouraging Critical Thinking

- Facilitate group discussions where students interpret their findings. Ask questions like:
 - *Why are certain areas losing more heat than others?*
 - *What external factors might be influencing the results (e.g., weather, building materials)?*
 - *What interventions would you prioritize, and why?*
- Encourage students to reflect on the limitations of thermal imaging, such as its sensitivity to environmental conditions or the challenges of interpreting data without context.

Engaging Students Through Technology

- **Gamify the Activity:** Turn the thermal imaging exercise into a challenge, such as "Spot the Biggest Heat Loss" or "Design the Best Insulation Fix." Reward creativity and scientific reasoning.
- **Leverage Apps and Software:** If the thermal camera app supports overlays or live annotations, encourage students to use these features to create detailed, annotated images or videos that explain their findings.

By embedding thermal imaging into the activity, students not only gain technical skills in using advanced tools but also develop a deeper understanding of how science can solve real-world problems. The activity becomes more engaging, collaborative, and impactful, helping students make connections between their learning and larger societal challenges like sustainability and climate action.



Launching new follow-up projects

Experimenting Renewable Energy & Insulation



Idea: Combine insulation studies with renewable energy exploration by designing miniature passive solar homes.

Activity: Students build small-scale models of energy-efficient homes, incorporating solar panels and optimizing insulation to reduce energy usage.

Goal: Explore how insulation and renewable energy technologies work together to minimize a building's carbon footprint.

Inspiration: Link this project to the concept of "net-zero energy buildings" and global efforts to combat climate change.

Designing Future-Proof Cities



Idea: Challenge students to imagine and design sustainable, energy-efficient urban areas.

Activity: Using mapping tools or design software (e.g., Google Earth, SketchUp), students create urban layouts incorporating green roofs, insulated buildings, and renewable energy infrastructure.

Goal: Foster critical thinking about how urban design influences energy efficiency and livability.

Inspiration: Connect to the UN's SDG 11 (Sustainable Cities and Communities) by exploring how cities can reduce heat islands and improve energy performance.

Investigating Global Insulation Practices



Idea: Compare insulation techniques used in different climates and cultures.

Activity: Research traditional and modern insulation practices worldwide (e.g., igloos, mud-brick homes, straw-bale construction).

Goal: Highlight the relationship between local resources, climate, and building design while inspiring students to think globally.

Inspiration: Discuss how indigenous knowledge can inform sustainable architecture today.

Building and Testing Smart Insulation



Idea: Explore how technology can enhance insulation performance.

Activity: Students integrate sensors into their insulation experiments to monitor temperature and humidity in real time. They test "smart materials" such as phase-change materials (PCMs) that adapt to temperature changes.

Goal: Combine insulation science with STEM skills like programming and data analysis.

Inspiration: Introduce the concept of smart homes and their role in future energy systems.

Organizing a Community Energy Audit



Idea: Scale up the urban heat mapping activity to engage the local community.

Activity: Students partner with local residents to analyze heat loss patterns in homes and propose collective solutions (e.g., sealing gaps, retrofitting older buildings).

Goal: Promote collaboration and awareness about energy efficiency within the community.

Inspiration: Use findings to advocate for local policy changes or community-driven retrofitting programs.

Exploring the Role of Materials in Sustainability



Idea: Examine the lifecycle impacts of insulation materials.

Activity: Research and compare the environmental footprints of various materials (e.g., foam, wool, cellulose). Discuss trade-offs between performance, cost, and sustainability.

Goal: Encourage students to think critically about material choices and their long-term impacts.

Inspiration: Introduce life-cycle analysis (LCA) tools to evaluate sustainability metrics.

Simulating Climate-Resilient Buildings



Idea: Test how insulation performs under extreme weather conditions.

Activity: Simulate different climates in the lab (e.g., use fans for wind, heat lamps for high temperatures) and analyze the performance of insulating materials.

Goal: Explore how insulation can make buildings more resilient to climate change impacts like heatwaves or cold snaps.

Inspiration: Discuss real-world challenges faced by architects and engineers in designing for extreme climates.

Storytelling through Data



Idea: Use storytelling to make data about heat loss and insulation accessible and engaging.

Activity: Students create videos, infographics, or social media posts that communicate their findings and proposed solutions to a wider audience.

Goal: Develop communication skills while raising awareness about energy efficiency.

Inspiration: Share student projects in local media or on social platforms to inspire others.

Exploring Policy and Economics



Idea: Examine how policies and incentives impact energy efficiency at the community level.

Activity: Students research local or national programs (e.g., tax incentives for retrofitting) and analyze cost-benefit scenarios for implementing insulation upgrades.

Goal: Understand the intersection of science, economics, and policy in driving sustainability efforts.

Inspiration: Connect this activity to careers in environmental policy, urban planning, or energy consulting.

Investigating Insulation and Health



Idea: Explore how insulation affects indoor air quality and occupant well-being.

Activity: Use sensors to measure temperature, humidity, and air quality in insulated and non-insulated spaces.

Goal: Demonstrate how good insulation contributes to health by preventing mold growth, maintaining comfort, and reducing exposure to extreme temperatures.

Inspiration: Connect findings to vulnerable populations and how energy efficiency can improve quality of life.



