Report

Energy Efficiency in Domestic Electrical Energy Use

An Empirical Study on Household s within Demonstration Projects of the SINFONIA Project Performed in Innsbruck/Austria 2016-2020

SINFONIA

"Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions"

CONTRACT NUMBER	**609019**	**INSTRUMENT**	**COLLABORATIVE PROJECT**
START DATE	**01-06-2014**	**DURATION**	**74 MONTHS**

Publishable executive summary

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 609019

As part of the SINFONIA project 40 Households from the demonstration projects participated in the electricity monitoring and electricity consulting in Innsbruck. Among them was a higher than average share of retired people and only few families. Within this sample the refrigeration and entertainment sectors are the dominant fields of electrical energy use. If new and highly energy efficient appliances were used throughout a considerable improvement could be expected, e.g. with modern A+++ Fridge/Freezers using only half of the observed value for the category. Entertainment equipment must, however, not be neglected. The recent development to ever larger screens and the growing diversity of decoders, set-top boxes and receivers adds to this. Particularly stand-by consumption can be large. The latter is also true for telephone/DSL routers as these are operated 24/7. These should be included in the ecodesign labelling scheme in the near future.

The results of the presented monitoring back the assumption that around 75 % of the reduction potential is due to the refrigeration and entertainment sectors. Hence deep retrofit activities like within the SINFONIA project should always include programmes to incentivise the replacement of old, inefficient household appliances. As many apartments have fitted kitchens it is a recommendation to incentivise landlords/housing companies to supply energy efficient refrigeration appliances as part of the retrofit. Their long-term perspective as owners of the building eliminates the hesitation older tenants may have towards investing in better appliances with only long-term rewards as well as the shortage in capital that prevents low-income households to invest despite the fact that the total cost of ownership would be reduced appreciably. In low-income housing such would also reduce utility bill poverty and resulting rent arrears.

For a few available items the in-situ performance of refrigeration appliances has been compared to ecodesign energy labelling figures. The results suggest that the standard energy consumption figures from energy labels can indeed be used to make a reasonable estimate of the actual in-situ performance.

An experiment on the effect of feeding back information on energy consumption was conducted in four households. After a blind reference phase for calibration feeback was given from a set date. A measurable effect was obtained in three out of four samples, while in one case the situation remained virtually unchanged. Despite the fact that the volunteering households might have been biased on some way to have a positive attitude to the experiment only in one case with observable changes a relevant reduction could be observed.

As the observed population has only been very limited no definite conclusions are possible. The available data do not, however, support the assumption of a meaningful energy savings potential from feeding back information on energy use.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

In a third experiment phase the effectiveness of shifting energy use to the daytime hours was tested by means of a special tariff with reduced energy price during high-yield hours of PV systems. Two out of three samples, however, did not support the viability of this approach, while one responded clearly. Given the very small population no authoritative conclusions are possible, however.

The results from the feedback experiment (likewise limited by a small population) support the hypothesis that electrical energy is a convenience that is used with little awareness. Its daily distribution may be a reflection of daily routines that do not seem accessible for fundamental changes in order to better match a RES availability characteristic.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

TABLE OF CONTENTS

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

TABLE OF FIGURES

SINFONIA; “Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions” has received funding from the European Union’s Seventh Programme for research, technological development and demonstration.

INTRODUCTION

The survey presented in this document was performed as part of Task 4.1 of the SINFONIA project.

In the field of in-situ measurement of the electrical energy use in households a first campaign was able to acquire data in 40 apartments over multiple weeks each. Most apartments in the studied buildings are small and many inhabited by elderly persons.

Data was acquired from late 2016 until summer 2018 for single appliances, or small groups of appliances coupled with multi-plugs as per tenant's preferences using EnOcean wireless smart plugs. These incorporate electronics to sense momentary power and integrate energy consumption and relay those values via the EnOcean wireless protocol.

As a result the first phase yielded data on individual appliances and their respective use patterns.

In a second stint the focus was shifted to the entirety of electrical energy use and a sensor was added to record the utility electricity meter reading. While smart plugs were also installed for completeness, the major concern was to learn about the user behaviour when feedback on their energy use was readily available as a web page supplied by the data acquisition unit via WiFi or energy use during daytime was incentivised.

1. AN EMPIRICAL STUDY ON HOUSEHOLDS WITHIN DEMONSTRATION PROJECTS

1.1 MATERIALS AND METHODS

The data acquisition unit was based on a small low power single board computer (Raspberry Pi) equipped with WiFi and EnOcean-gateway hardware. With a Linux operating system an instance of the [FHEM] server was run, providing a free and open source software solution.

FIGURE 1: LEFT: DATA ACQUISITION SET COMPRISING SMART PLUGS AND SINGLE BOARD COMPUTER, RIGHT: SMART PLUG IN USE

Each system was configured to listen to and log the output of a definite set of eight smart plugs respectively. These incorporate electronics to sense momentary power and integrate energy consumption and broadcast those values with the smart plug ID via the EnOcean wireless protocol.
In order to limit the measuring uncertainty of the system, a comprehensive research of various smart plug products was carried out and a type with acceptable specifications was identified (Permundo Smartplug PSC234). Among these was also the power dissipation of the smart plug itself. The specifications according to the manufacturer’s information are as follows.

Power dissipation	< 0.5 W
Real Power measurement uncertainty	5 %
Energy integration uncertainty	5 %
Minimal load	0.5 W
Energy integration resolution	0.1 Wh
Energy integration power fail safe	yes

TABLE 1: SMART PLUG CHARACTERISTIC VALUES

SINFONIA; “Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions” has received funding from the European Union’s Seventh Programme for research, technological development and demonstration.

This plug normally comprises a relay in order to be able to also switch loads via the wireless protocol for smart home applications. However, field tests revealed that inadverted switching happens and due to this fact undisturbed operation of the connected devices was not ensured. Hence, in cooperation with the manufacturer a small batch of customised plugs without a relay was procured. (Unfortunatley the production of this item was terminated in 2018, apparently due to a lack of demand for higher spec'ed (and hence more expensive) smart plugs.)

For configuration and maintenance the data acquisition unit provides its own WiFi hotspot and the most important information and system access is displayed as a html website. Full system access is also possible using secure shell (ssh). The WiFi coverage was sufficient to extend into the staircase of the respective building such that data readout and general checks of functionality were possible without physical access to the apartment.

When setting up the systems the respective households were inspected for the inventory of appliances and a selection was made of the appliances to be equipped with smart plugs. While the focus has been on refrigeration and entertainment as known heavy weights it was not always possible to follow a predetermined scheme. In some instances for example the fridge was plugged into a socket that was not accessible without removing the unit from a fitted kitchen.

Data acquisition took place for times ranging from 3 weeks to 2 months.

Data was evaluated for total energy use per apartment as well as per sector of application. Based on the annual total energy use the household was attributed a household efficiency rating according to [ISOE].

After that, where data was available, the identified main drivers in energy use were evaluated for simple efficiency improvements and virtually replaced by new, more efficient units. The household efficiency rating was reiterated based on the new figure for the potential annual energy use thus obtained, designated "optimised".

Utility meters were read when installing and removing the data acquisition equipment in order to find the relative weight of the share of energy use via the smart plugs. Moreover, utility bills were analysed for the electricity consumption in previous years.

1.2 SAMPLE OF HOUSEHOLDS

40 Households participated in the electricity monitoring and electricity consulting in SINFONIA demonstration projects in Innsbruck. Among them was a higher than average share of retired people and only few families. There was little influence on the composition of households volunteering to participate in the monitoring.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

The floor area of the apartments averages to 67 m², a typical size for apartments of the era of construction.

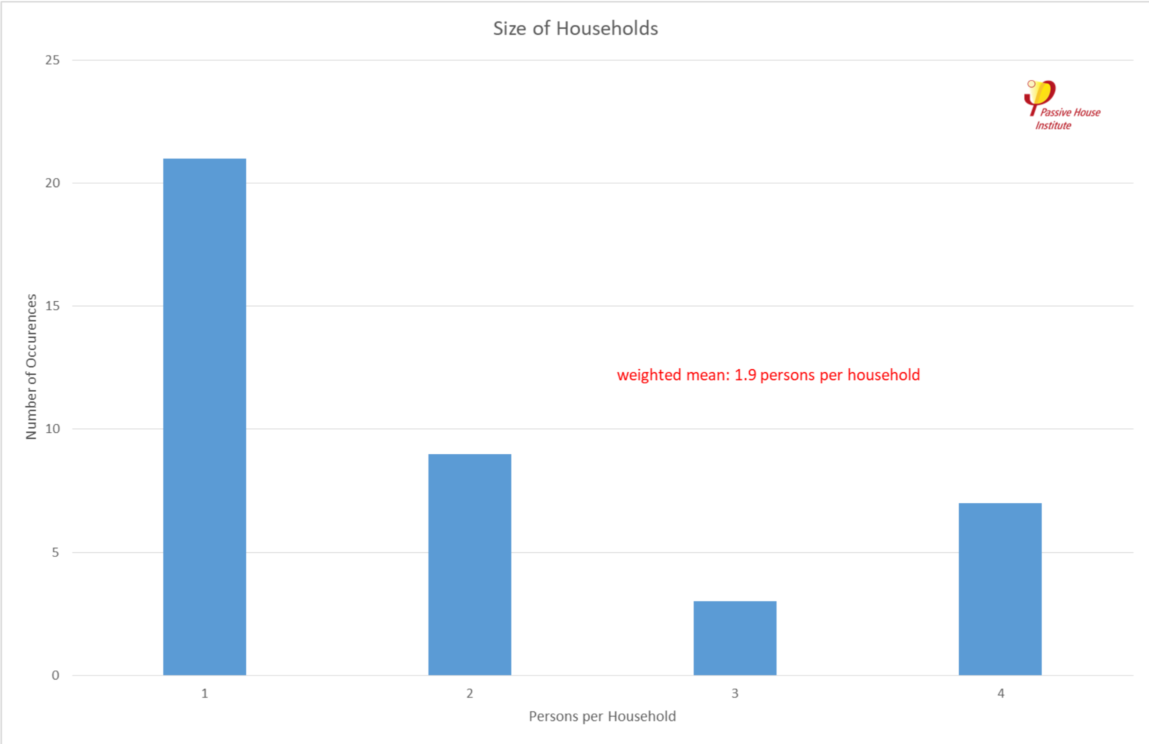


FIGURE 2: NUMBER OF HOUSEHOLDS PER NUMBER OF OCCUPANTS

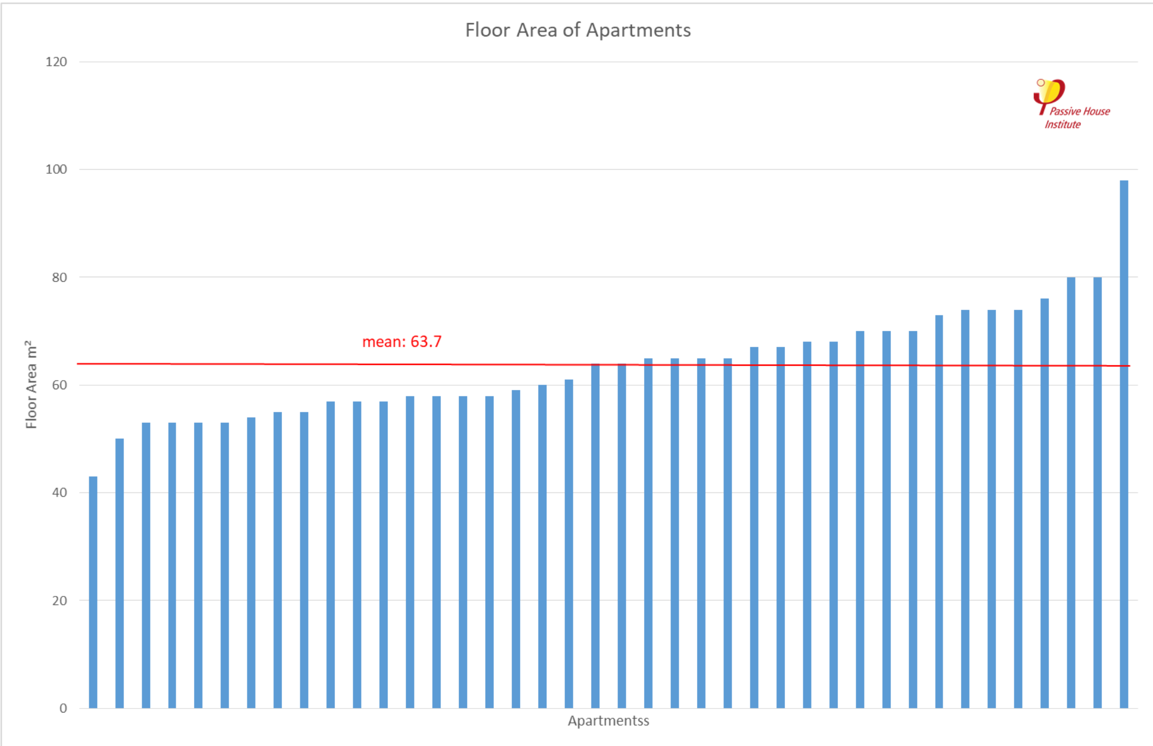


FIGURE 3: FLOOR AREA OF APARTMENTS, IN ASCENDING ORDER

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

1.3 TOTAL DOMESTIC ELECTRICAL ENERGY USE

The total annual electrical energy use was mainly derived from historical utility bills and ascertained by extrapolation from the measured data. In the following it will be assessed in a per household, per capita and per floor area perspective respectively.

