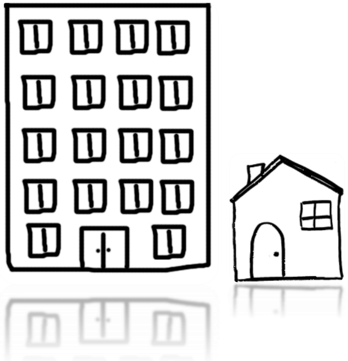
International Energy Policies & Programmes Evaluation Conference

Connecting Evaluators, Implementers and Stakeholders of Low Carbon Policies and Programmes

2014 Event - Berlin, Germany - September 9-11 - Pre-Conference Workshops on September 8

Evidence of an indirect rebound effect with air-to-air heat pump: to have and not to use?

D.Osso, EDF-R&D, Moret-sur-Loing, France
M.Raynaud, EDF-R&D and CES – MINES ParisTech, Moret-sur-Loing, France
B.Bourges, GEPEA – MINES Nantes, Nantes, France
B.Duplessis, CES – MINES ParisTech, Paris, France
J.Adnot, MINES ParisTech, Paris, France



Context

- In housing sector:
  - In EU, few *ex-post* evaluations of local energy efficiency programs
  - Less studies about **indirect rebound effect** linked to air conditioning than studies about direct rebound effect linked to space heating (Sorrell 2007)
  - Whereas direct electric heating space heating systems replaced by **reversible air-to-air heat pumps** in France
  - In 2012 **1,3 millions air-to-air heat pumps sold in UE including** 80,000 in France (EurObservER 2013)

- Our approach:
  - **Statistical modeling** of the annual energy consumption change where air-to-air heat pumps have been installed

Aims of this study

- To **quantify energy savings** generated by air-to-air heat pump installations in southern France
- To assess the **robustness** of observed energy savings
- To study potential **rebound effects** (direct and/or indirect) occurring after such refurbishment

The operation studied…
and the dedicated inquiry

- The energy efficiency operation:
  - **Southern regional energy efficiency programme** in France in *Provence-Alpes-Côte d'Azur* launched by EDF in 2009
  - **Target:** an annual rate of refurbishment of 10%/y instead of 3%/y actually, within a building stock of 200,000 houses built before 1990 and heated by electricity

- The inquiry:

  - Telephone survey during 2012
  - Informations required: building typology, energy systems, **behaviour**, retrofitting actions (with and outside the program), **total energy bills** (on the last three years)
  - 212 filled questionnaires

The sample

- 91 questionnaires presenting both situations (”before” and ”after ”)

- Type of dwellings: **recent** (built >1975 and <2001) **single family housing** mainly initially equipped with **direct electric heating**