Exploring Inspiring Initiatives

1. **Energy Efficiency Campaigns in Local Communities: Chaque geste compte: Economize Energy (France)** – A national campaign encouraging energy savings and promoting eco-friendly habits. [Chaque geste compte](#)
2. **Energy Efficiency meetup: Eco-Home Lab(UK)** – A meetup promoting energy-efficient homes and raising awareness about thermal insulation. [Eco-Home Lab Meetup](#)
3. **Aerial thermography mapping: PrRE (La Rochelle Urban Community, France)** – A regional program supporting energy renovation for residential buildings, offering guidance, funding, and resources to improve energy efficiency. [Aerial thermography mapping](#)
4. **Participatory Energy Audits: Energy Communities Tipperary Cooperative (Ireland)** – A cooperative helping local communities conduct energy audits and implement retrofit solutions. [Energy Communities Tipperary](#)
5. **Earth Hour and Energy Awareness Events: Earth Hour (Global)** – Organized by WWF, this global event promotes awareness about energy conservation and climate action. [Earth Hour](#)
6. **Local Urban Greening and Cool Roof Initiatives: Cool Roofs NYC (USA)** – A program that installs reflective rooftops to reduce urban heat islands and promote energy efficiency. [Cool Roofs NYC](#)
7. **Energy Transition Citizen Cooperatives: Enercoop (France)** – A renewable energy cooperative enabling citizens to invest in and use green energy. [Enercoop](#)
8. **Home Retrofit Volunteer Programs: Habitat for Humanity's "Home Energy Retrofit" Program (Global)** – A volunteer program helping families improve home energy efficiency through retrofitting. [Habitat for Humanity](#)
9. **Climate Advocacy Groups: Fridays for Future (Global)** – A youth-led movement advocating for climate action, including sustainable building policies. [Fridays for Future](#)
10. **Thermal Mapping of Public Buildings: PrioRénovation for Public Buildings (France)** – A free service offering energy mapping of public building stocks to help prioritize renovation plans. [PrioRénovation Public Buildings](#)
11. **Community Education Workshops: Energy Savings Trust's Education Program (UK)** – Offers resources and workshops for schools and communities on energy conservation. [Energy Saving Trust](#)
12. **Zero Energy Building Advocacy: Zero Energy Project (USA)** – Advocates for zero-energy homes and provides resources for implementing energy-efficient building solutions. [Zero Energy Project](#)



Bibliography

Scientific References:

1. **ASHRAE Handbook—Fundamentals**
 - A comprehensive guide on building thermal performance, heat transfer, and insulation standards.
 - Publisher: ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers)
2. **Thermal Insulation Handbook for the Building Professional**
 - Author: Thomas J. Fennell
 - A practical resource on insulating materials, design principles, and performance metrics.
3. **Thermal Properties of Building Materials: Concepts and Applications**
 - Author: R.W. Powell
 - Explains thermal conductivity, resistance, and advanced materials used in construction.

Tools and Technical Resources:

1. **FLIR Thermal Camera User Manual**
 - Instructions for using thermal imaging cameras effectively in building inspections.
 - Available on the official [FLIR Systems website](#).
2. **Insulation Materials Comparison Guide**
 - A side-by-side comparison of common insulating materials, including foam, cellulose, fiberglass, and wool.
 - Available at [Energy.gov](#).
3. **Umap**
 - uMap lets you create maps (e.g custom urban heat maps) with OpenStreetMap layers in a minute and embed them in your site.
 - [Umap website](#)
4. **Life Cycle Analysis Tools**
 - Tools like [SimaPro](#) or [OpenLCA](#) for evaluating the environmental impact of insulation materials.

Case Studies and Applications:

1. **Passive House Institute**
 - Research and case studies on highly energy-efficient buildings.
 - Visit [Passive House International](#).
2. **Urban Heat Island Mitigation Strategies**
 - Published by the U.S. Environmental Protection Agency (EPA).
 - Explores how urban design influences heat retention and energy efficiency.
 - Available at [EPA Urban Heat Islands](#).
3. **Global Cool Cities Alliance**
 - Studies and strategies for reducing urban heat islands through cool roofs, green spaces, and improved insulation.
 - Visit [Global Cool Cities Alliance](#).

Educational Resources:

1. **Insulation Experiments for Classrooms**
 - Hands-on activity guides for testing thermal insulation properties in schools.
 - Available at [TeachEngineering.org](#).
2. **Thermal Imaging and Energy Efficiency**
 - A free online course on using thermal imaging for building inspections.
 - http://www.flirmedia.com/MMC/THG/Brochures/T820325/T820325_EN.pdf
3. **UN Sustainable Development Goals (SDGs)**
 - Explore SDG 7 (Affordable and Clean Energy) and SDG 11 (Sustainable Cities and Communities).
 - Visit [United Nations SDGs](#).

Scientific Papers and Articles:

- 1. A New Approach for Analysis of Complex Building Envelopes in Whole Building Energy Simulations**
 - Authors: J. Kosny *et al.*
 - Focuses on the science of heat transfer in construction materials.
- 2. Urban Heat Island: Causes, Effects and Mitigation Measures - A Review.**
 - Authors: Nuruzzaman, Md.
 - Journal: International Journal of Environmental Monitoring and Analysis
 - Discusses the relationship between building insulation and urban heat islands.
- 3. Smart Materials Innovative Technologies in architecture; Towards Innovative design paradigm**
 - Authors: *Abeer Samy Yousef Mohamed*
 - Journal: Energy Procedia
 - Explores advanced insulation technologies like aerogels and phase-change materials.