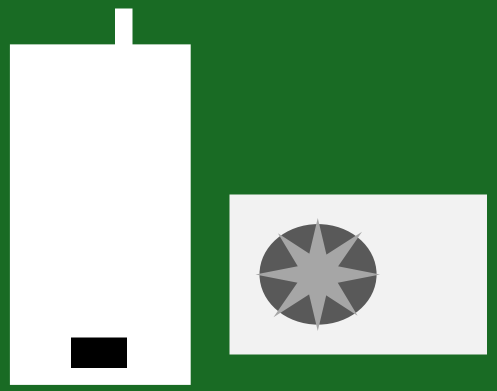

# Assessing the Impact of Behavioral Aspects on Energy Consumption: A RCT approach


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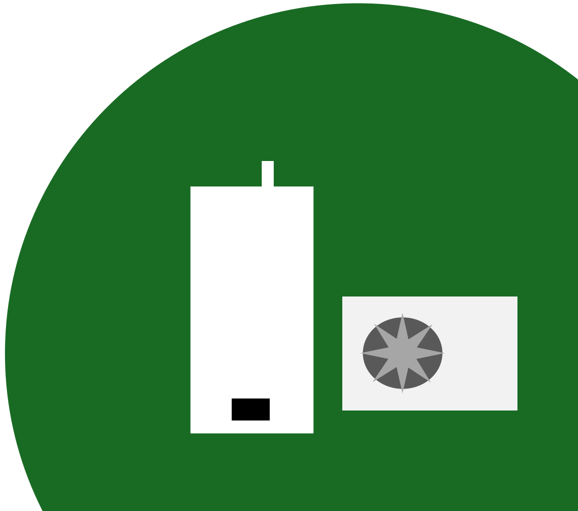
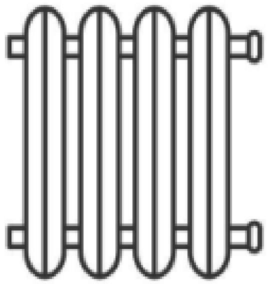
# Context

- The **Italian State** is interested in giving an incentive for people to change their heating system.
- 2 aspects must be distinguished to comprehend the amount of the incentive given:
  - Efficiency Improvement
  - **Behavioral Change**

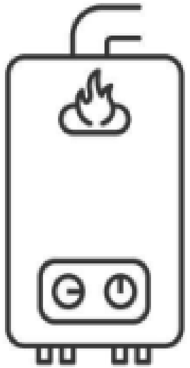


# What we are talking about: Gas Boiler

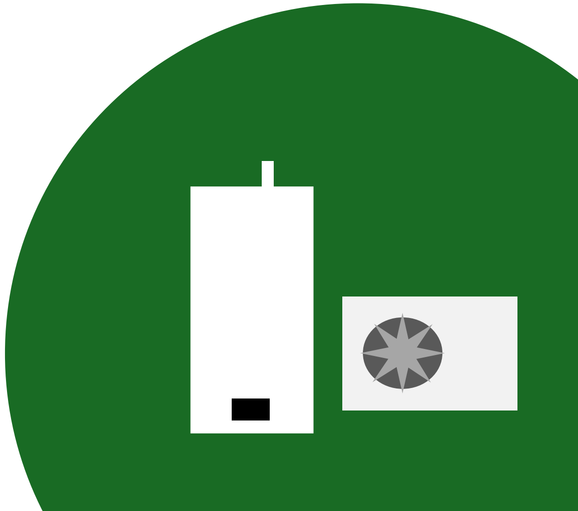
- Gas boilers heat homes by **burning natural gas to warm water**.
- Gas ignites in the combustion chamber, heating water in a surrounding exchanger.
- Hot water flows to radiators or taps.