1.3.1 PER HOUSEHOLD

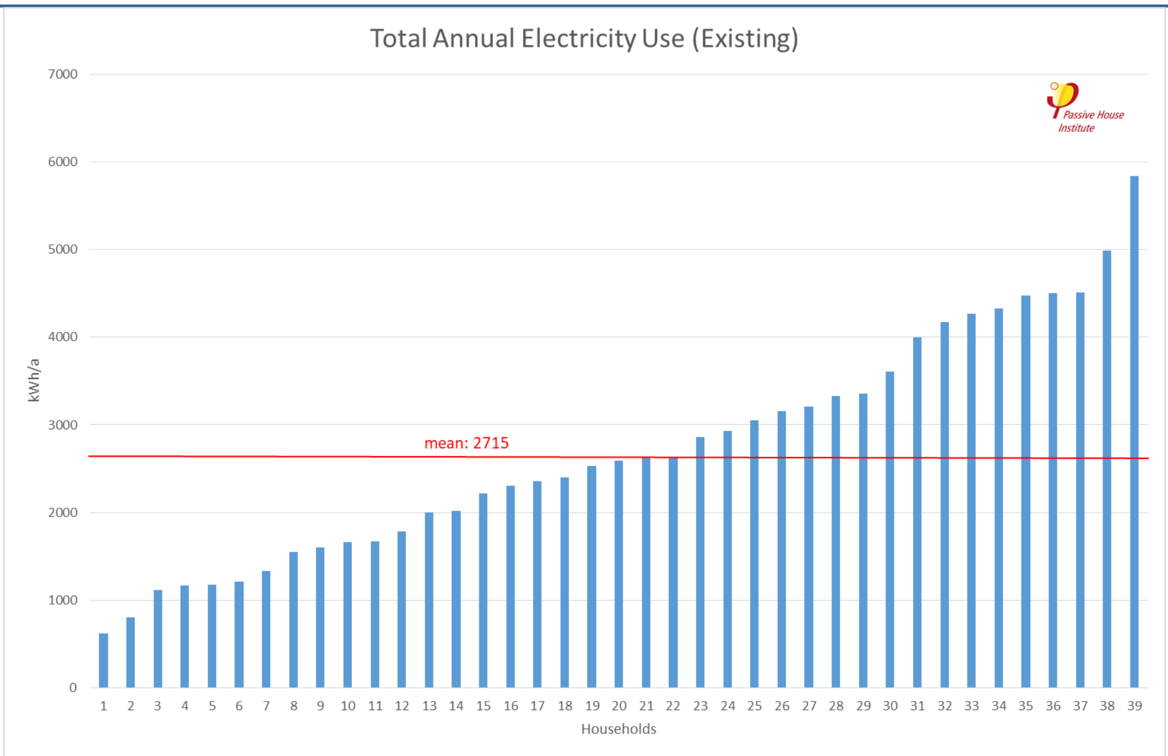


FIGURE 4: TOTAL ANNUAL ELECTRICITY USE OF HOUSEHOLDS, IN ASCENDING ORDER, AS FOUND

As can be seen in Fig. 3 the electricity usage is spread over a wide range, with a factor of about 8 between the smallest and the largest value. In this it resembles the variability of domestic hot water usage. The data were not formally probed for random distribution but do not suggest a deviation from a normal distribution either. The mean value is hence considered a useful representation of the total sample, it amounts to 2715 kWh/a per household.

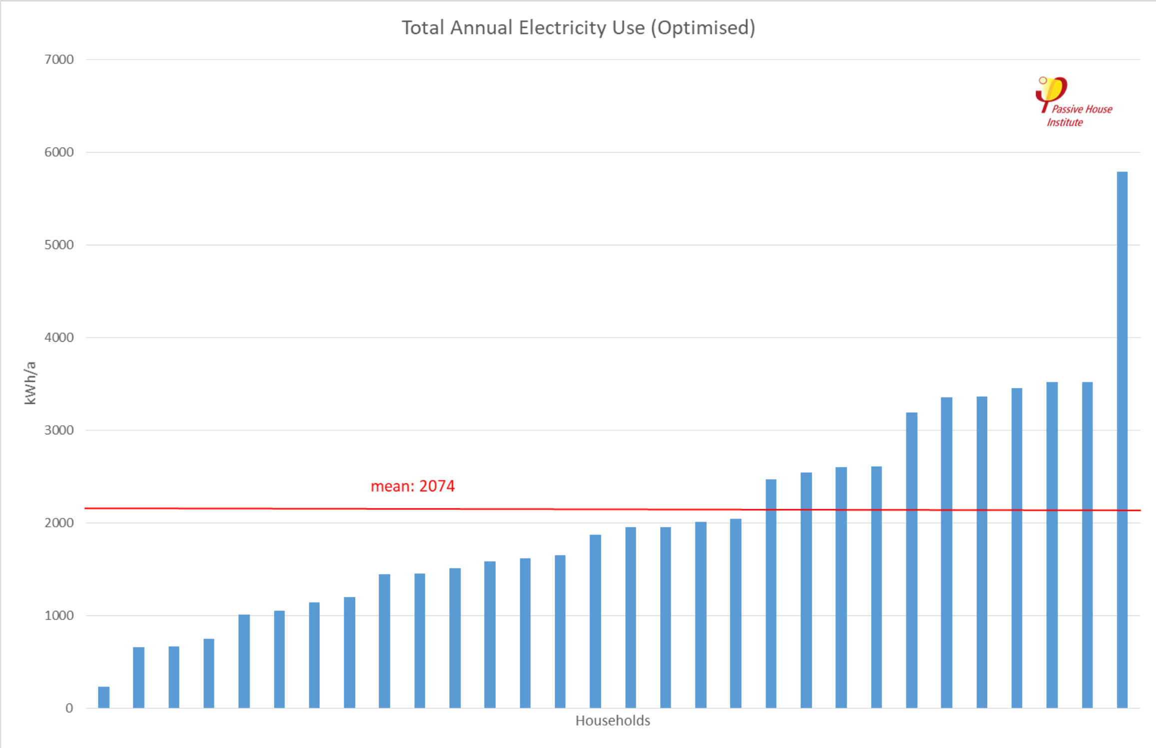


FIGURE 5: TOTAL ANNUAL ELECTRICITY USE OF HOUSEHOLDS, IN ASCENDING ORDER, OPTIMISED

A 24% reduction can be expected if a routine energy consulting encourages the replacement of old, inefficient refrigeration, entertainment and other household appliances including incandescend light bulbs that are easily detected as drivers in energy use. These represent the “low hanging fruits” and offer clear economic benefits over their lifecycles. These measures do not, however, use the comprehensive potential that were theoretically accessible for a newly equipped household.

1.3.2 ENERGY EFFICIENCY CLASSIFICATION FOR HOUSEHOLDS

A rating system developed by [ISOE] was applied to group the households into energy efficiency classes. It allows for DHW (domestic hot water)-preparation based on electricity or not as well as for the number of persons and the fact whether the unit is a flat or house.

SINFONIA; “Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions” has received funding from the European Union’s Seventh Programme for research, technological development and demonstration.

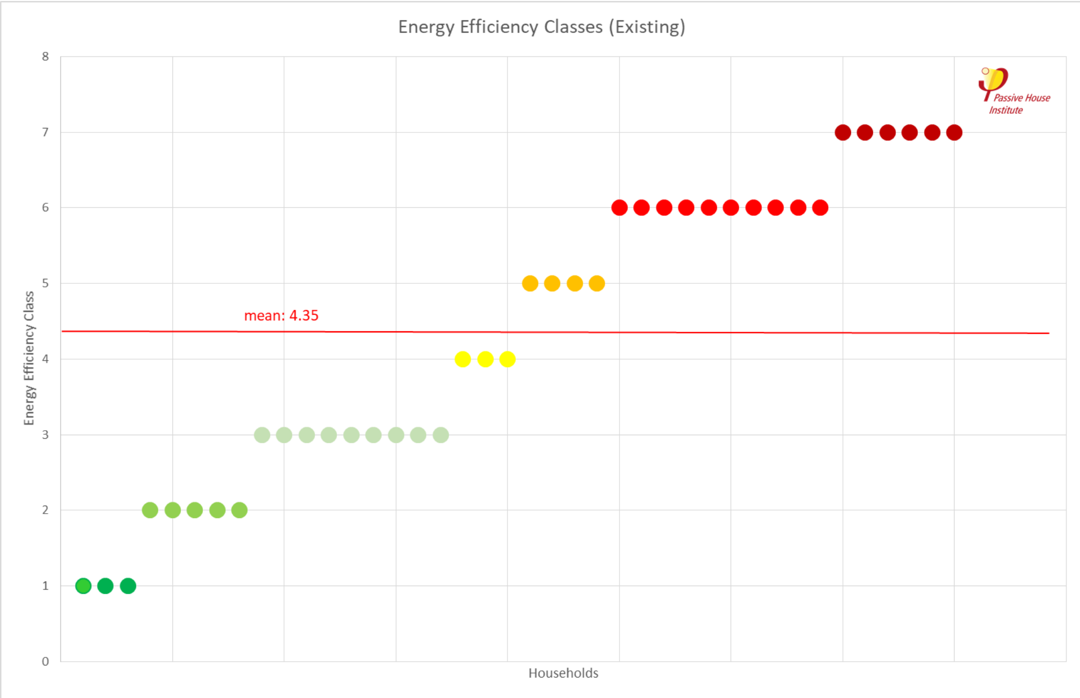


FIGURE 6: ENERGY EFFICIENCY CLASSES OF HOUSEHOLDS, AS FOUND

In the existing condition the average rating is 4.35 out of 7. The highest ratings occur for very small households with high electricity use as well as for 4-person households. Given the not representative composition of the sample of households under consideration no systematic correlations can be studied.

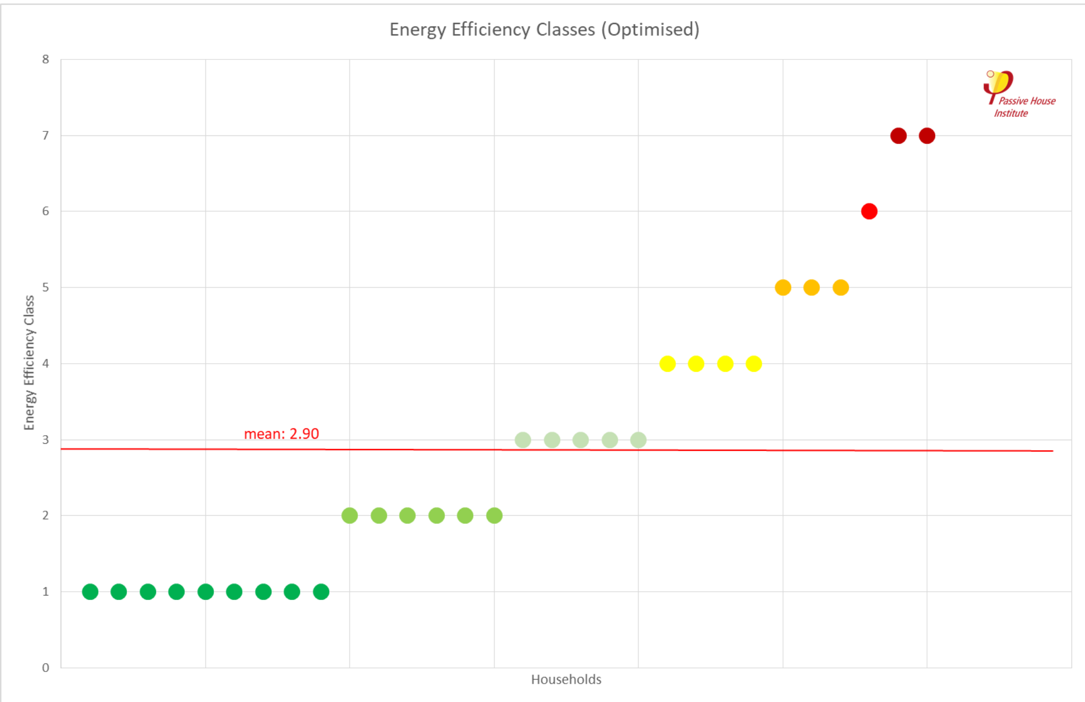


FIGURE 7: ENERGY EFFICIENCY CLASSES OF HOUSEHOLDS, OPTIMISED

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

If the improvements described above are made, the household classification averages to 2.9, a considerable improvement. However, in some households very high consumption still prevails. While the relative order of the highest-consuming households does not change in most of the cases, in one instance a drop from 6 to 3 rating can be observed, based on the replacement of a very poor deep freezer in a single person household.

