Some like it hot: An experiment on comfort expectations and energy retrofit decisions

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Outline

- **Indoor comfort** as an umbrella concept made of thermal, air quality, aesthetic, noise, and control considerations, among others
- Thermal comfort often said to be the most important aspect (**Huebner, 2013**)
- Reasons for implementing residential retrofit measures (e.g. **Wilson et al., 2015**; **Achtnicht and Madlener, 2014**):
  - Improve thermal comfort
  - Increase the value of the property
  - Fulfill regulations
  - Save on energy costs
  - Reduce CO_2 emissions
- Studies on preferences for different measures (Discrete Choice Experiments, DCE)
  - **Achtnicht (2011)**: new heating system VS. insulation among homeowners
  - **Banfi et al. (2008)**: ventilation systems VS. insulation of windows and facades among houseowners and tenants
  - **Alberini et al. (2013)**: upfront costs of the renovation projects, government rebates, savings in energy bills, time horizon, and **thermal comfort** improvements matter

- **Direct rebound effect** as increase in demand for energy services that follows the implementation of energy-saving measures (e.g. **Sorrell and Dimitropoulus, 2008**). In buildings it might result from e.g.:
  - occupants wanting to achieve higher room temperatures
  - occupants unexpectedly enjoying higher room temperatures

- **"Technical" rebound effect**: no change in the way the system is operated, higher thermal comfort brought about by a **physical change** in the building structure (**Galvin, 2015; Milne and Boardman, 2000**)

- Studies on rebound effect in buildings largely based on **measurement data**

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Gap in empirical investigation of relationship between comfort expectations, retrofit decisions, and rebound effect

Outline

- **Hypothesis 1**: Individuals prefer retrofit scenarios characterized by **higher room temperatures**, other things being equal

Research hypotheses

- **Hypothesis 1**: Individuals prefer retrofit alternatives with the effect of an **increase in room temperature**, other things being equal
- **Hypothesis 2**: The **higher** the **potential for technical savings** in energy costs, the **bigger the preference** for **higher room temperatures**

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- **Hypothesis 3**: Individuals prefer retrofit solutions able to guarantee **better air quality**

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- **Hypothesis 4**: Reducing the **noise** coming **from both the outside and inside** of the building matters

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- **Hypothesis 4**: Reducing the **noise** coming **from both the outside and inside** of the building matters
- **Hypothesis 5**: Refurbishments that reduce the ability to **control** the system to adjust the level of comfort are disliked

Research questions

- **Hypothesis 1**: Individuals prefer retrofit alternatives with the effect of an **increase in room temperature**, other things being equal
- **Hypothesis 2**: The **higher** the **potential for technical savings** in energy costs, the **bigger the preference** for **higher room temperatures**
- **Hypothesis 3**: Individuals prefer retrofit solutions able to guarantee **better air quality**
- **Hypothesis 4**: Reducing the **noise** coming **from both the outside and inside** of the building matters
- **Hypothesis 5**: Refurbishments that reduce the ability to **control** the system to adjust the level of comfort are disliked
- **Hypothesis 6**: Retrofit measures improving the **external appearance** of the dwelling are preferred when the **interior design is not compromized**

Outline

Composition and main socio-demographics

- **3,161 owner-occupiers** and **tenants** living in Germany ("Respondi" panel)
- **Tenancy status**: 1,884 tenants (59.60%) and 1,277 owner-occupiers (40.40%)
- **Gender**: Ca. 46% women
- **Age**: range 18-80 years; average ca. 45 years
- **Net household income**: ca. 52% of respondents disposing of an overall income of <2,600 €/month
- **Environmental concern**: average = 56.29 and s.d. = 8.23, measured through the New Ecological Paradigm (NEP) scale (**Dunlap and van Liere, 1978; Dunlap et al. 2000**), 15 items in a 5 agree-disagree Likert scale