Radiators



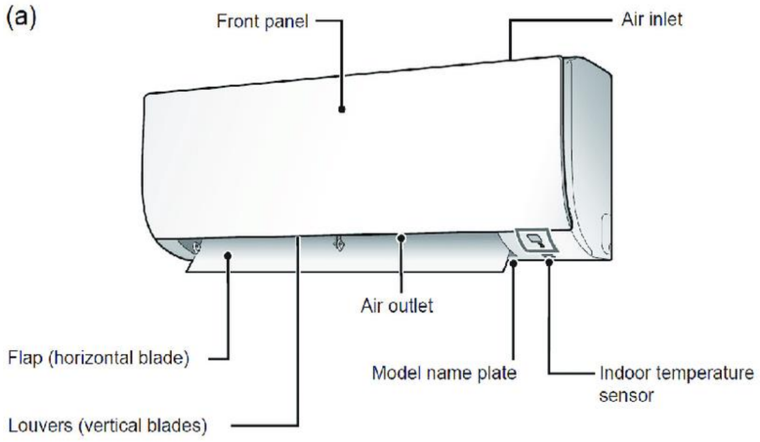
Gas
water heater

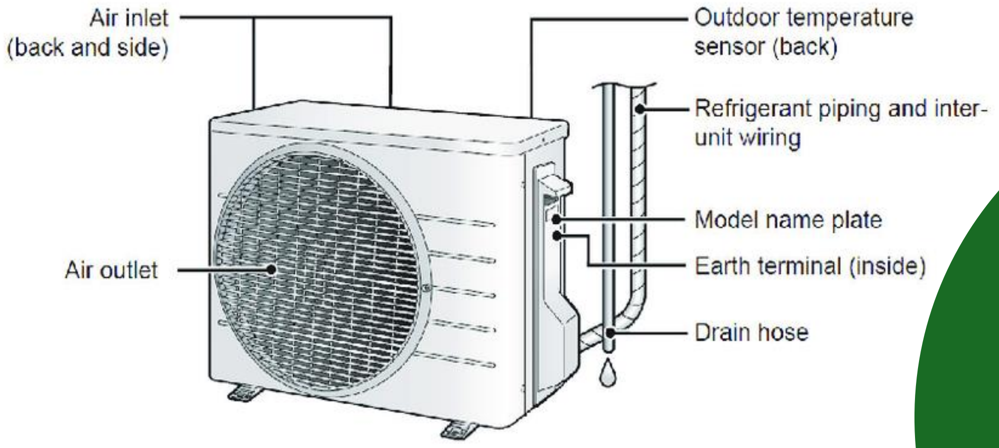


# What we are talking about: Heat Pumps

- They **absorb environmental heat** using a fluid, which is compressed to increase its temperature.

- This hot fluid then **releases heat inside the home** through coils, warming the air.



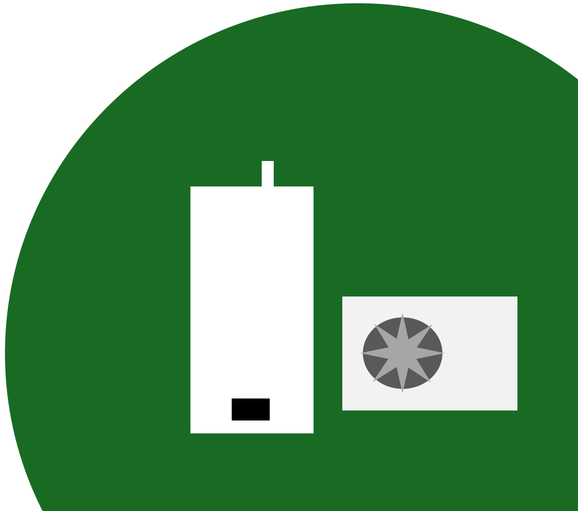
# The Experiment Description

Randomly selected sample of N apartments:

- **Treatment group**: Heat-pump installed
- **Control group:** Traditional gas-boiler installed

The consumptions are monthly monitored for **18 months.**

**Treatment receive for free the heat pump at the beginning and control gets it for free after 18 months of providing data.**

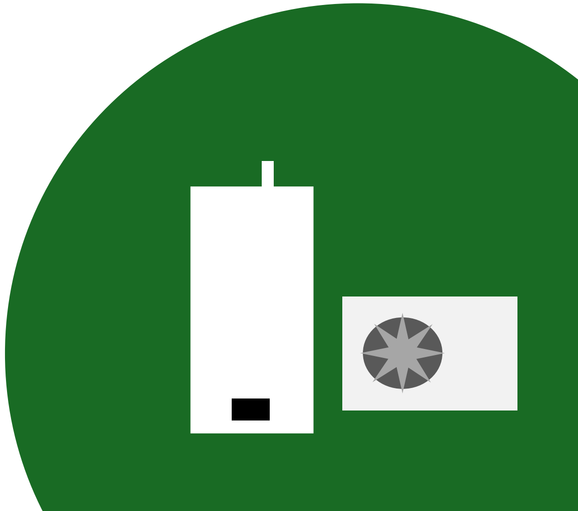


# Randomization Method

The apartments will be randomly selected from the registry of all **Italian households** that are **currently heated by boiler system** and will be classified as a control or a treatment unit.