1.3.3 PER CAPITA

On a per-capita basis the electricity use amounts to 1777 kWh/(p a) on average. The spread is considerable with a factor of ca. 2.5 for min and max relative to the mean.

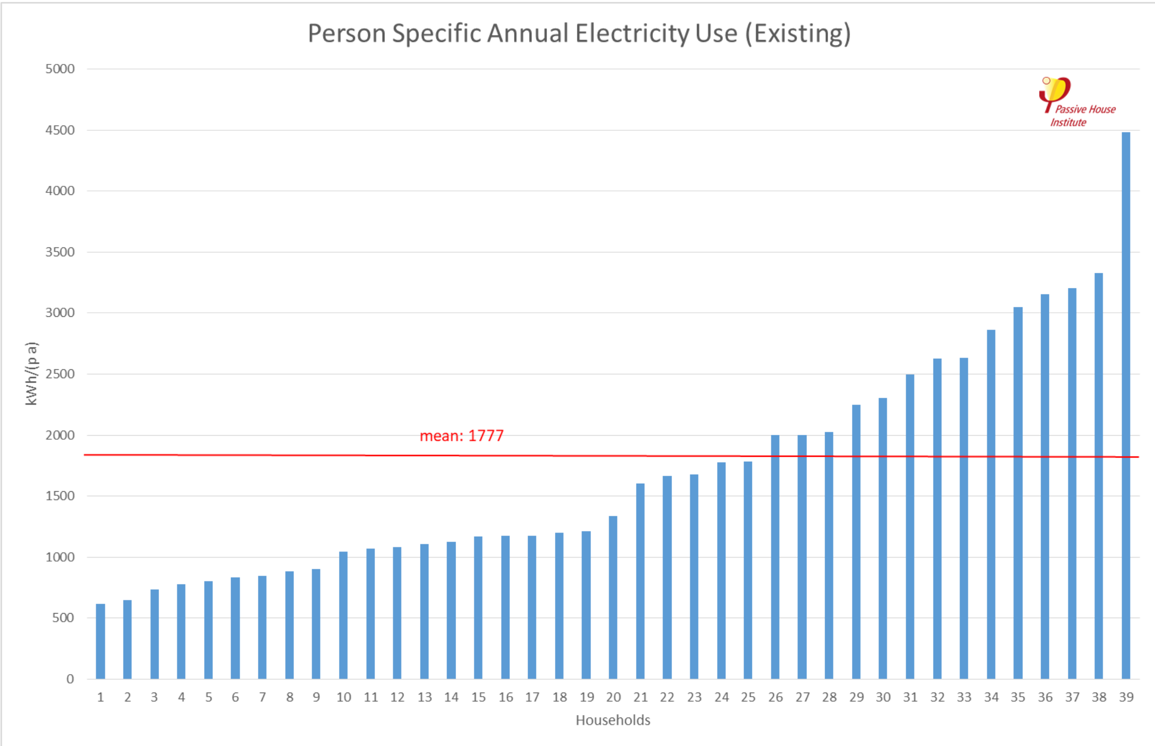


FIGURE 8: PERSON SPECIFIC ELECTRICITY USE, AS FOUND

With low hanging fruits reaped the mean is lowered to 1432 kWh/(p a) while the spread rather increases. Particularly the highest-consuming households appear to respond less to such measures.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

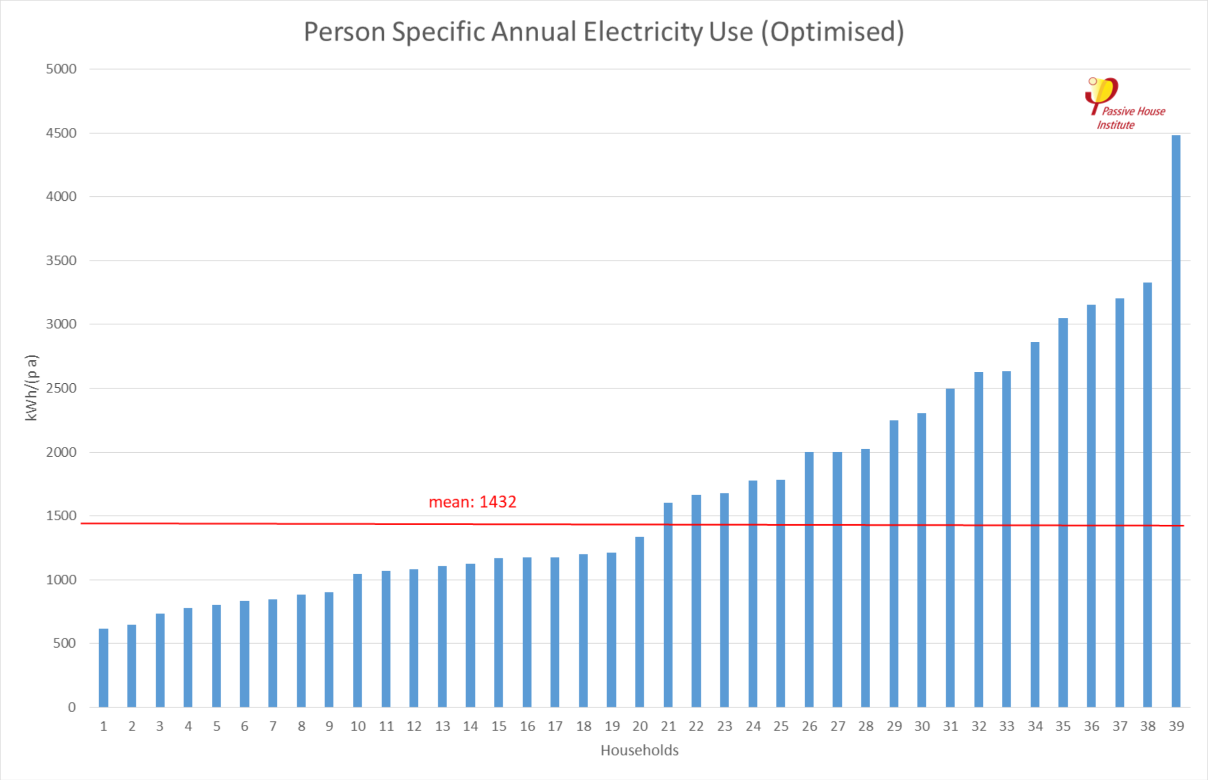


FIGURE 9: PERSON SPECIFIC ELECTRICITY USE, OPTIMISED

1.3.4 PER FLOOR AREA

Metric for area related assessment is the Treated Floor Area (TFA) as is used in energy calculation. The TFA is largely identical with the rented floor space (heated part, excluding balcony or basement storage).

The area-specific electricity use was found to average 43 kWh/(m²a), with the lowest value less than half the average and the highest more than twice this value. The area-specific value's spread is thus much narrower than the spread in absolute numbers.

For newly build Passive House buildings with all-recent appliances of reasonable energy efficiency and typically also larger TFA values of 20 kWh/(m²a) and below are typical. Accounting for the smaller size of the apartments present in this study (65 m²) but with a similar inventory of appliances values around 23 kWh/(m²a) would be expected according to [PHPP]. This in comparison to the measured mean value of 43 kWh/(m²a) suggests a considerable potential for improvements.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

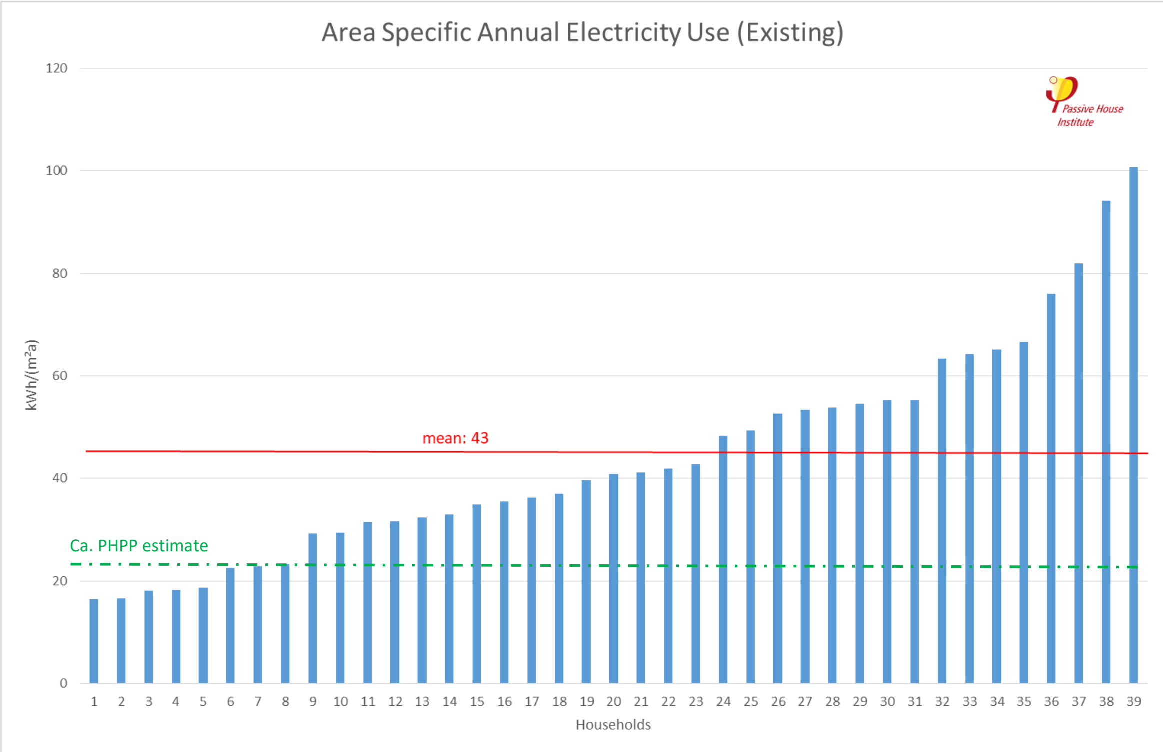


FIGURE 10: AREA SPECIFIC ELECTRICITY USE, AS FOUND

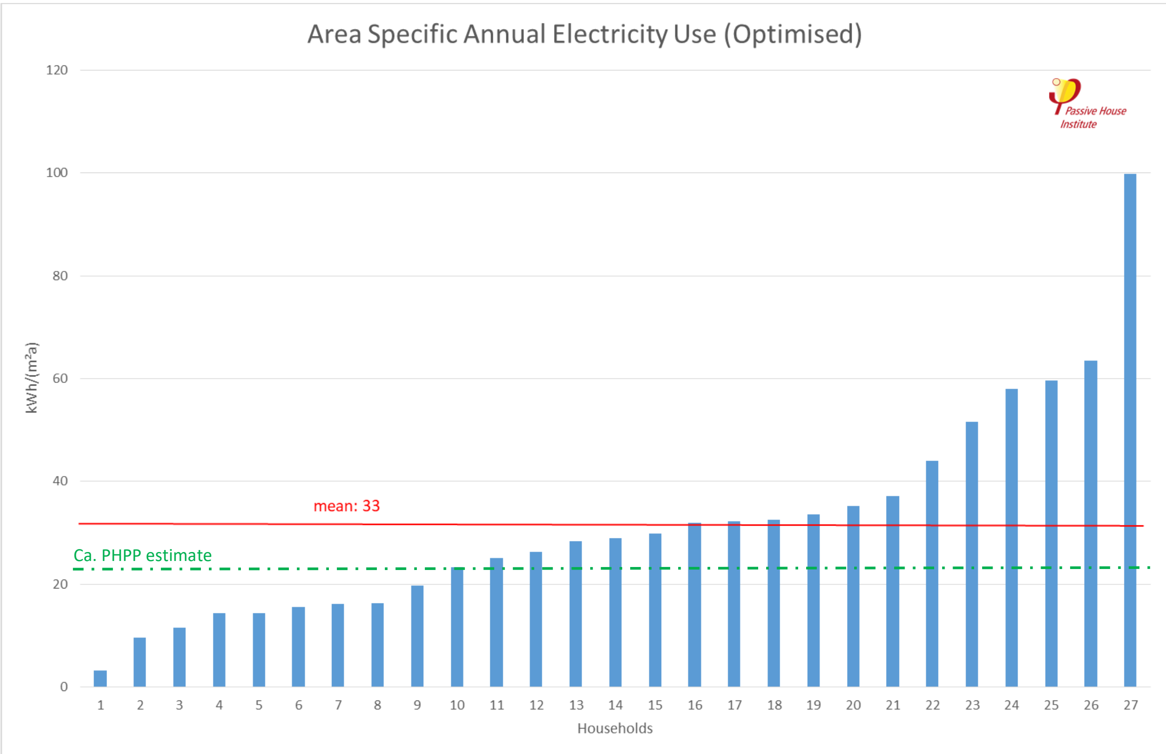


FIGURE 11: AREA SPECIFIC ELECTRICITY USE, OPTIMISED

In the scenario with low hanging fruits reaped about half of the potential estimated before is incurred. It might be even more, as the usage of some sorts of equipment, in particular the use of

TV/entertainment has shown to be much more intense than in the standard assumptions of [PHPP] as will be studied in the following chapter.