Outline

- Survey conducted in Winter 2015/2016 through CAWI technique
- DCE survey methodology allows to elicit consumers' preferences for a product (or service) by inducing respondents to trade off different product characteristics
- **6 random** choice cards + **2** identical **holdouts**
- **2 unlabeled** alternatives + "**None**" option
- **Fractional-factorial** and **full-profile** design
- Complete enumeration computer-optimized design (by Sawtooth Software®)
- **7 attributes**, monthly costs customized based on:
  - Respondents' tenancy status
  - Size of current dwelling
  - Type of building
- Choice of attributes and their wording based on **literature review** and **12 semi-structured interviews** among occupants of retrofitted dwellings in Rintheim, Germany
- **Cognitive pretest** was conducted before fielding the survey

Attribute	Level
A1. Room air quality (AIRQ)	1.1 As before 1.2 Better than before 1.3 Worse than before
A2. Room temperature (TEMP)	2.1 As before 2.2 Slightly warmer than before
A3. Monthly payment for the system/ monthly increase in rent (COST)	3.1 Low, customized 3.2 Intermediate, customized 3.3 High, customized
A4. Control over windows and heating system (CONTR)	4.1 High 4.2 Intermediate 4.3 Low
A5. Noise reduction (NOISE)	5.1 Reduction of noise from inside and outside the building 5.2 Reduction of noise from outside the building 5.3 Reduction of noise from inside the building 5.4 No reduction of noise from outside nor inside the building
A6. Aesthetics of the flat (AESTH)	6.1 Improved inside and outside appearance 6.2 Improved inside appearance 6.3 Improved outside appearance 6.4 Improved outside appearance but worsened inside appearance 6.5 Improved inside appearance but worsened outside appearance
A7. Potential savings in energy costs (SAV)	7.1 20% 7.2 40% 7.3 80%

Scenario description: Imagine you are currently living in an old and non-retrofitted dwelling. You are interested in insulating the walls and roof, installing new windows and a more efficient heating system. Which of the following alternatives best describes your ideal of comfort in your living room on a winter day?

	Alternative A	Alternative B	
Room air quality	Worse than before	Like before	I would rather remain in a none retrofitted dwelling than choosing any of the previous alternatives
Room temperature	A bit warmer than before	Like before	
Monthly payment of the credit for the retrofit	140€	110€	
Personal control over the system	High	Low	
Noise reduction	Reduction of noise from outside the building	Reduction of noise from inside the building	
Aesthetic of the dwelling	Improved internal appearance of the dwelling, but worsened external appearance	Improved external appearance of the dwelling, but worsened internal appearance	
Potential savings in energy costs	40%	20%	
YOUR CHOICE	☐	☐	☐

Example of a choice card for owner-occupiers

- Random Utility Theory based on neo-classical approach (**McFadden, 1974**)
  ⇒Utility respondent *n* gains from choosing alternative *j* is given by

  $$U_{nj} = V_{nj} + \varepsilon_{nj},$$

  V_{nj} is a function of observable choice attributes x_{nj} and socio-demographic variables z_n; ε_{nj} is the unknown error term

- Estimation of mixed logit model (**McFadden and Train, 2000**) with alternative-specific constant (ASC) and
  - different specifications for COST (Model 1–4)
  - correlated coefficients (Model 5)(**Revelt and Train, 1998**)
  - socio-demographics (Model 6)

- Main characteristics of the mixed logit model:
  - it relaxes the IIA assumption
  - estimated via simulation techniques (**Train, 2003**)
  - random coefficients assumed to be normally distributed with idiosyncratic error term i.i.d. extreme value