**Complete randomization** will give the least amount of bias and will allow us to have a fair comparison between the two groups

The **mandatory** nature of the experiment will help us solve **compliance issues**. However, raises ethical questions that will be discussed later.



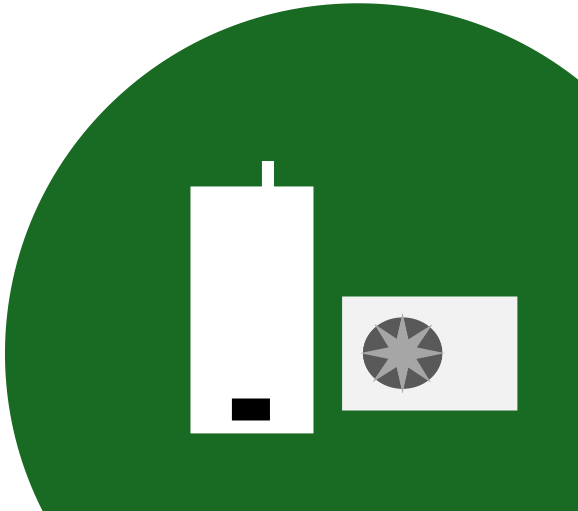
# The Model

$$Y_{it} = \alpha_0 + \beta_1 D_i + \beta_2 X_i + e_{it}$$

$$Y_{it} = \alpha_0 + (\beta_{Technological} + \beta_{Behavioural})D_i + \beta_2 X_i + e_{it}$$

Where:

- $\mathbf{Y_{it}}$ represents the kWh consumption of appartment **i** at time **t**.
- $\mathbf{D_i}$ is a dummy variable that equals 1 if appartment i is assigned to the treatment group (modern heating system), and 0 if it is in the control group (traditional gas heating).
- $\mathbf{X_i}$ represents the control variables included in the model
- $\mathbf{e_{it}}$ is the error term, capturing unobserved influences on energy consumption.
- The control group doesn't change the behaviour
- $\beta_{tech}$ is assumed to be fixed



The **contol variables** considered are:

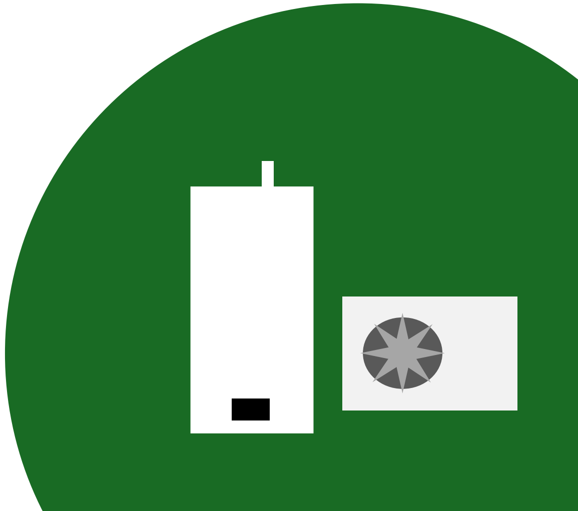
$$Y_{it} = \alpha_0 + \beta_1 D_i + \beta_2 X_i + e_{it}$$

- **Baseline Energy Consumption**: control for the *energy consumption* levels of participants before the implementation of behavioral interventions.

- **Demographic Variables**: such as *age* or *family composition* to account for differences in energy consumption patterns that may be related to these factors.

- **Building Characteristics**: such as *building size*, age, *construction materials and insulation levels,* and *orientation* to account for differences in energy efficiency and thermal performance.