- 84 % of the dwellings **without air conditioning** system

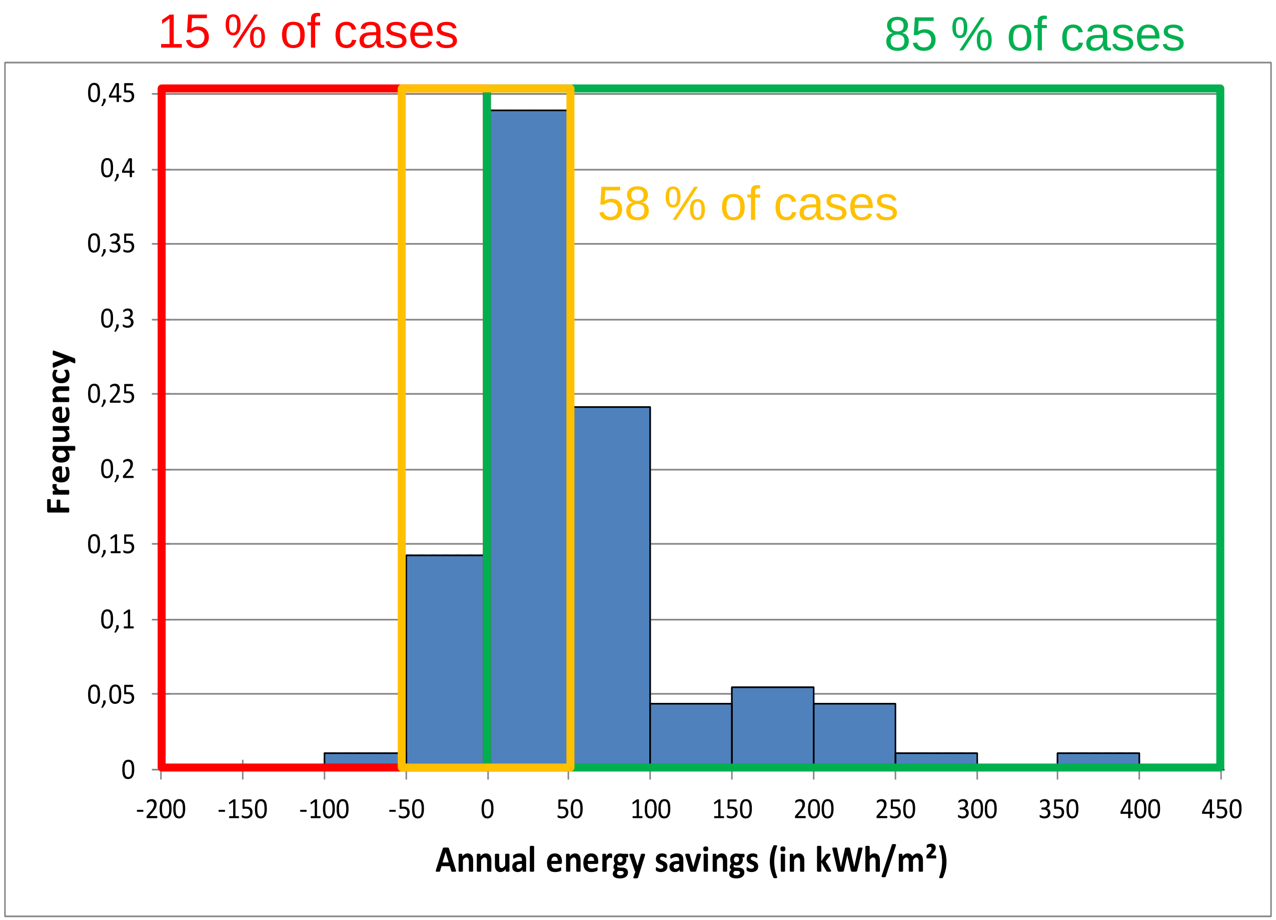
- Type of refurbishment: installation of **heat pump coupled with a second action** (roof insulation, solar water heater)

Energy savings calculations

$$ES_i = C_{i,be}^{norm.} - C_{i,af}^{norm.}$$

- with ES_i annual energy savings of case i (in kWh, final energy)
- $C_{i,\vartheta}^{norm.}$: **climate adjusted** annual **total** energy consumption (in kWh) with ϑ = before (be) or after (af) retrofitting
- Total end-uses consumption = sum of declared consumptions for different energies (electricity, gas, LPG, wood…)(in kWh_{LCV})
- Climate normalization only done on space heating consumption:
  - Normal climate (average over 20 years): HDD between 1600 and 1300 °.day per year
  - Space heating consumption share: 70% of total final consumption (average national value for individual housing)
  - No Cold Degree Day adjustment, not reliable (Day 2004)

Existence of energy savings?



No surface increase

- **A large majority presents positive energy savings (*i.e.* consumption drop)**
  - Nevertheless, a large share of cases presents energy savings in an interval between -50 and 50 kWh/m²

Robustness of energy saving: methodology

- Calculation of **uncertainties linked to energy savings** by propagation of uncertainties from:
  - Declared consumptions of fuel oil, LPG, wood (lack of proper metering)
  - Share of space heating consumption in the all end-uses consumption used for the climate adjustment

- Definition of the uncertainties by the confidence intervals at level 95 %:
  - Are robust, energy savings with **a reliable sign (+ or -)**, *i.e.* the lack of zero in the confidence interval at level 95 %

Robustness of the energy savings: results

- Given the difficulty to choose a value of uncertainty, we performed a sensitivity analysis based on three scenarios of uncertainties

Breakdown of 91 cases according to energy savings robustness (in %)