Outline

Levels	(1) Mean	(1) s.d.	(2) Mean	(2) s.d.	(3) Mean	(3) s.d.	(4) Mean	(4) s.d.
AIRQ_better	.498*** (.020)	.164*** (.054)	.520*** (.020)	.135* (.071)	.536*** (.021)	.190*** (.052)	.550*** (.022)	.187*** (.054)
AIRQ_worse	-.636*** (.023)	.289*** (.037)	-.666*** (.023)	.288*** (.040)	-.680*** (.024)	.339*** (.036)	-.701*** (.027)	.346*** (.038)
TEMP_warm	.083*** (.011)	.160*** (.031)	.088*** (.011)	.160*** (.033)	.089*** (.012)	.197*** (.029)	.092*** (.012)	.201*** (.030)
COST	-.006*** (.000)		-.010*** (.000)	.011*** (.001)				
COST_low					.374*** (.019)		.382*** (.021)	.248*** (.045)
COST_high					-.412*** (.020)		-.418*** (.021)	.163** (.067)
CONTR_high	.223*** (.018)	.197*** (.047)	.231*** (.018)	.194*** (.053)	.235*** (.019)	.228*** (.044)	.242*** (.019)	.221*** (.053)
CONTR_low	-.198*** (.018)	.117 (.082)	-.208*** (.018)	.171*** (.054)	-.207*** (.019)	.197*** (.051)	-.213*** (.019)	.184*** (.060)
NOISE_in/out	.170*** (.022)	.015 (.092)	.177*** (.023)	.037 (.085)	.176*** (.023)	.030 (.104)	.179*** (.023)	.098 (.094)
NOISE_out	.035 (.021)	.000 (.106)	.036 (.022)	.042 (.089)	.048** (.022)	.008 (.115)	.047** (.023)	.026 (.117)
NOISE_none	-.260*** (.023)	.219*** (.065)	-.273*** (.024)	.224*** (.063)	-.278*** (.025)	.275*** (.057)	-.283*** (.025)	.221*** (.064)

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AESTH_in/out	.192*** (.026)	.122 (.154)	.195*** (.027)	.229*** (.082)	.206*** (.027)	.219*** (.083)	.213*** (.028)	.271*** (.075)
AESTH_in	.111*** (.026)	.153 (.101)	.122*** (.027)	.084 (.126)	.117*** (.027)	.139 (.127)	.121*** (.028)	.180* (.097)
AESTH_out	.012 (.026)	.033 (.124)	.014 (.027)	.067 (.101)	.015 (.027)	.064 (.179)	.014 (.027)	.074 (.148)
AESTH_out+in-	-.217*** (.026)	.071 (.172)	-.229*** (.027)	.042 (.135)	-.227*** (.028)	.147 (.104)	-.231*** (.029)	.127 (.128)
SAV_20	-.410*** (.019)	.095 (.100)	-.423*** (.020)	.194*** (.050)	-.438*** (.020)	.181*** (.059)	-.449*** (.021)	.229*** (.050)
SAV_80	.440*** (.019)	.273*** (.037)	.456*** (.020)	.284*** (.038)	.468*** (.020)	.297*** (.038)	.481*** (.022)	.319*** (.038)
NONE	-1.626*** (.089)	3.376*** (.089)	-1.977*** (.097)	3.394*** (.096)	-.780*** (.074)	3.322*** (.088)	-.786*** (.074)	3.320*** (.088)
N° Obs.	56,898		56,898		56,898		56,898	
N° Resp.	3,161		3,161		3,161		3,161	
LR χ^2	6,868.57		7,004.22		6,705.44		6,707.82	
d.f.	15		16		15		17	
p-value	0.000		0.000		0.000		0.000	
AIC	32,222		32,088		31,870		31,871	
BIC	32,499		32,375		32,156		32,175	
Pseudo R^2	0.1760		0.1795		0.1741		0.1742	

*** = p≤0.01; ** = p≤0.05; * = p≤0.1; Standard errors in brackets

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Attribute	%
Air quality	27.67
Savings on bill	20.38
Monthly costs	17.90
Noise	10.25
Control	10.09
Aesthetics	9.77
Room temperature	3.94
Total	100.00

- Stated attribute non-attendance
  - **Control, noise, aesthetics**: said to be ignored in ca. 39% of the choices
  - **Potential energy savings** is least ignored attribute (ca. 32% of the choices)
- Respondents' **consistency**: 72.07% of the cases
- "Straightliners": 0.82%
- 95.25% of the respondents found attributes clear; COST most often mentioned as unclear; room temperature was clear in almost all instances

By looking at the cumulative density function...