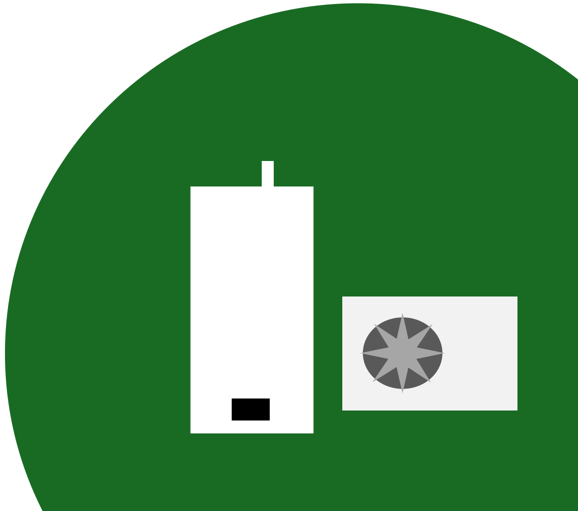
- **Energy Prices**: Control for energy prices (electricity, gas) to account for differences in energy consumption patterns related to variations in energy costs.



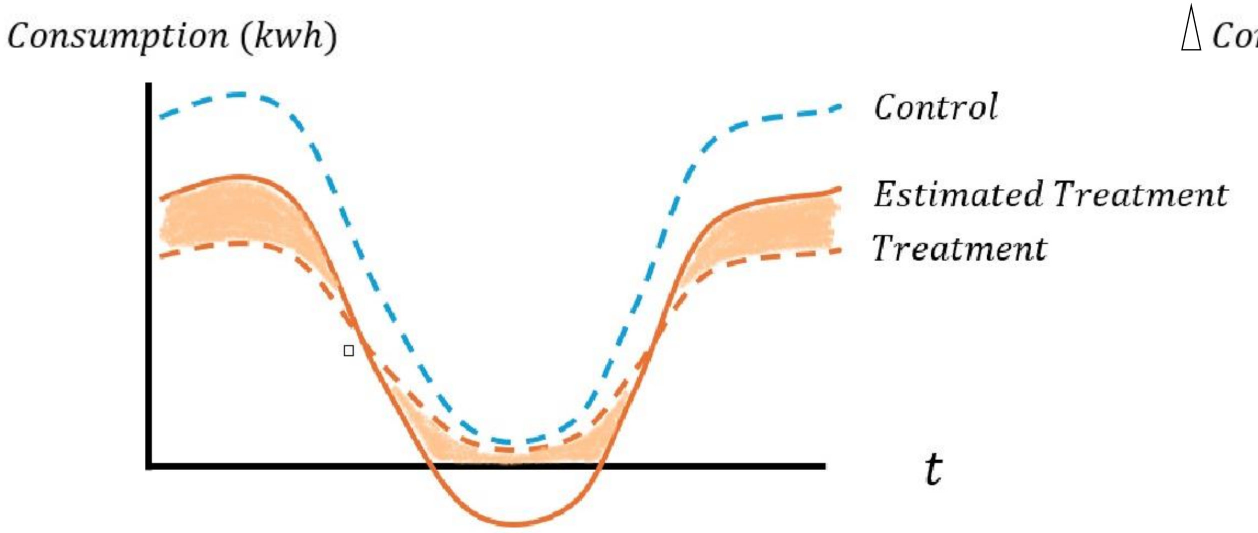
$$Y_{it} = \alpha_0 + \beta_1 D_i + \beta_2 X_i + e_{it}$$

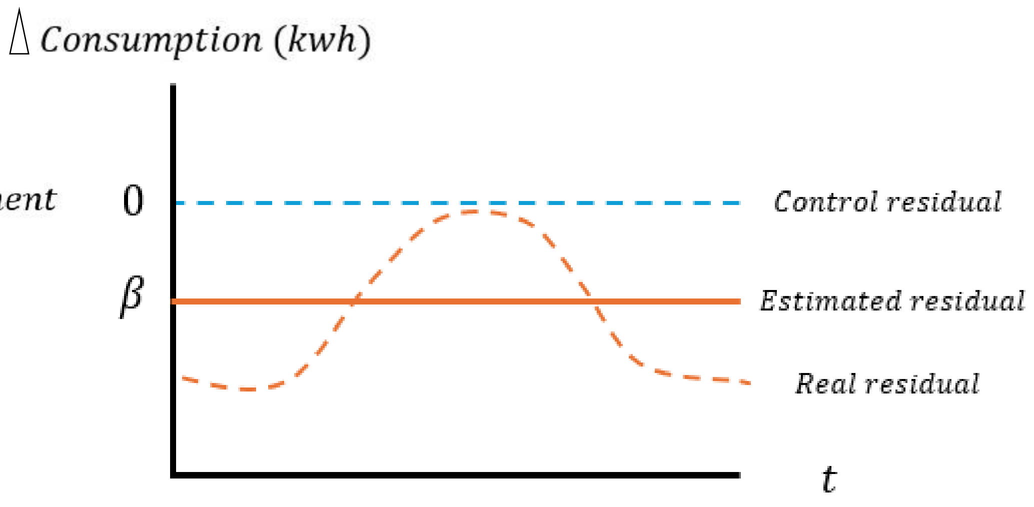
Other **control variables** considered are:

- **Occupancy Variables**: such as *the number of occupants*, occupancy hours, and *daily routines* (e.g., working hours, sleeping hours), to account for differences in energy usage associated with occupancy behavior.
- **Climate Data**: such as *temperature*, humidity, and seasonal variations to account for differences in energy demand due to climate conditions.
- **Household Socioeconomic Status**:such as *income level*, *education level*, and employment status to account for differences in energy consumption behavior associated with socioeconomic factors.



# The Model




The model assumes that Beta is fixed in time, but it is more appropriate to imagine the **real difference in consumption (dotted orange line)** to follow trends since **consumptions cannot be negative:** the treated might become similar to control group in low consumption months and our Beta will be **underestimating or overestimating seasonally**.

# Minimum Detectable Effect

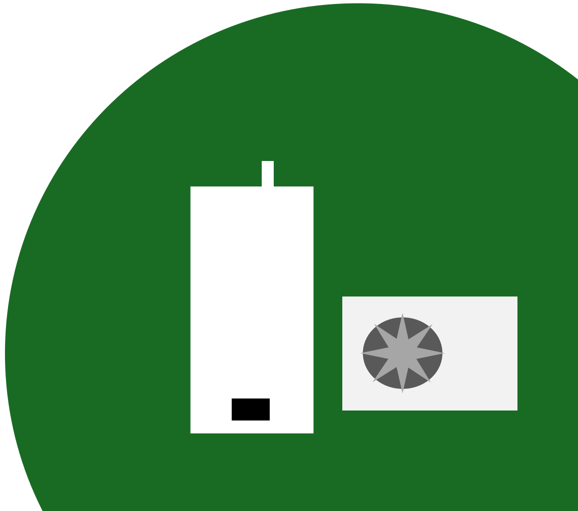
$\beta_1$ = - **Tech** ± **Behaviour**

The consumption of heat pump varies between **0.86-9.00 kWh** per hour.
while an old heater can consume between **2-12 kWh** per hour.

From these values we can get the **Tech** part of the beta, the one assumed to be fixed. To do so, we compute the average of these values for each product and we find the difference in percentage.

**7 kWh** is the average consumption of an old **heater**, while **4.93 kWh** is the average consumption of a **heat pump**.

The average difference in consumption is 29,57%, meaning that our technological **fixed part** of the beta is assumed to be **-0,2957.**



# Minimum Detectable Effect

$$\beta_1 = -\ 0{,}2957 \pm \text{Behaviour}$$

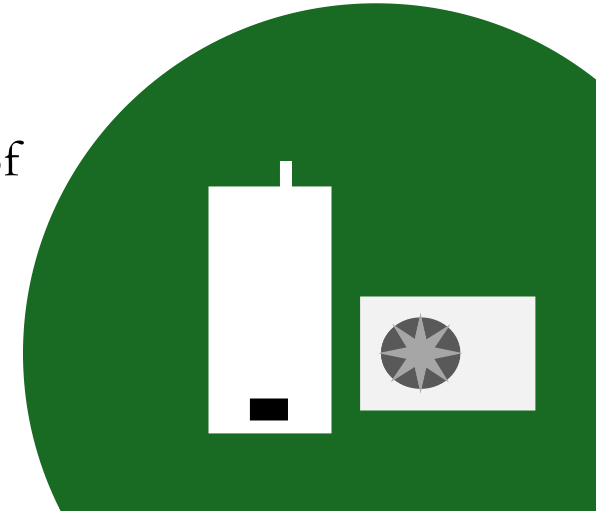
For the **Behaviour** part we take informations by the coefficient from similar papers. In this case we use an italian paper about differences in behaviour before and after installation of a smart screen allowing to visualize electric consumptions.
( **Marangoni, Tavoni 2021 - Real-time Feedback On Electricity** )

We then assume the Behaviour part of the beta to be **-0.07**.