	Uncertainty scenario		
Share (%)	Optimistic	Realistic	Pessimistic
Non-robust	5.5	10.0	18.0
Robust with - sign	13.0	10.0	4.0
Robust with + sign	81.5	80.0	78.0

➢ **Whatever the uncertainty scenario, the cases with robust and positive energy savings are predominating**

Does it exist declared rebound effects?

$$variable_i^{explained} = \alpha + \sum_{j=1}^{N_j} a_j * variable_{j,i}^{quantitative} + \sum_{k=1}^{N_k} \sum_{l=1}^{m_k} b_{kl} * variable_k^{qualitative}\_modality_{l,i} + \varepsilon_i$$

- **Response** variable: total annual energy consumption after retrofitting at normal climate and for 1 m² of surface area (in kWh/m²)

- **Change model** type: include the annual energy consumption **before** retrofitting

- **Explanatory** variables linked to rebound effects:
  - **Declared change of heating set temperature** in the living rooms between before and after retrofitting (in °C) ⇒ Direct rebound effect
  - **Declared use of air conditioning after** retrofitting (a coupling between the declared time of use during summer and declared set temperature) ⇒ Indirect rebound effect

Statistical method used

- Quantitative and qualitative variables → **covariance analysis** (ANCOVA, general linear statistical modeling)
- **Backward selection** to retain significant variables with at least a significance level of 0.05 on Student's test
- Reference of the quantitative variables with constraint «coefficient of the first category = 0»
- It is verified that:
  - Explanatory variables do not present colinearity (Variat. Inflat. Factor ≤ 3)
  - Residuals are homoscedastic (graphic verification)
  - Residuals are normally-distributed (Jarque-Bera's test)

✓ Model highly significant (Pr to Fisher's test <0.0001)

CAUTION Explanation and prediction capacities limited (adj. $R^2 = 0.37$; RMSE* = 36.5 kWh/m²)

* RMSE= Root-Mean-Square Error

Results of the statistical model

$$C_{i,af}^{norm.,m^2} = \alpha + a_1 * C_{i,be}^{norm.,m^2} + \sum_{l=1}^{4} b_{1l} * \textit{declared use air conditioning\_modality}_{l,i} + \varepsilon_i$$

- **Energy savings* of 69.2 kWh/m²** for the reference case**

- Only **two variables kept** by the selection procedure amongst 8 variables:
  - Energy consumption before retrofitting
  - **Declared use of air conditioning after retrofitting**

- "Energy consumption before retrofitting" effect: an additional energy savings of 0.7 kWh/m² per each kWh/m² of initial overconsumption relative to the sample mean (174.5 kWh/m²)

- **Direct** rebound effect: **no statistical evidence**

*confidence interval at level 95 %: [59.5; 78.9])
** hypothetical case with an annual energy consumption before retrofitting equals to the sample mean (174.5 kWh/m²) and a household having declared to not use air conditioning after retrofitting (and for all categories or values of non significant variables)

Indirect rebound effects

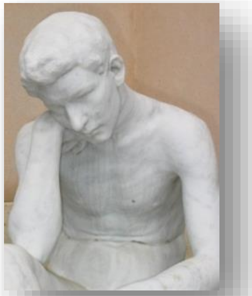
- An **important use** of air conditioning after retrofitting presents **higher energy** consumptions after retrofitting:
  - around an increase of +39.5 kWh/m²
  - but with a large uncertainty: confidence interval at level 95 %=[21.9 ; 57.1]
  - and representing **only 31%** of studied households

- Indirect rebound effect **quantification**:

$$\frac{\text{energy savings losses estimated with declared air conditioning use}}{\text{energy savings estimated with no air conditioning use}}$$

- **Average** on every cases of the sample: **29 %** with a confidence interval at level 95 % =[12 % ; 46 %]

Conclusions



- This study of a regional operation promoting air-to-air **heat pumps in a Mediterranean area** has shown:
  - Whatever the uncertainty scenario, **the vast majority** of studied households presents **robust and positive energy savings**
  - Only **31 %** of the sample **declaring an important use** of air conditioning after retrofitting have **significant energy savings losses** BUT the quantified effect presents a **high uncertainty**
- Future works needed in order to enhance the validity of those results:
  - To increase the samples from a new survey
  - To reduce the uncertainties linked to the information about households behaviours

Many thanks for your attention !