- Almost **all respondents** positively value
  - **Better air quality** w.r.t. levels before retrofitting
  - **Reduction of the noise from outside** w.r.t. to a mere reduction of the noise coming from inside the building
- Ca. **94%** of respondents would rather **save 80%** of the energy costs than 40%; almost all would prefer 40% to 20% savings
- Ca. **82.38%** of respondents would **improve the internal and external image of the building** over a retrofit strategy that improves external appearance but compromises internal appearance
- **84%** of respondents would prefer **high levels of personal control** over the system to intermediate ones
- **Post-retrofit room temperatures which are higher than pre-retrofit** seem to be desirable only for about **33%** of our sample

	A3.1	A3.3	A1.2	A1.3	A2.2	A4.1	A4.3	A5.1	A5.2	A5.4	A6.1	A6.2	A6.3	A6.4	A7.1	A7.3	None
Mean	.495***	-.538***	.849***	-1.184***	.130***	.389***	-.353***	.255***	.096***	-.447***	.309***	.214***	.043	-.420***	-.667***	.680***	-.629***
	(.027)	(.028)	(.036)	(.049)	(.018)	(.028)	(.030)	(.032)	(.032)	(.038)	(.039)	(.037)	(.039)	(.045)	(.036)	(.033)	(.085)
		A1.2	**.585*** **						.486	-.374		.428		.354			.368
		A1.3	-.762***	**1.060*** **				-.347	-.507	.314		-.388		.377			-.438
		A2.2	-.005	.006	**.112*** **				.392								
		A4.1	.118***	-.094**	-.020	**.270*** **		.368									.362
		A4.3	-.098***	.109**	.034	-.197***	**.298*** **										
		A5.1	.103***	-.099*	.012	.053	-.023	**.077** **				.692	-.411				
		A5.2	.099**	-.139***	.035	-.021	.005	.049**	**.071* **			.354	-.449	-.502			
		A5.4	-.188***	.213***	-.039	-.059	.058	-.156***	-.138***	**.433*** **							
		A6.1	.074	-.113*	-.006	.004	-.012	.045	.021	-.047	**.399*** **						
		A6.2	.104**	-.127**	-.003	.044	.003	.061**	.030	-.105*	.125**	**.101** **					.396
		A6.3	-.007	-.027	-.027	.015	-.036	-.059*	-.062*	.052	-.060	-.025	**.268*** **				
		A6.4	.208***	.298***	.037	-.036	.023	-.052	-.009	.121*	-.320***	-.156***	-.155**	**.591*** **			
		A7.1	-.041	.146***	.026	-.063*	-.014	.018	-.039	.054	-.028	.013	-.025	.073	**.632*** **		
		A7.3	.057	-.201***	.028	.048	.001	-.021	.056	-.055	.028	.028	.013	-.077	-.590***	**.679*** **	
		None	1.125***	-1.800***	.007	.752***	-.626***	.267*	.210	-.555***	.390*	.503**	.227	-.818***	-.390**	.562***	**15.986*** **
N°Obs.:	56,898																
N°Resp.	3,161																
LR $\chi^2(120) =$	7,484.62																
p-value	0.000																
AIC:	31,300																
BIC:	32,526																
Pseudo R^2:	0.194																

*** = $p \leq 0.01$; ** = $p \leq 0.05$; * = $p \leq 0.1$; Standard errors for *W* not reported but available upon request

	Mean	s.e.	SD	s.e.
Fem*AIRQbetter	.043**	.018		
Fem*AIRQworse	-.065***	.020		
Fem*TEMPhigh	-.006	.012		
Fem*CONTRhigh	.047**	.018		
Fem*CONTRlow	-.058***	.019		
Fem*NOISEin/out	.055**	.022		
Fem*NOISEnone	-.089***	.023		
Fem*AESTHin	.046**	.022		
Fem*SAV80	-.033**	.016		
Fem*NONE	.153**	.069		
Old*AIRQbetter	.023	.016		
Old*TEMPhigh	.009	.012		
Old*NOISEin/out	.082***	.022		
Old*NOISEnone	-.089***	.023		
Old*NONE	.335***	.069		
Rich*AIRQbetter	.061***	.018		
Rich*AIRQworse	-.040	.020		
Rich*TEMPhigh	-.011**	.012		
Rich*SAV80	.046***	.017		
Green*AIRQbetter	.083***	.018		
Green*AIRQworse	-.104***	.020		
Green*TEMPhigh	.006	.012		
Green*COSTlow	.047**	.018		
Green*COSThigh	-.039**	.019		