This value alone will be our MDE since we are trying to measure variations on beta only given by the behaviour.

The **expected beta** will be atleast **-0.3657**, while the MDE used for the computation of the minimum N will be only **-0.07**.

$$\beta_1 = -\ 0{,}2957 -\ 0{,}07$$

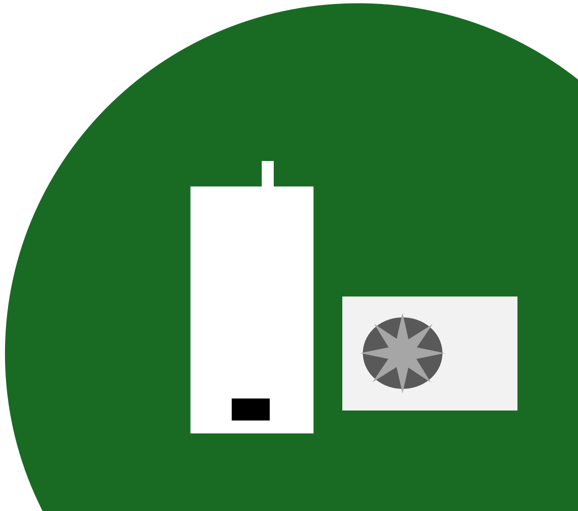


# Minimum Detectable Effect

We want to demonstrate that italians have less consumptions when they use the heating pumps also **thanks to behavioural effect**. In this case the MDE is expected to be a negative value and we want the estimated behavioural effect to be more negative than the MDE.

Counterintuitively, we have to interpret the results in the other way around, so for the sake of simplicity we traduce this in **absolute values**:

$$|\text{MDE}| \leq |\text{Expected Behaviour}|$$



# Sample size

We calculated the sample size based on key parameters including power (0.8), alpha level (0.05), N ratio (1), and Minimum Detectable Effect (MDE).

Inputting these parameters yielded a **sample size of 3206** participants, evenly distributed between groups, ensuring sufficient statistical power to detect the specified effect size with confidence.

**Sample Size Calculation Results**

| Parameter | Value |
|---|---|
| Power | 0.800 |
| Alpha | 0.050 |
| N Ratio | 1.000 |
| MDE | -0.070 |
| Sample Size | 3204.577 |

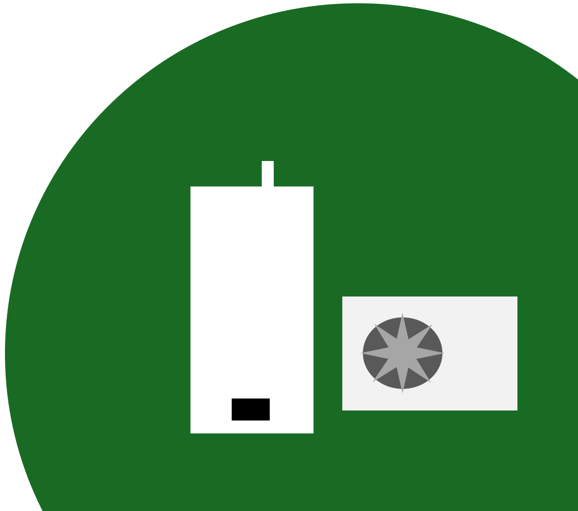
Table of inputs and resulting N

# Internal Validity

Possible internal validity problems addressed are:

Internal validity concerns:

- **spillover effects:** internal thermal insulation;
- **partial compliance:** people are obliged to participate in the experiment;
- **attrition:** people are forced to provide data for the duration of the experiment.