1.3.5 DISCUSSION

Independent from the choice of reference the electricity use in the studied apartments was found to be comparatively high, with a clear potential for improvement. Low hanging fruits such as new refrigeration appliances, LED light bulbs and stand-by cutting promise a considerable improvement. However, even the improved figures are still high when compared to [PHPP] estimates. Whether this can be attributed to certain applications will be the subject of the next chapter.

From the social structure of the households under consideration it is evident that a larger than representative share of elderly persons is present. It may be that this group tends to spend more time at home and run entertainment electronics longer times than the demographic mean. Moreover, the small size of these households (1-2 persons) puts them on the higher end of the energy use per person spectrum as the base load of running a fridge or cooking a meal is attributed to less persons than would be in families. Last but not least elderly persons tend to maintain their household for a long time already, with a higher than average share of old, less efficient appliances. Many are also reluctant to invest in new appliances due to the uncertain remaining lifespan and limited budget.

Finally the electricity prices in Innsbruck are comparatively low (~0.18 €/kWh), thus rewards on energy saving measures tend to be lower than in other places, e.g. Germany (~0.30 €/kWh).

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

1.3.6 DOMESTIC ELECTRICAL ENERGY USE PER SECTOR OF APPLICATION

1.3.7 SECTORS

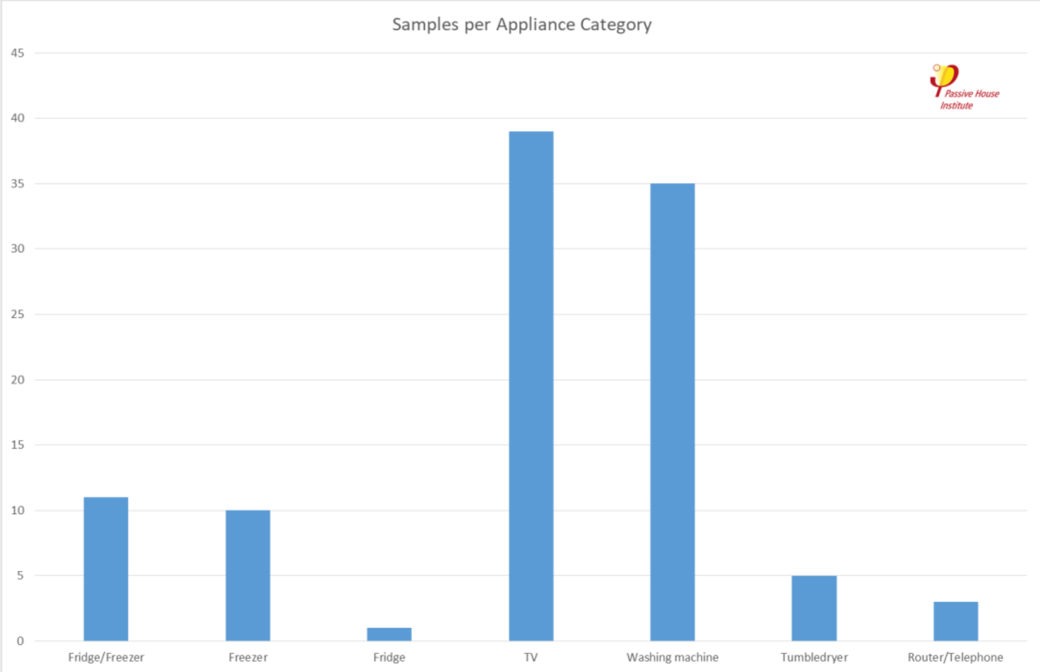


FIGURE 12: APPLIANCE CATEGORIES AND RESPECTIVE NUMBER OF SAMPLES

While many more specific items were measured, a useful evaluation can be performed on the major categories of household appliances as given in Fig. 11 above.

Regrettably it was not possible to apply a uniform configuration to all households as fitted kitchens made plugs of fridges in many instances inaccessible. Nevertheless it is informative to first have a look at the absolute annual consumption of the respective appliance category.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

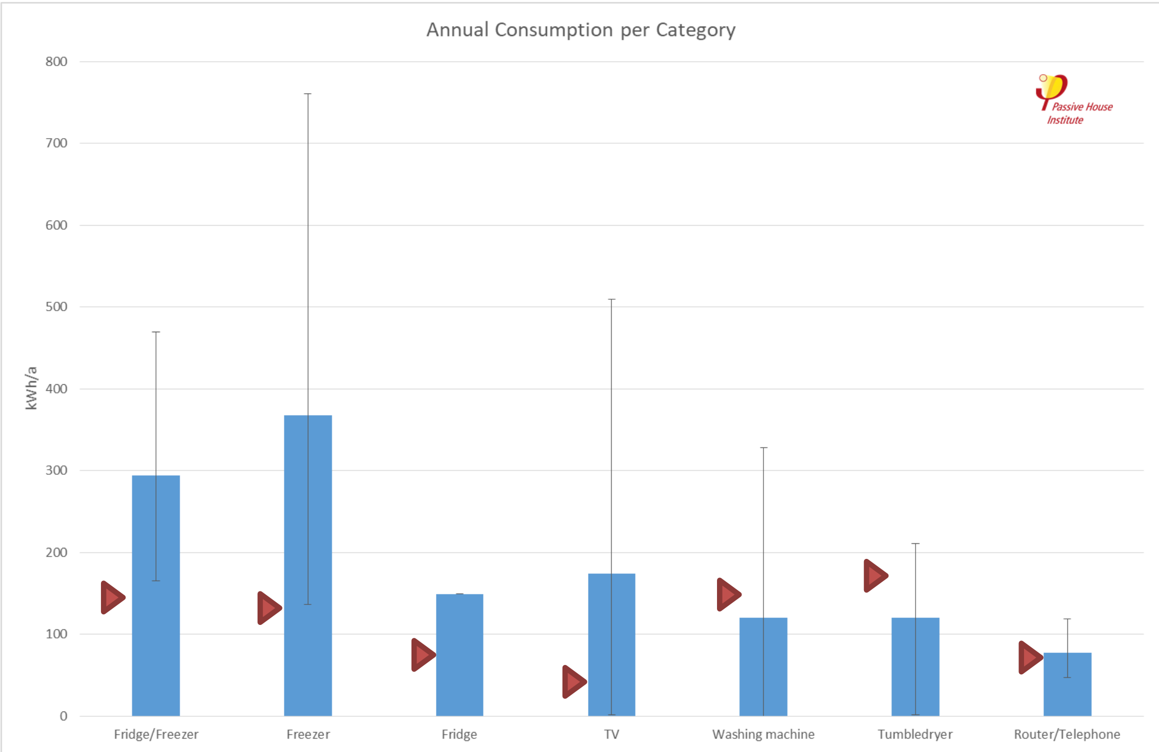


FIGURE 13: MEAN ANNUAL CONSUMPTION PER APPLIANCE CATEGORY, MIN AND MAX VALUES. WHERE AVAILABLE AN APPROXIMATE A+++ FIGURE FOR STANDARD CONSUMPTION IS SUPPLEMENTED AS A TRIANGULAR MARK [ECOTOPTEN]

The electricity consumption of refrigeration equipment is greatly variable, as can be expected for a mixture of appliances with differing energy efficiency characteristics and age. Also user preferences differ. The same holds for TV sets of different size and vastly variable daily runtime. For washing and drying the usage differs much which might explain the greater part of the variation, while different appliance characteristics also play a role. Interesting is the variation in routers combined with the absolute amount of energy consumed. The mean value is equivalent to a continual power of 8.9 W in 24/7 operation.

Meaningful efficiency improvements are thus mainly possible in the fields of refrigeration, TV/entertainment and telecommunication, where very long/continuous operation leverages even small power draw to large amounts of electrical energy.

This points to a requirement for policies that ensure that only highly energy efficient refrigeration appliances will be bought. Replacement of old units should be incentivised on condition that the old unit is safely disposed of and not used anymore.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

1.3.8 SHARE OF THE SECTORIAL ELECTRICAL ENERGY USE IN THE TOTAL

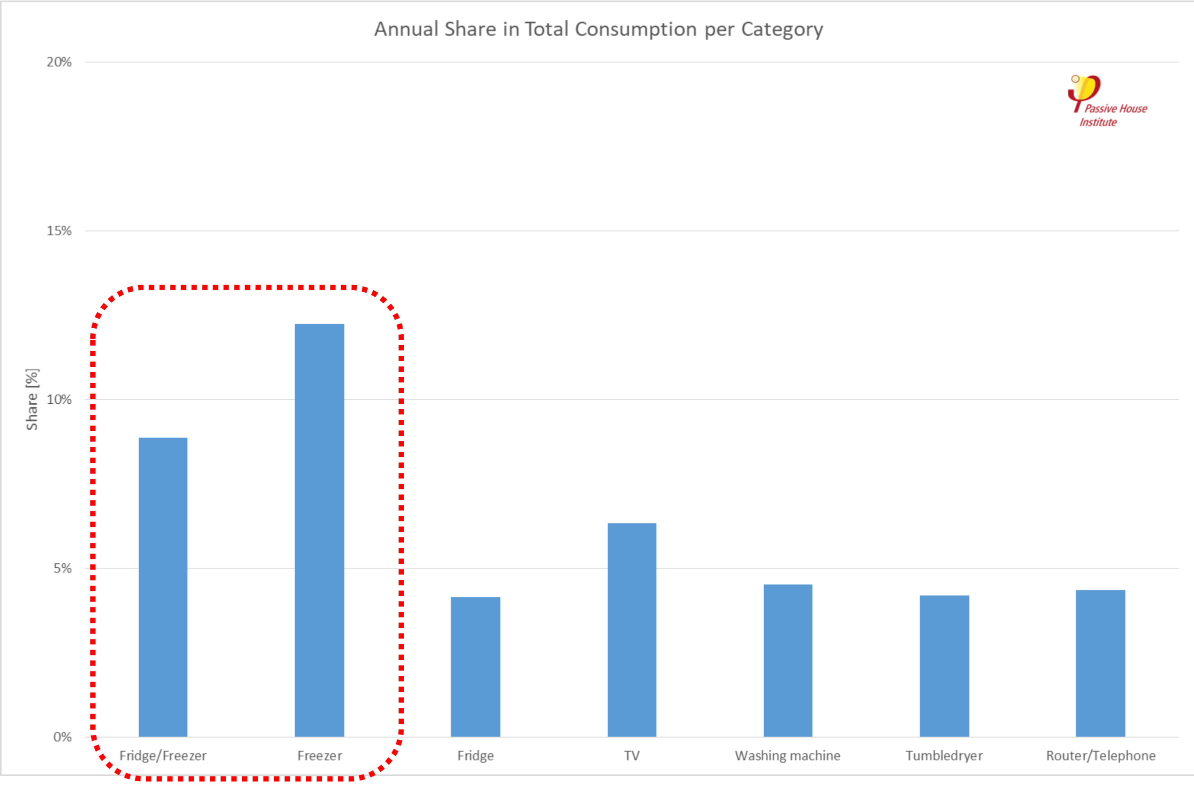


FIGURE 14: SHARE OF MEAN CONSUMPTION PER APPLIANCE CATEGORY IN TOTAL ANNUAL CONSUMPTION. HIGHLIGHTED IS THE "REFRIGERATION" GROUP OF CATEGORIES

Refrigeration appliances lead also the relative consumption, particularly as two of the listed categories are sometimes present in the same household. Reportedly many appliances were "12-15 years old" and no energy label was available for any of them. Interestingly entertainment/TV comes in second overall, while in some specific households it is even the dominant consumption category. Washing/Drying/Telecommunication each contribute in the range of 5 %.

As a conclusion it can be noted that also in this limited sample the refrigeration sector is dominant. If new and highly energy efficient appliances were used throughout a considerable improvement could be expected, e.g. with modern A+++ Fridge/Freezers using much less than 150 kWh annually [ecotopten], half of the observed value for the category.

Entertainment equipment must, however, not be neglected. The recent development to ever larger screens and the growing diversity of decoders, set-top boxes and receivers adds to this. Particularly stand-by consumption can be large (5 W observed in one instance).