	Mean	s.e.	SD	s.e.
Green*CONTRhigh	.036**	.016		
Green*NOISEout	.067***	.022		
Green*NOISEnone	-.069***	.023		
Green*AESTHin/out	.082***	.025		
Green*AESTHout+in-	-.069***	.025		
Green*SAV20	-.102***	.019		
Green*SAV80	.135***	.019		
Green*NONE	.270***	.069		
Ten*TEMPhigh	-.005	.012		
Ten*COSTlow	.103***	.018		
Ten*COSThigh	-.115***	.019		
Ten*SAV20	.033**	.017		
TEMPwarm*SAV20	-.052**	.026	.003	.087
TEMPwarm*SAV80	.007	.025	.144	.098
TEMPwarm*COSTlow	-.042	.026	.246***	.079
TEMPwarm*COSThigh	.002	.026	.145	.154
N of Obs.	56,898			
N of Resp.	3,161			
LR χ^2	6631.47			
d.f.	76			
p	0.0000			
AIC	31,642			
BIC	32,224			
Pseudo R^2	0.1737			

*** = $p<0.01$; ** = $p<0.05$; * = $p<0.1$

Outline

What can be said about comfort expectations and rebound effect?

1. **Evidence for technical RE** in preferences for higher room temperature after retrofit $\Longrightarrow$ **low share** might be an **experimental construct** or is **Germany not fuel poor**? (for UK see **Milne and Boardman, 2000**)

2. An increase in indoor temperature of about 1°C leads to a 5-10% increase in heating consumption, no matter how good the building's insulation is (**Hens, 2012**; **Galvin, 2015**), BUT **hard to quantify** the magnitude of technical RE

3. Besides hypothesis 2 (on the non-linearity of the RE), **all remaining hypotheses are met**

4. **Heterogeneity** in preferences for thermal comfort **left unexplained** by age, gender, income, environmental concern, and tenancy status

5. Correlated coefficients allow to capture **heuristic behaviors** across choice tasks

Thanks for your attention!

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References

Achtnicht, M. Do environmental benefits matter? Evidence from a choice experiment among house owners in Germany. *Ecological Economics*, 2011, 70(11), 2191-2200.

Achtnicht, M., and Madlener, R. Factors influencing German house owners' preferences on energy retrofits. *Energy Policy*, 2014, 68, 254-263.

Alberini, A., Ban, S., and Ramseier, C. Energy Efciency Investments in the Home: Swiss Homeowners and Expectations about Future Energy Prices. *The Energy Journal*, 2013, 34(0), 1.

Banfi, S., Farsi, M., Filippini, M., and Jakob, M. Willingness to pay for energy-saving measures in residential buildings. *Energy economics*, 2008, 30(2), 503-516.

Dunlap, R.E., and Van Liere, K.D. The new environmental paradigm. *The journal of environmental education*, 1978, 9(4), 10-19.

Dunlap, R.E., Van Liere, K.D., Mertig, A.G., and Jones, R.E. New trends in measuring environmental attitudes: measuring endorsement of the new ecological paradigm: a revised NEP scale. *Journal of social issues*, 2000, 56(3), 425-442.

Galvin, R. *The rebound effect in home heating: A guide for policymakers and practitioners*. 2015, Routledge.

Huebner, G.M., Cooper, J., and Jones, K. Domestic energy consumptionWhat role do comfort, habit, and knowledge about the heating system play?. *Energy and Buildings*, 2013, 66, 626-636.

McFadden, D. Conditional logit analysis of qualitative choice behavior. *Frontiers in Econometrics*, Academic press, 1974.

McFadden, D., and Train, K. Mixed MNL models for discrete response. *Journal of applied Econometrics*, 2000, 447-470.

Milne, G., and Boardman, B. Making cold homes warmer: the effect of energy efficiency improvements in low-income homes A report to the Energy Action Grants Agency Charitable Trust. *Energy policy*, 2000, 28(6), 411-424.