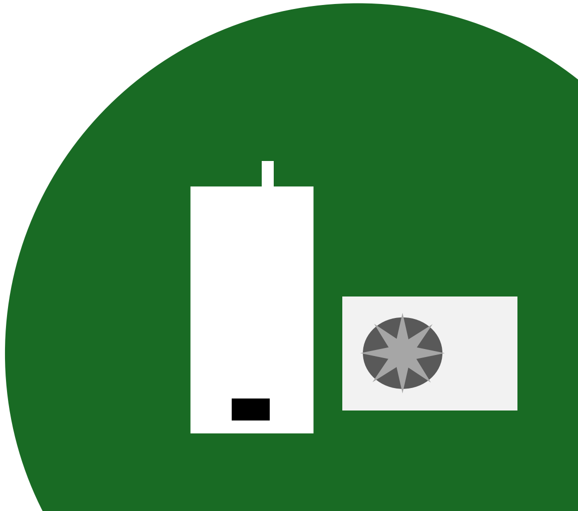


# External Validity

The study's **findings are applicable primarily to Italy** and may vary in other regions based on other factors.

Therefore, while the results offer insights for Italy, generalizing them to other states requires consideration of **local climate conditions** and **average house characteristics**.

The **RCT could still be reproduced** in another country keeping similar settings but using **different data**, also while computing the MDE.

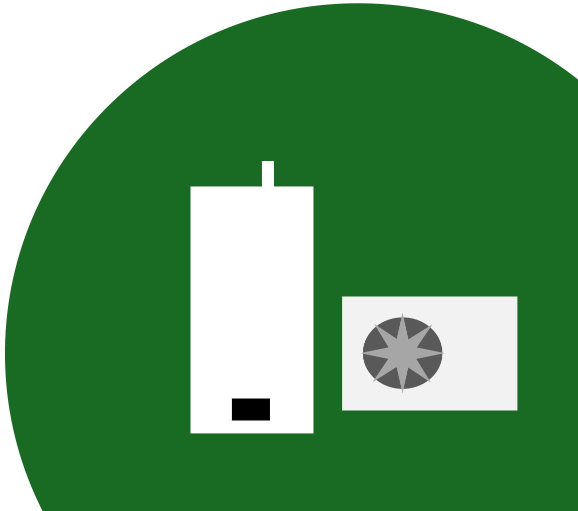


# Ethical Constraints

Ethically, the experiment is made acceptable since participants receive a **free heat pump** despite the obligement to participate.

However, in practice, **individuals may choose to accept or decline the offer**, potentially leading to complications such as **self-selection bias**.

The gift might reduce the Attrition problems and allow for a correct randomization.



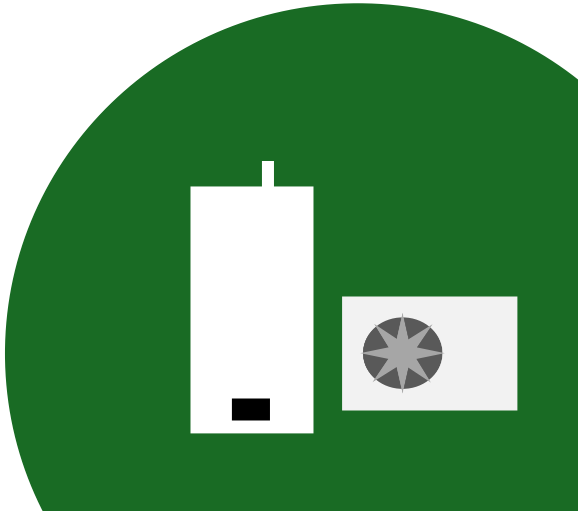
# Financial Costs

The first cost consideration arises from the necessity of providing **3206 heat pumps free of charge**.

However, another significant expense stems from the need to monitor consumption data. To address this, the state must opt for the most cost-effective approach.

- One option is manually measuring consumption monthly by **sending personnel to households** within the sample.

- Alternatively, **equipping all 3206 participants with smart meters** that automatically measure and transmit consumption data to the state presents an efficient alternative.



# Interpreting the results

$\beta_1 =$ - Tech - Behaviour

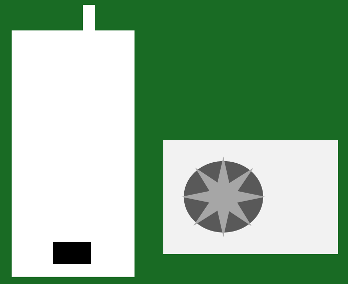
The result we are interested into is that **MDE is smaller or equal in absoulte value than the behavioural part of the beta.**

As the results are provided the behavioural part will be obtained simply by subtracting the beta to the tech fixed delta.

$$\text{Estimated Behaviour} = \text{Tech} - \text{Estimated } \beta_1$$

$$|\text{MDE}| \leq |\text{Expected Behaviour}|$$

If the italian state detects values that don't belong to this relationship, then the italians are overconsuming when they have the heating pump and the
state will not provide incentives to buy them. Oppositely, if the values belong to the disequation, they will give the incentives.