The latter is also true for telephone/DSL routers as these are operated 24/7. These should be included in the eco-design labelling scheme in the near future. However, some improvement might

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

already happen as the power supplies are part of the scheme already and the lifetime of such equipment is usually less than 10 years.

1.4 COMPARISON OF MONITORING RESULTS TO NATIONAL AND EUROPEAN AVERAGES

This comparison is mainly an excerpt from a Bachelor thesis by T. Molitor, UIBK, which was compiled along the work on the SINFONIA project. It is enlightening to put the results from the monitoring campaign in Innsbruck into a larger perspective and compare them to national averages from Austria and other European countries.

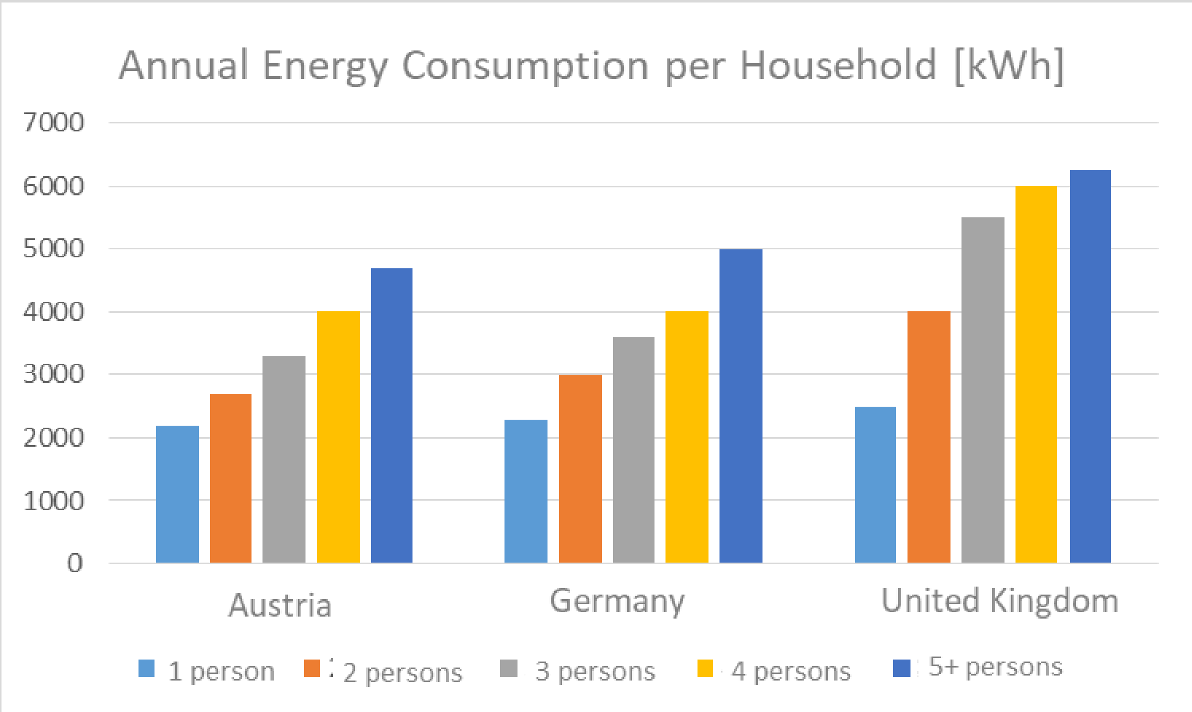


FIGURE 15: ANNUAL TOTAL ELECTRICITY CONSUMPTION IN AUSTRIA COMPARED TO GERMANY AND UK

The monitoring yielded an average annual electricity consumption of 2715 kWh, the majority of samples being taken from one and two person households (cf. Fig. 1). This is a little higher than the national figures in Fig. 14 would suggest. One reason might be the higher than average age of the tenants in the sample with their older than average stock of appliances (Fig. 12).

Statistical surveys available for various countries and the EU average are hampered by the fact that Austria applies a different set of categories to group the shares. Given the very similar total amounts for Austria and Germany in Fig. 14 and generally similar preferences it may not miss the reality much if the German shares are compared instead.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

FIGURE 16: ANNUAL SHARE PER CATEGORY IN DIFFERENT COUNTRIES

It strikes that in the German case the lighting sector is much smaller than in other countries and the EU average. This might be attributed to a larger proportion of CFL and LED lamps used. Generally speaking, however, the refrigeration and entertainment categories make up for almost half the energy consumption in Germany as well as the EU average.

According to the Report for the UK situation [Zimmermann 2012] the greatest potential for reductions is in the refrigeration category amounting to 310 kWh/a, followed by the laundry, drying, dishwashing category at 288 kWh/a and the TV, entertainment, office sector at 217 kWh/a.

The study by the Swedish Energy Agency [Zimmermann 2009] even projects a potential of 390 kWh/a per household if only top of the line efficient refrigeration appliances were used (date of the study 2009). For the TV, entertainment, office sector another ca. 200kWh/a potential was found. In contrast the reduction potential in the laundry, drying, dishwashing category is much lower, at 66 kWh/a. As a reason for this it is given that the measured consumption in this field has often already been lower than the nominal consumption of the best available appliances.

From a physics perspective all applications that involve heating water like laundry and dishwashing can be improved mainly by using less water while the heat capacity of the water is a given and heat recovery options are very limited. One notable exception is the heat pump dryer that reuses the condensation heat of the extracted water to heat up the air.

The overall reduction potential found by the various studies depends much on the size and type the household. It spans from 500 kWh/a for a single retired person in the UK up to 1800 kWh/a for a family in a single family home in SE. An average reduction by 17 % is the reported relative potential in [Zimmermann 2012].

It is highlighted that 75 % of the reduction potential is due to the refrigeration and entertainment sectors. This finding is further backed by the results of the SINFONIA monitoring in Innsbruck.

Hence deep retrofit activities like those performed in Innsbruck and Bolzano within the SINFONIA project should always include programmes to incentivise the replacement of old, inefficient household appliances. This holds particularly for the refrigeration and entertainment categories. As many apartments have fitted kitchens it is a recommendation to incentivise landlords/housing companies to supply energy efficient refrigeration appliances as part of the retrofit. Their long-term perspective as owners of the building eliminates the hesitation older tenants may have towards investing in better appliances with only long-term rewards as well as the shortage in capital that prevents low-income households to invest despite the fact that the total cost of ownership would be reduced appreciably. In low-income housing such would also reduce utility bill poverty and resulting rent arrears.

2. STUDY: COMPARISON OF MEASURED CONSUMPTION OF REFRIGERATION APPLIANCES AND DATA FROM ENERGY LABELLING

To further assess the electricity use reduction potential in households it is reasonable to probe the standardised demand figures as available from the eco-design energy labelling scheme and compare them to the measured in-situ performance.

As no energy labels were available for any of the old devices found in the sample of households in Innsbruck, data from test runs in various households in Darmstadt/Germany were used in order to shed some light on the in-situ performance of energy labelled appliances.

Three examples were assessed, with one sample each for the A+, A++ and A+++ rating respectively. The A+++ rated fridge/freezer was further studied with various temperature settings for fridge and freezer. All appliances were in regular use in households at the time of measurement.

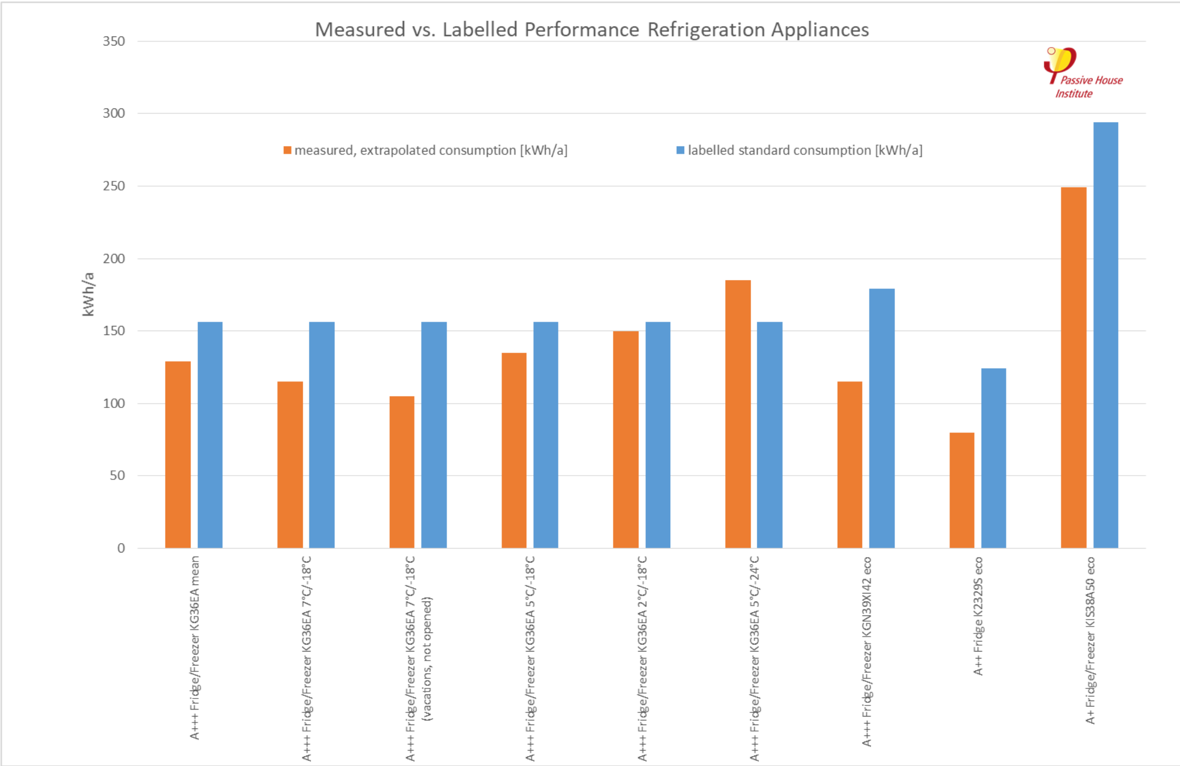


FIGURE 17: COMPARISON OF MEASURED ANNUAL ENERGY CONSUMPTION AND ENERGY LABEL STANDARD DEMAND FIGURES FOR THREE APPLIANCES AND NUMEROUS TEMPERATURE SETTINGS IN ONE INSTANCE.

This limited sample of appliances is, of course, not statistically significant. The results suggest, however, that the standard energy consumption figures from energy labels can indeed be used to make a reasonable estimate of the actual in-situ performance. It appears that the figures are even on the conservative side for all but the most extreme temperature settings. With extreme temperature settings the actual consumption rose by 20 % above the standard consumption as labelled. With

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

economic temperature settings the studied unit outperformed the labelled standard consumption by a good 25 %. During vacations, when the door remains shut, the consumption decreases further. This effect contributes to the conservative estimate as such periods happen in most households.

Further research should be carried out in order to improve the population of available samples.

2.1 ENERGY CONSULTING BASED ON MEASURED RESULTS

The implementation of the Passive House Standard and NZEB in new construction as well as deep retrofit to NZEB levels results in a drastic reduction of the heating energy demand. As a result the remaining energy consumption, of which the household electricity is a considerable part, becomes a focus of attention. Looking at the primary energy in many cases the electrical energy consumption represents the largest share on a household level. The issue of electrical efficiency is generally hardly ever being discussed during the design process of new construction or redevelopment projects despite the fact that low energy consumption is also to be aimed at for comfort reasons, e. g. to avoid overheating in the summer.

2.2 TOOL FOR THE ELECTRIC ENERGY EFFICIENCY CONSULTATION

In order to do a target-oriented consultation to reduce the energy consumption of households, a tool was developed that allows the listing of all household appliances individually with their power and energy consumptions per usage. Besides the energy-related parameters, the recording of frequency and duration of usage is equally important, as only with the knowledge of power input AND usage the consumption per year can be estimated.

1.) White Ware				Existing Appliance		Alternative Appliance		Comparison
	Estimated consumption [kWh/a] or [kWh/use]	# uses	per	Standard consumpt. per use	(Energy-) consumpt. Per year	Standard consumpt. per use	(Energy-) consumpt. per year	Savings per year
Fridge	70-450 kWh/a		unit					
Freezer	100-1000 kWh/a	1.0	unit	500 kWh	500 kWh	120 kWh	120 kWh	47 €
Fridge-freezer	150-1000 kWh/a	1.0	unit	250 kWh	250 kWh	150 kWh	150 kWh	9 €
Dishwasher	0,8-2,2	3.5	week	0.9 kWh	164 kWh	0.7 kWh	127 kWh	4 €
Washing machine	0,5-1,1	2.0	week	0.8 kWh	83 kWh	0.7 kWh	73 kWh	2 €
Tumble dryer	1,8-4,4							
Cooking simple	0,5..1 / meal	1.7	day	0.7 kWh	434 kWh			

FIGURE 18: SECTION FROM THE ENERGY EFFICIENCY TOOL TO LIST ALL ENERGY CONSUMER INDIVIDUALLY. HERE YOU CAN SEE THE INPUT AREA FOR WHITE WARE INCLUDING FREQUENCY OF USAGE, RECOMMENDED ALTERNATIVES AND SAVINGS PER YEAR.