Your comments and suggestions are welcome at:

dominique.osso@edf.fr

References

Day, A. R. 2004. “Cooling energy consumption and temperature.” *Market Transformation Programme Seminar*

EurObservER 2013, http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro218.pdf

Sorrell, S. 2007. *The Rebound Effect: an assessment of evidence for economy-wide energy savings form improved energy efficiency.* Technology and Policy Assessment function, UK Energy Research Centre. ISBN 1-903144-0-35

Sorrell, S., and J. Dimitropoulos. 2008. “The rebound effect: Microeconomic definitions, limitations and extensions.” *Ecological Economics* 65:636-649

Appendix

- Synthesis of the three uncertainty scenarios:

	Scenario	Bounds $[a_- ; a_+]$	Probability distribution[1]	Standard uncertainty
Observed consumptions for oil (C_{oil}), LPG (C_{LPG}), wood log (C_{woodl}) or wood pellets (C_{woodp})	Optimistic (interval/2)	$[0.9C_e ; 1.1C_e]$	Symmetric trapezoidal distributions having equal sloping sides, with bases of width $a_+ - a_-$ and tops of width $(a_+ - a_-)*0.5$	$\sqrt{\frac{(a_+ - a_-)^2 * (1 + 0.5^2)}{24}}$
	Realistic	$[0.8C_e ; 1.2C_e]$		
	Pessimistic (interval*2)	$[0.6C_e ; 1.4C_e]$		
Hypothesis on space heating share in total consumption (0.7)	Optimistic (interval/2)	[0.665 ; 0.74]	Rectangular distributions with widths $a_+ - a_-$	$\sqrt{\frac{(a_+ - a_-)^2}{12}}$
	Realistic	[0.63 ; 0.78][2]		
	Pessimistic (interval*2)	[0.56 ; 0.86]		

Appendix

- Explanatory variables used for the statistical model of $C_{i,af}^{norm.,m^2}$ (sample=82):

Variable	Definition
Quantitative variables	
Energy consumption before retrofitting	Difference between the total annual energy consumption before retrofitting at normal climate ($C_{i,bf}^{norm.,m^2}$) and 174.5 kWh/m² (mean of the sample); reference unit: 1 kWh/m² (final energy); [-118.2 ; 360.1]
Declared change of heating set temperature	Declared change of heating set temperature due to the retrofitting; reference unit: 1°C; [-3.5 ; 5.5] (22 % of a value different to zero with 17 % of a positive value and 5 % of a negative value).
Qualitative variables and their categories	
Type of heat pump installed	0- air-to-air heat pump (85 % of the sample); 1- air-to-water heat pump (15 %)
Type of second action realized	0- roof insulation (79 % of the sample); 1- SHW (21 %)
Declaration of action realized outside the operation	0- no additional action(s) declared (78 % of the sample); 1- additional action(s) declared (22 %)
Declared use of air conditioning after retrofitting	0- no use declared (45 % of the sample); 1- low use declared with set temperature <23 °C (13 %); 2- low use declared with set temperature ≥23 °C (11 %); 3- important use declared with set temperature <23 °C (16 %); 4- important use declared with set temperature ≥23 °C (15 %)
Declared change in occupation	0- no change declared between before and after retrofitting (77 % of the sample); 1- increase declared (8 %); 2- decrease declared (15 %)
Bad workmanship	0- no bad workmanship declared (90 % of the sample); 1- bad workmanship declared (10 %)

The type of heat pump installed

- Air-to-air (85 % of the sample) vs air-to-water (15 %): variable found **non statistically significant BY THE MODEL**

- Whereas **a difference exists according to energy savings calculations:**

ES_i (in kWh/m²)		Mean	Confidence interval at level 95 %
Type of heat pump installed	Air-to-air	47.3	[31.2; 63.4]
	Air-to-water	115.0	[70.8; 159.3]

- Difference taken into account by the statistical model via:
  - A higher inital energy consumption for air-to-water installations than for air-to-air installations (averages: 244.4 kWh/m^2 vs 162.5 kWh/m^2)
  - Declarations of more intensive use of air conditioning for air-to-air installations than for air-to-water installations (all households declaring important use installed air-to-air)