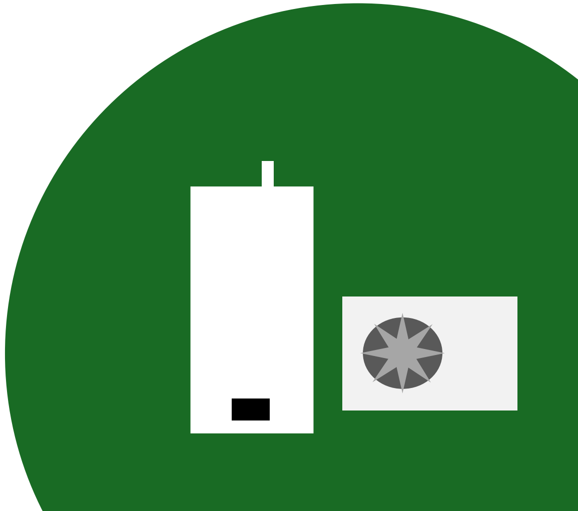


# Interpreting the results

We can additionally analyze the statistical difference of the **obtained behavioural effect** from the MDE by running a **T-test** with alpha 5% and the following settings:

- **Null Hypothesis (H0)**: MDE = obtained behavioural effect
- **Alternative Hypothesis (H1)**: MDE ≠ obtained behavioural effect

This additional test would add another layer of understanding to the results and can help the Italian State choosing **whether to provide the incentive or not**.

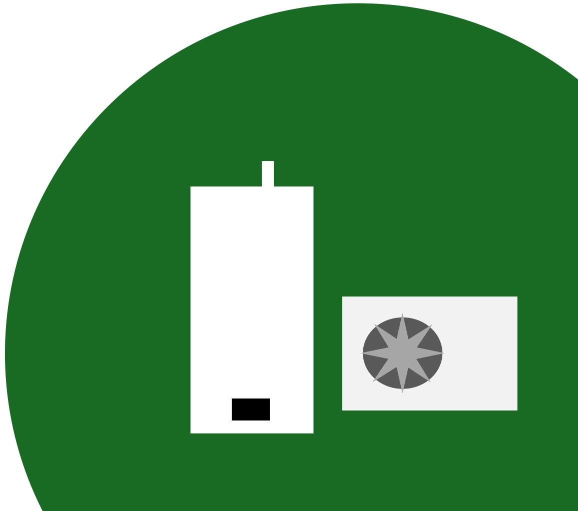


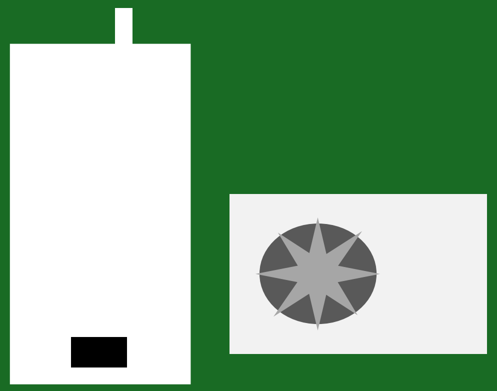
# References


- Marangoni, Tavoni 2021 - Real-time Feedback On Electricity

- https://www.google.com/search?q=how+much+a+heating+pump+consume+in+kwh%3F&oq=how+much+a+heating+pump+consume+in+kwh%3F&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRigATIHCAIQIRigATIHCAMQIRigATIHCAQQIRifBTIHCAUQIRifBTIHCAYQIRifBTIHCAcQIRifBdIBCjEyMDEwajBqMTWoAgiwAgE&sourceid=chrome&ie=UTF-8

- https://energit.it/qual-e-il-consumo-medio-di-una-caldaia-a-gas/#:~:text=Il%20consumo%20di%20una%20caldaia%20a%20gas%20standard%20da%2024,in%20rapporto%20a%20diversi%20fattori.



Thank you for your attention!