A general assumption for the usage could lead to strayed optimisations in many cases. This applies especially for white ware such as refrigeration appliances, dish washers, washing machines and tumble driers. Depending on the frequency of usage, which e. g. for the tumble dryer can vary between a few times per month to up to several times per day, investing in a new appliance can be absolutely not recommendable or highly profitable. Furthermore the usage and standby periods are recorded and the energy consumption for lighting can be taken into consideration.

The total energy consumption per year has turned out to be an important benchmark for making sure all relevant appliances have been listed. Previous experience has shown good correlation of the overall consumption and the calculated prognosis with a typical deviation of less than 15 %. In addition to the presently used appliances alternatives can be entered and savings can be calculated accordingly.

2.3 MONITORING OF THE ELECTRIC ENERGY CONSUMPTION

In addition to the energy consumption the user profiles can be determined from the monitoring results. The following figure shows the measured energy consumption of individual appliances in one exemplary household. In combination with the information from the consultation tool this results in a potential overall reduction of 30 %.

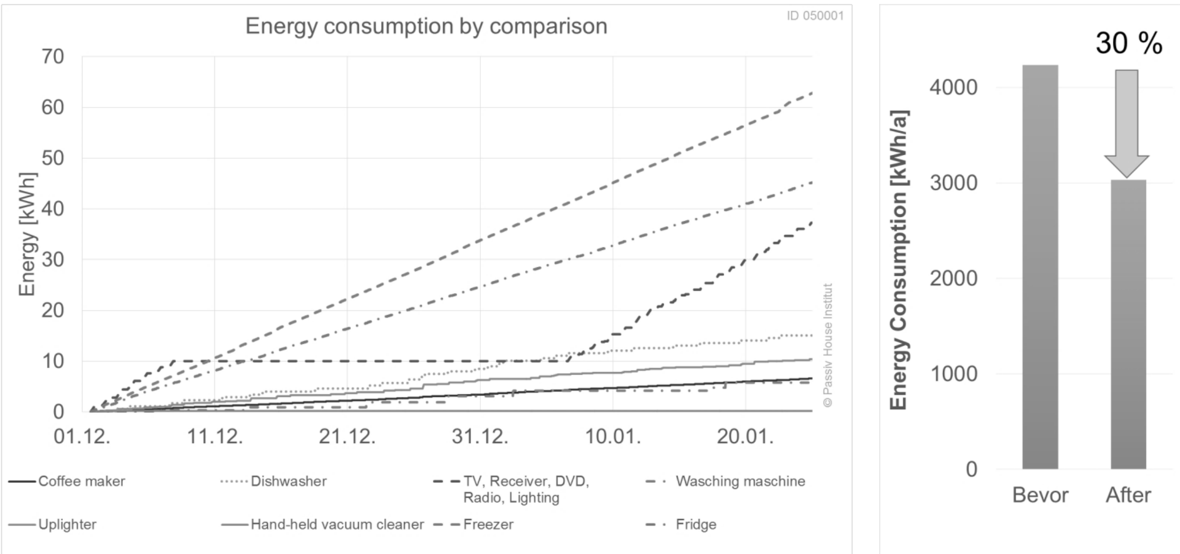
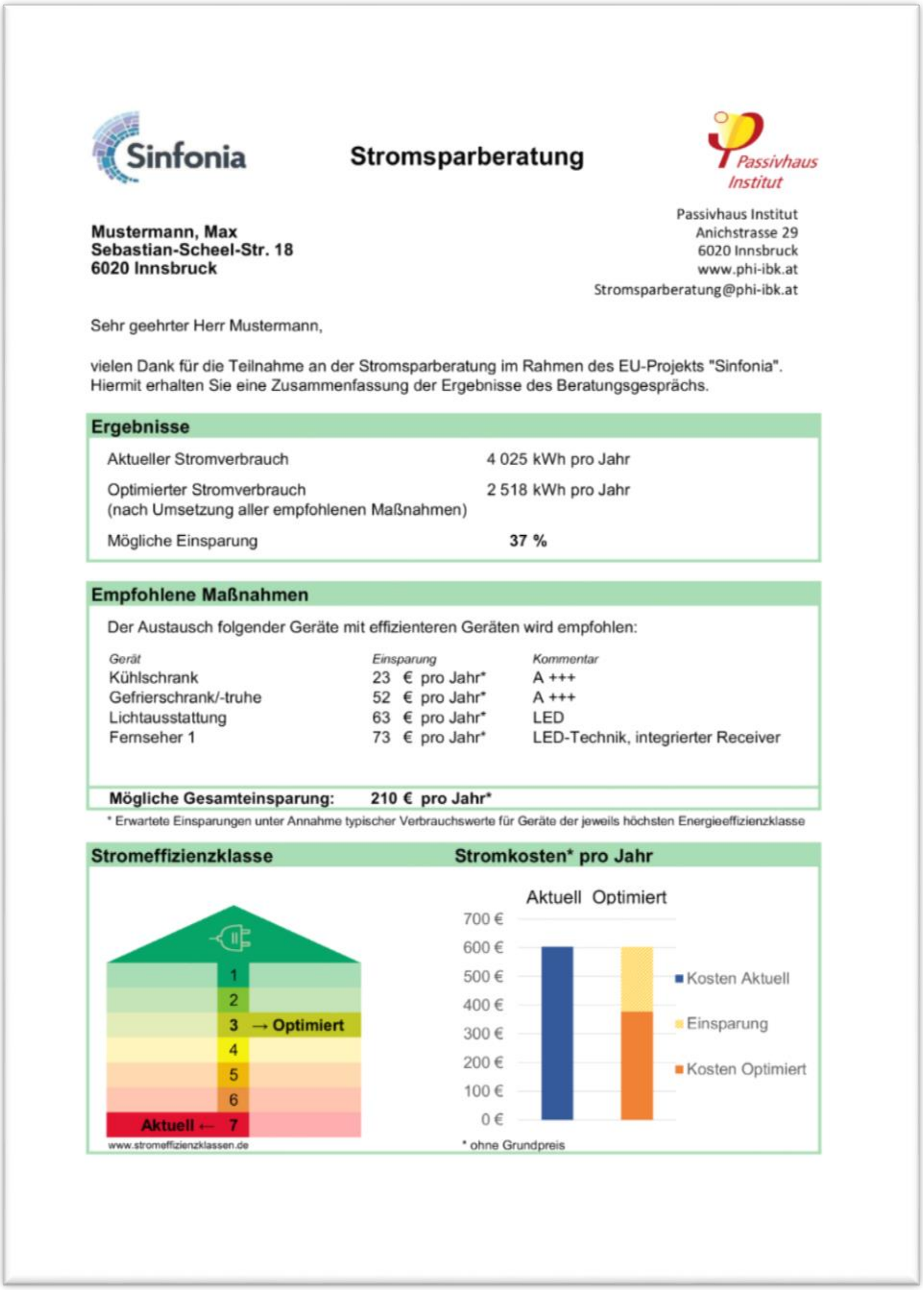


FIGURE 19.: OVERVIEW OVER MEASURED CONSUMPTION CURVES OF VARIOUS CONSUMERS IN A HOUSEHOLD (LEFT). NEXT TO IT THE CURRENT ENERGY CONSUMPTION AND THE EXPECTED CONSUMPTION AFTER ALL RECOMMENDED MEASURES FORM THE CONSULTATION PUT INTO ACTION WITH AN OVERALL REDUCTION OF 30 % (RIGHT).

Based on the available data an economic evaluation of the viability of optimisations was performed. The assessment was based on a life cycle cost approach. Finally the household electrical energy efficiency class rating for actual and optimised configuration are also shown.

All results and recommendations thus obtained are wrapped up on a results sheet and explained to the participants comprehensively and in person. This is considered a very important factor for the success of the approach as it builds confidence as well as understanding.



Sinfonia

Stromsparberatung

Passivhaus Institut

Mustermann, Max
Sebastian-Scheel-Str. 18
6020 Innsbruck

Passivhaus Institut
Anichstrasse 29
6020 Innsbruck
www.phi-ibk.at
Stromsparberatung@phi-ibk.at

Sehr geehrter Herr Mustermann,

vielen Dank für die Teilnahme an der Stromsparberatung im Rahmen des EU-Projekts "Sinfonia". Hiermit erhalten Sie eine Zusammenfassung der Ergebnisse des Beratungsgesprächs.

Ergebnisse

Aktueller Stromverbrauch	4 025 kWh pro Jahr
Optimierter Stromverbrauch (nach Umsetzung aller empfohlenen Maßnahmen)	2 518 kWh pro Jahr
Mögliche Einsparung	**37 %**

Empfohlene Maßnahmen

Der Austausch folgender Geräte mit effizienteren Geräten wird empfohlen:

Gerät	*Einsparung*	*Kommentar*
Kühlschrank	23 € pro Jahr*	A +++
Gefrierschrank/-truhe	52 € pro Jahr*	A +++
Lichtausstattung	63 € pro Jahr*	LED
Fernseher 1	73 € pro Jahr*	LED-Technik, integrierter Receiver

Mögliche Gesamteinsparung: 210 € pro Jahr*

* Erwartete Einsparungen unter Annahme typischer Verbrauchswerte für Geräte der jeweils höchsten Energieeffizienzklasse

Stromeffizienzklasse

Stromkosten* pro Jahr

FIGURE 20: ENERGY CONSULTING RESULTS SHEET COMPARING ACTUAL AND OPTIMISED ELECTRICITY USE, THE SAVING POTENTIAL, POINTING OUT RECOMMENDED IMPROVEMENTS AND THEIR ECONOMIC BENEFIT.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

3. EXPERIMENTS WITH REAL-TIME FEEDBACK ON ENERGY USE TO THE TENANTS

3.1 OBJECTIVES

To evaluate with reference to a blinded first phase of the experiment whether visual feedback on the household's total electricity use will lead to significant changes in behaviour, presumably a decreased energy use due to raised awareness.

To evaluate the effectiveness of reduced electricity tariffs during the daytime yield from PV arrays on the user behaviour, primarily the potential to incentivise a temporal shift of energy consumption.

3.2 MATERIALS AND METHODS

Equipment from earlier electricity monitoring was complemented with a pulse counter and an optical sensor head on the LED output of newly fitted smart meters as truly "smart" meter data was not available.

The extended experiments were conducted in late 2019/early 2020 in five apartments.

In a first stage reference data was recorded in blinded mode after which the tenants were given access to the graphed data using any WiFi capable device. The measurement results indicate whether measurable changes in energy use can be achieved by feeding back visualisations of the user behaviour.

As a third part of the experiments the tenants were offered electricity at half the usual rate during the time corresponding to meaningful PV yields, from 10:00h to 16:00h. This could result in some motivation to shift energy use in parts to the low price period. The data will be helpful to estimate the potential of unburdening the power grid from domestic peak demands in the morning and evening respectively. It will also be very important background for the housing companies to consider the viability / business case of selling PV electricity from the roof of a building to tenants at a lower than market rate.