Revelt, D., and Train, K. Mixed logit with repeated choices: households' choices of appliance efficiency level. Review of economics and statistics, 1998, 80(4), 647-657.

Train, K. E. *Discrete choice methods with simulation*. Cambridge university press, 2003

Sorrell, S., and Dimitropoulos, J. The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics*, 2008, 65(3), 636-649.

Wilson, C., Crane, L., and Chryssochoidis, G. Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Research & Social Science*, 2015, 7, 12-22.

Screening questions

- Exclusion of residential buildings erected after 2009
- Screening questions ensure that respondents:
  - Are involved decision-making processes related to energy-consumption matters within the household
  - Do not live in shared dwellings

The German regulatory framework

EnEV 2009 and ff. set standards for retrofitting existing housing stock

- **Partial retrofit** has to fulfil heat transmission coefficient standards (or U-value, indicated with H_T)
- **Comprehensive retrofits** have to satisfy **also** requirements on primary energy consumption (Q_P)(**Galvin and Sunikka-Blank, 2013**)

Computation of monetary attributes: Use of EnerOpt

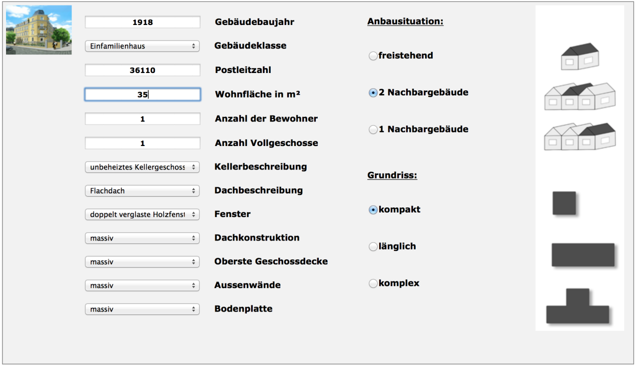
- Building matrix for the input parameters

			# people in dwelling[a]	Building size (# of dwellings)	Building size	# people in building	# of Vollgeschosse	Energieverbrauch[c]	Baujahr[b]									
									vor 1861	1861-1918	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	2002-2009
									1918	1918	1919	1949	1958	1969	1979	1984	1995	1995
Multi-family	under 40	35	1	13	455	13	5	57785										
	40-59	50	1	10	500	10	4	63500										
	60 - 79	70	2	5	350	10	3	44450										
	80 - 99	90	2	5	450	10	3	57150										
	100 - 119	110	2	2	220	4	2	27940										
	120 - 139	130	4	2	260	8	2	33020										
	140 - 159	150	5	2	300	10	2	38100										
	160 - 179	170	5	2	340	10	2	43180										
	180 - 199	190	4	2	380	8	2	48260										
	200+	210	4	2	420	8	2	53340										
Single-family	under 40	35	1	1	35	1	1	4445										
	40-59	50	1		50	1	1	6350										
	60 - 79	70	2		70	2	1	8890										
	80 - 99	90	2		90	2	1	11430										
	100 - 119	110	2		110	2	1	13970										
	120 - 139	130	4		130	4	2	16510										
	140 - 159	150	5		150	5	2	19050										
	160 - 179	170	5		170	5	2	21590										
	180 - 199	190	4		190	4	2	24130										
	200+	210	4		210	4	2	26670										

Legenda
Green: input data from respondents
Blue: assumptions made based on Destatis
Orange: assumptions made out of common sense
a=Dwelling size based on Mikrozensus categories
b=Baujahr categories based on IWU; single years based on the paper by Loga et al. (from IWU)
c= Energieverbrauch in kWh/m2 taken from Destatis (for the year 2012)

Computation of monetary attributes: Use of EnerOpt

Grunddaten des Gebäudes



Computation of monetary attributes: Use of EnerOpt

Vorhandener Wärmeerzeuger

Heizöl	**Energieträger**
Brennwertkessel	**Wärmeerzeuger**
90er Jahre	**Baujahr**

Verbrauchsdaten des Gebäudes

Bitte geben Sie die Verbrauchsdaten der letzten drei Jahre an.