3.3 RESULTS - FEEDBACK PHASE

3.3.1 SAMPLE 01

Data sample 01 was acquired in a three-person household within a multifamily building, domestic hot water was prepared with an electric resistance heater. Coincidentally, data acquisition ended on the date when the CoVID19-related lockdown commenced.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

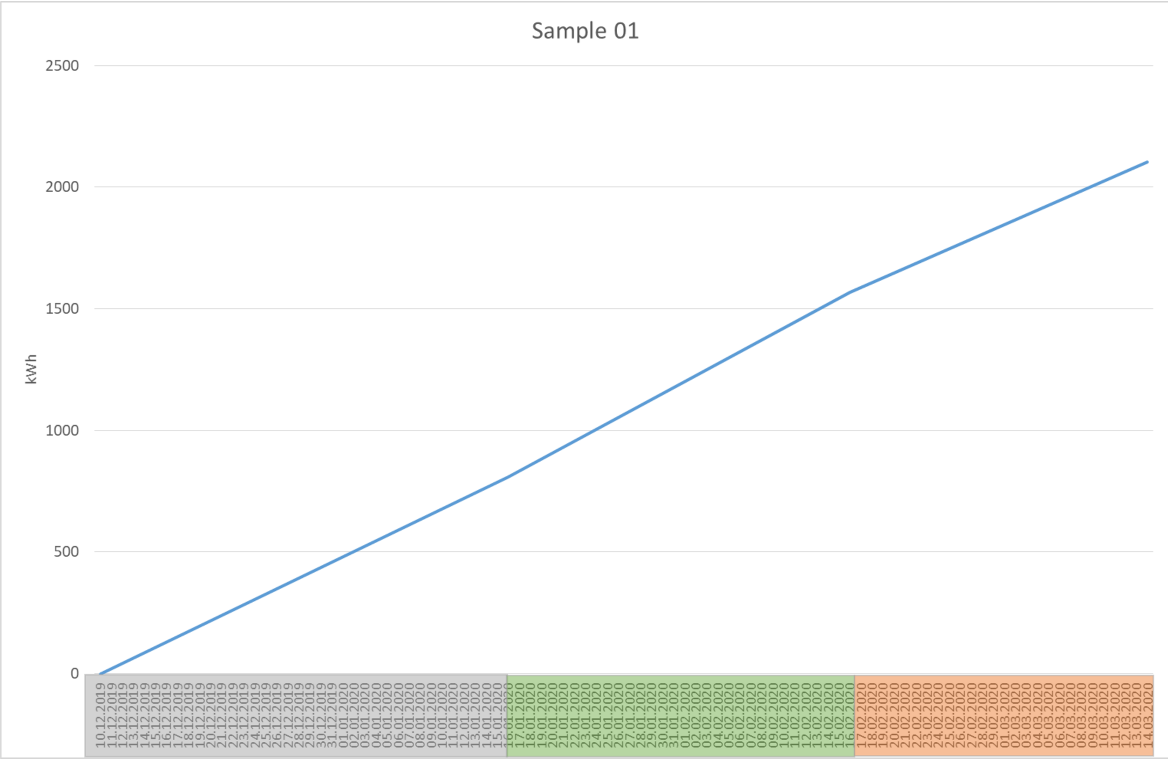


FIGURE 21: SAMPLE 01, OVERVIEW OF METERED CONSUMPTION, LINEARISED FOR THE EXPERIMENT PHASES

The total consumption in the time period of the experiment amounted to a good 2000 kWh in sample 01, which extrapolates to around 8000 kWh per annum. This is certainly a household with very high energy consumption, which is only in part explained by the electrical DHW preparation.

-Sample 01-	Reference	Feedback	Special tariff	Total
Gradient [kWh/d]	21.89	24.43	19.84	22.14

TABLE 2: GRADIENTS FOR ALL EXPERIMENT PHASES, AVERAGE KWH PER DAY

It is obvious from the gradients given in table 2 that feeding back information on the energy consumption had no considerable effect in the case of sample 01. Rather the consumption has slightly increased within the feedback phase. However, since it decreased again in phase 3 and since the variation is only small it is assumed that random effects and the advent of spring are the most probable explanation for the observation. There is no obvious explanation for the clear reduction in Phase 3.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

3.3.2 SAMPLE 02

Data sample 02 was acquired in a three-person household within a multifamily building, domestic hot water is prepared with a gas boiler. Coincidentally, data acquisition ended on the date when the CoVID19-related lockdown commenced.

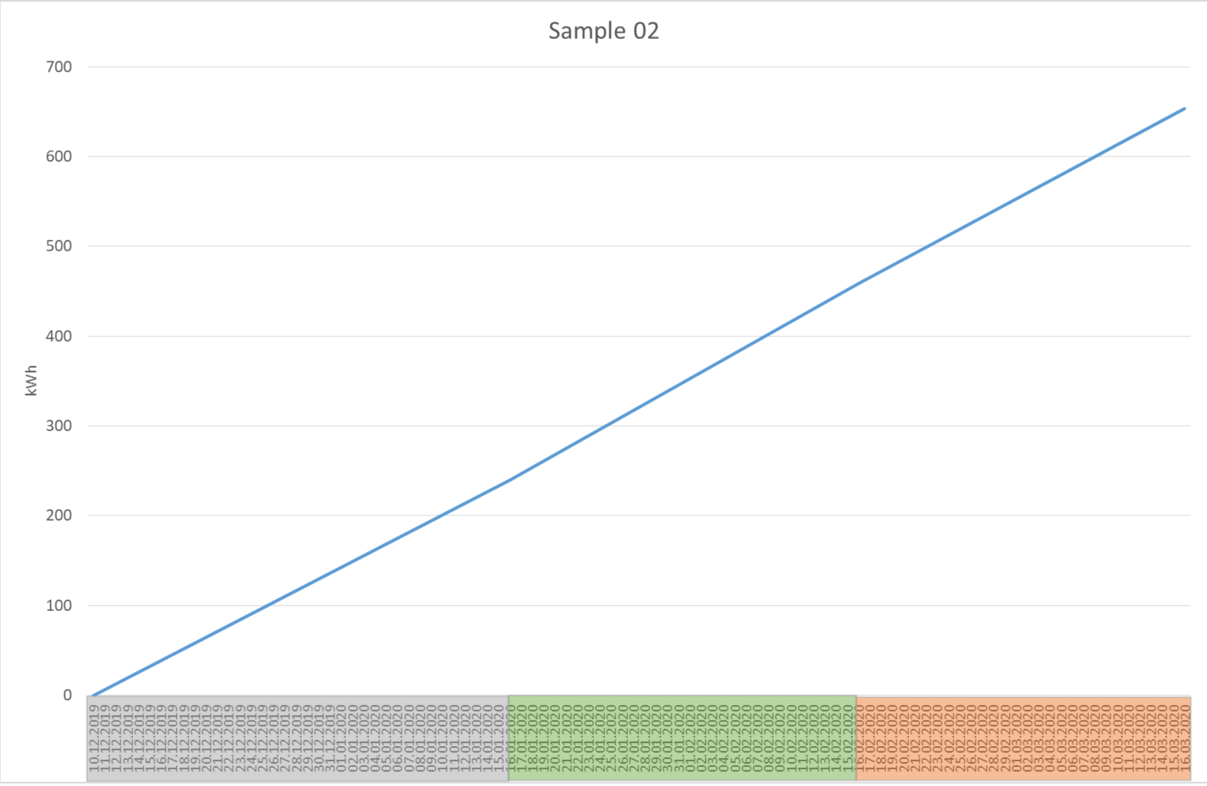


FIGURE 22: SAMPLE 02, OVERVIEW OF METERED CONSUMPTION, LINEARISED FOR THE EXPERIMENT PHASES

The total consumption in the time of the experiment amounted to a good 600 kWh in sample 02, which extrapolates to around 2400 kWh per annum. This is a household with very low energy consumption, without electrical DHW preparation.

-Sample 02-	Reference	Feedback	Special tariff	Total
Gradient [kWh/d]	6.48	7.06	6.72	6.74

TABLE 3: GRADIENTS FOR ALL EXPERIMENT PHASES, AVERAGE KWH PER DAY

It is obvious from the gradients given in table 3 that feeding back information on the energy consumption had no reduction effect in the case of sample 02. On the contrary, the average daily consumption has slightly increased within the feedback phase. However it decreased again in phase 3 and the variation was minimal. Essentially the energy use has been unaffected by the changing boundary conditions of the different experimental phases, despite the advent of spring.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

3.3.3 SAMPLE 03

Data sample 03 was acquired in a three-person household within a multifamily building, domestic hot water is prepared with a gas boiler. Data acquisition continued for about 10 days onto the period of the CoVID19-related lockdown.

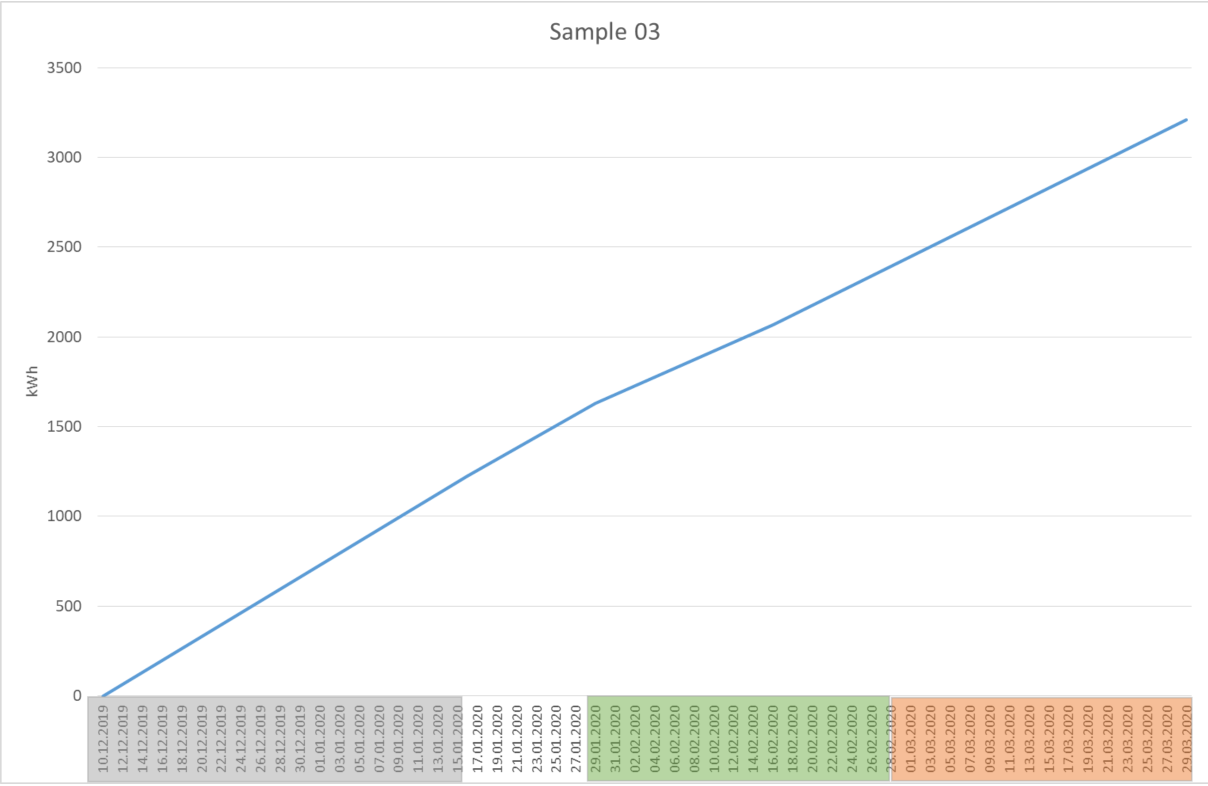


FIGURE 23: SAMPLE 03, OVERVIEW OF METERED CONSUMPTION, LINEARISED FOR THE EXPERIMENT PHASES

The total consumption in the time of the experiment amounted to a good 3000 kWh in sample 03, which extrapolates to around 10000 kWh per annum. This is a household with extremely high energy consumption, without electrical DHW preparation included in the data.

-Sample 03-	Reference	Feedback	Special tariff	Total
Gradient [kWh/d]	33.09	24.42	27.21	29.20

TABLE 4: GRADIENTS FOR ALL EXPERIMENT PHASES, AVERAGE KWH PER DAY

It is obvious from the gradients given in table 4 that feeding back information on the energy consumption had a persistent reduction effect in the case of sample 03. It held into phase 3, however, a slight reduction in energy consumption might also be attributed to the advent of spring and changed habits due to the CoVID19-related lockdown.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

3.3.4 SAMPLE 04

Data sample 04 was acquired in a two-person household within a multifamily building, domestic hot water preparation was electric but metered separately and is thus not part of the shown data. Data acquisition continued for about five weeks onto the period of the CoVID19-related lockdown.