2012	**Jahr**	27000	**Gesamtverbrauch in kWh**
2013	**Jahr**	27000	**Gesamtverbrauch in kWh**
2014	**Jahr**	27000	**Gesamtverbrauch in kWh**

Computation of monetary attributes: Use of EnerOpt

Auswertung

Das optimale Heizsystem für Ihr Gebäude besteht aus folgenden Wärmeerzeugern:

Optimierungswert: Primärenergiebedarf

Warmwasser: Elektrowärmepumpe Erdsonde
Raumheizung: Elektrowärmepumpe Erdsonde

Übersicht

13.061	Primärenergiebedarf in kWh pro Jahr	-56%
5.442	Endenergiebedarf in kWh pro Jahr	-80%
22.302	Investitionskosten in € *	
1.526	Laufende Kosten in € pro Jahr	-39%
3.570	CO2-Emissionen in kg pro Jahr	-50%
76	Staubemissionen in kg pro Jahr	-91%
1.137	Stickoxidemissionen in kg pro Jahr	-77%

*) Investitionskosten des (standardisierten) Gesamtsystems

- Total retrofit costs (V) as sum of costs for a new heating system (H) and for the envelope insulation (I)

Computation of monetary attributes: Use of EnerOpt

Auswertung

Vergleich unterschiedlicher Maßnahmenpakete:

Paket 1: Dämmung des Bodens

11 - 13	Endenergieeinsparung in %
1.583 - 1.909	Investitionskosten in € *

Paket 2: Dämmung des Bodens + Dämmung der Aussenwände

28 - 31	Endenergieeinsparung in %
4.428 - 5.432	Investitionskosten in € *

Paket 3: Dämmung des Bodens + Dämmung der Aussenwände + Innendämmung Dach

75 - 81	Endenergieeinsparung in %
13.970 - 16.092	Investitionskosten in € *

Paket 4: Dämmung des Bodens + Dämmung der Aussenwände + Innendämmung Dach + Erneuerung Wärmeerzeuger

95 - 96	Endenergieeinsparung in %
36.272 - 38.394	Investitionskosten in € *

*) Investitionskosten des (standardisierten) Gesamtsystems

- **For owner-occupiers**: Monthly payment computed following the KfW credit line n°151 under the assumption that the retrofit fulfils the standard set by KfW-Effizienzhaus 100
- **Tenants**:Investment costs computed using the same matrix and partially transferred to the tenants following the §559 of the Tenancy Law in the German Civil Code (BGB) ⇒ important to look at tenants' preferences for retrofitting measures

- The probability that the respondent *n* chooses alternative *i* can be written as:

$$P_{ni} = Pr(U_{ni} > U_{nj}) \forall j \neq i \quad (1)$$
$$= Pr(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj}) \forall j \neq i \quad (2)$$
$$= Pr(\varepsilon_{nj} - \varepsilon_{ni} < V_{ni} - V_{nj}) \forall j \neq i \quad (3)$$

- Different assumptions about ε_{nj} lead to different estimation models and techniques
- The likelihood function

$$L_{nit}(\beta) = \frac{exp(\beta'_n x_{nit})}{\sum_{j=1}^{J} exp(\beta'_n x_{njt})}, \tag{4}$$

- From which it derives that the mixed logit combined probability of an individual choosing alternative i across all T choice tasks following Achtnicht, 2011 can be written as:

$$P_{ni} = \int \prod_{t=1}^{T} \left(\frac{exp(\beta'_n x_{ni})}{\sum_j exp(\beta'_n x_{nj})} \right) f(\beta) d\beta, \tag{5}$$

- We later relax the assumption of normal parameters being independent from each other. Following Revelt and Train (1998), $\beta_n \sim N(b, \Omega)$, where $\Omega = LL'$, being L the lower triangular Choleski factor.

When the model with socio-demographics is estimated allowing for correlation (results not reported here)...

- **Better air quality** X **female** turns insignificant
- **Worse air quality** X **higher income** turns insignificant
- **Lower savings** X **tenancy status** turns insignificant
- **Warmer indoor temperature** X **20% savings** turns insignificant