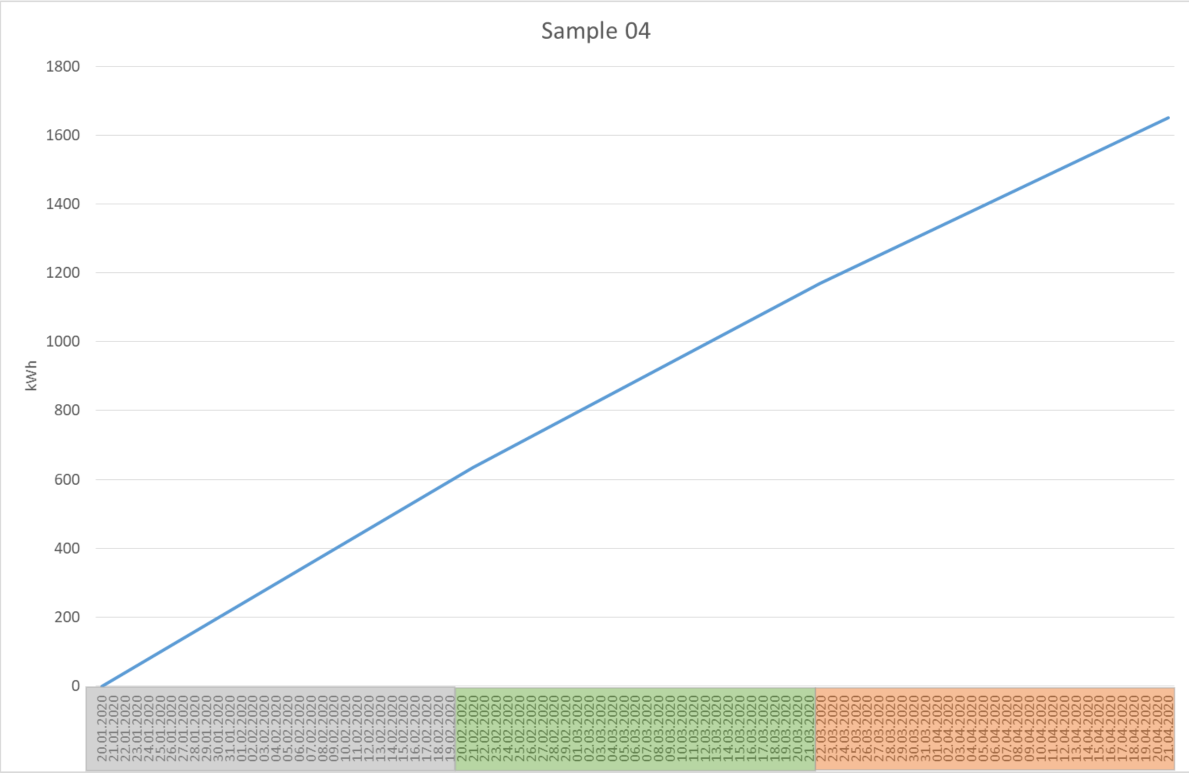


FIGURE 24: SAMPLE 04, OVERVIEW OF METERED CONSUMPTION, LINEARISED FOR THE EXPERIMENT PHASES

The total consumption in the time of the experiment amounted to a good 1600 kWh in sample 04, which extrapolates to around 6500 kWh per annum. This is another household with extremely high energy consumption, without electrical DHW preparation included in the data.

-Sample 04-	Reference	Feedback	Special tariff	Total
Gradient [kWh/d]	19.80	17.89	16.01	17.95

TABLE 5: GRADIENTS FOR ALL EXPERIMENT PHASES

It is obvious from the gradients given in table 5 that feeding back information on the energy consumption had a slight reduction effect in the case of sample 04. It held into phase 3, however, a slight reduction in energy consumption might also be attributed to the advent of spring and changed habits due to the CoVID19-related lockdown. Since the latter covered a substantial part of the experiment's time added uncertainty must be assumed as to the effect of changed habits.

3.4 DAYTIME ENERGY USE INCENTIVES PHASE

According to the literature, the usual temporal distribution of electricity use as observed in the field is not optimally aligned with the PV generation characteristics and peaks in the early morning and, particularly, in the evening hours (cf. figure, exemplary taken from [Zimmermann_2012]).

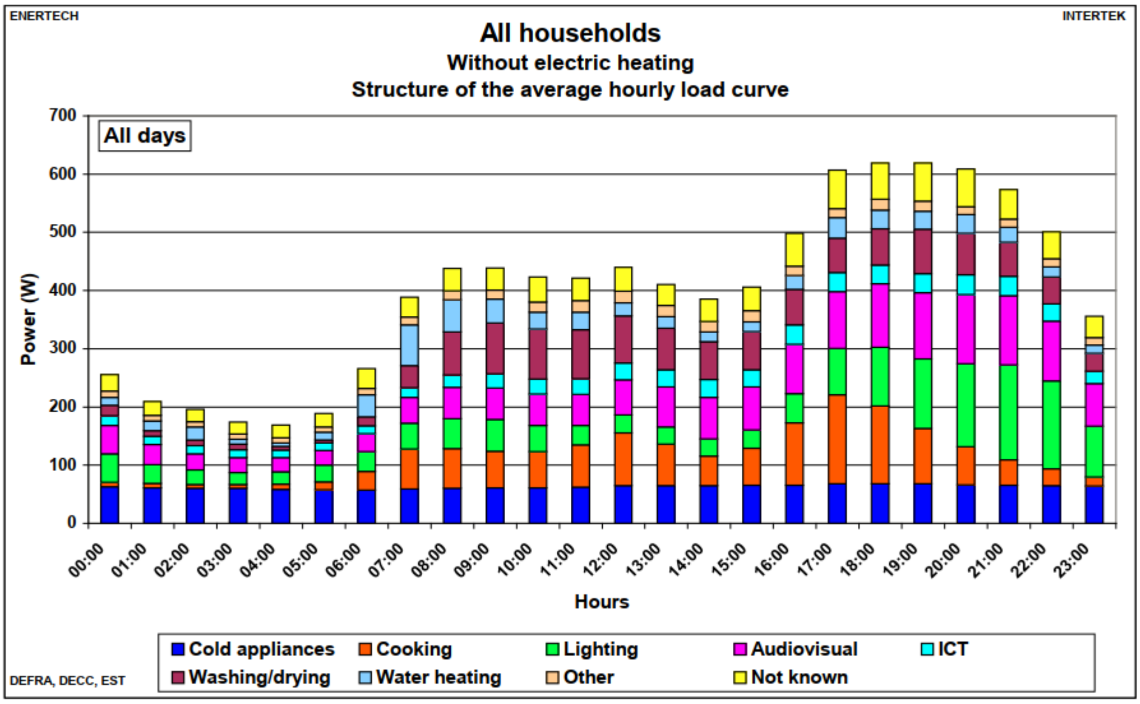


Figure 245 Structure of the average hourly load curve – All days – All households - Without electric heating -

FIGURE 25: AVERAGE HOURLY LOAD CURVE FOR HOUSEHOLDS ACCORDING TO [ZIMMERMANN_2012]

In order to test the viability of special electricity tariffs offered by housing companies to their tenants on the base of on-site RES, namely photovoltaics, a third experimental phase was conducted. Here, tenants were offered a 50% reduction on the regular electricity price (~0.18 €/kWh in Innsbruck at the time of the experiment), in the time from 10:00h to 16:00h, which is the main time of PV yield. This model appeals to tenants if a significant proportion of the daily energy use can be shifted to this period of time. It is likewise attractive to housing companies as the marginal cost of PV electricity is still lower than the special tariff.

The typical daily load curve for households is well known from various studies. The above figure illustrates this with a chart from [Zimmermann_2012]. During the small hours of the night the load is low, with a steep increase in the morning when people get up and start their daily routine. After this rush hour a slight decrease and a minor peak around lunch time can be observed. The main activities only begin after four in the afternoon when inhabitants return home, cook meals, and start electronic entertainment equipment.

Five data logging systems were deployed in late 2019/early 2020 of which three provided data with sufficient quality for hourly evaluation.

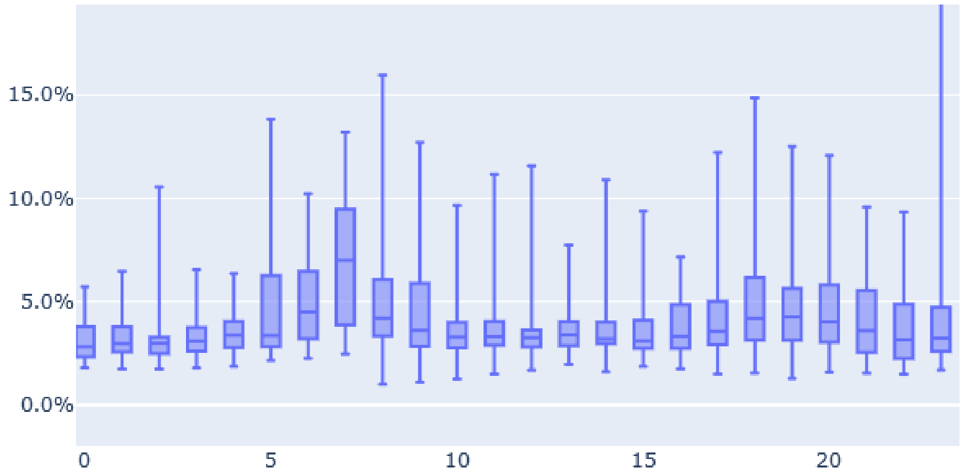


FIGURE 26: SAMPLE 01, LOAD CURVE FOR FEEDBACK PHASE OF EXPERIMENT. BOXPLOT WITH QUARTILES.

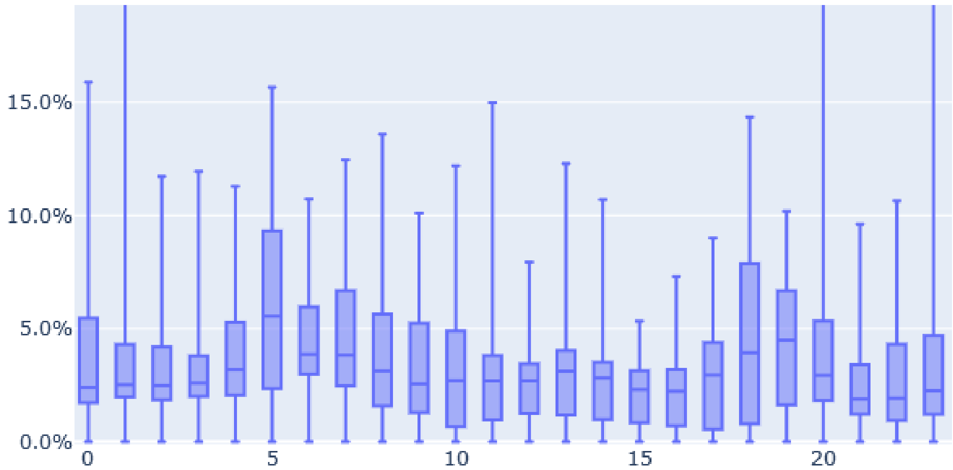


FIGURE 27: SAMPLE 01, LOAD CURVE FOR SPECIAL TARIFF PHASE OF EXPERIMENT. BOXPLOT WITH QUARTILES.

In sample 01 it seems that the variability of electricity use differed somewhat in the two consecutive experiment phases but the general pattern of the median hourly share in the daily total appears to exhibit no significant change. The median curve largely follows the characteristics determined by other studies, e.g. [Zimmermann_2012]. There is no indication that daytime energy use had been incentivised in a significant way by the daytime price.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

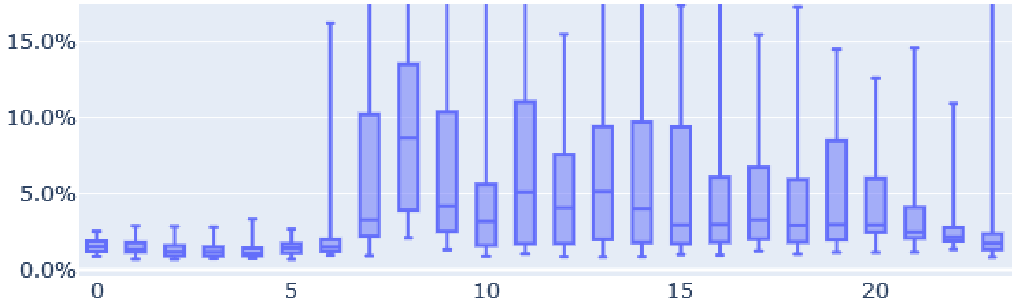


FIGURE 28: SAMPLE 02, LOAD CURVE FOR FEEDBACK PHASE OF EXPERIMENT. BOXPLOT WITH QUARTILES.

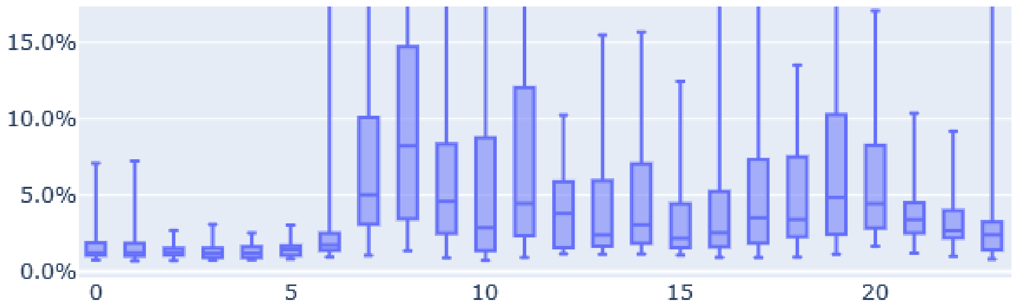


FIGURE 29: SAMPLE 02, LOAD CURVE FOR SPECIAL TARIFF PHASE OF EXPERIMENT. BOXPLOT WITH QUARTILES.

In sample 02 it seems that the variability of electricity use is pronounced in this household and differed less than in sample 01 in the two consecutive experiment phases. The general pattern of the median hourly share in the daily total, however, still follows the average profile rather well. One notable difference, for both phases of the experiment is, that in this household the morning hump is more pronounced than the evening hump. If a change in user behaviour can be observed it is a shift of the energy use towards the evening but there are no signs for increased daytime energy use.

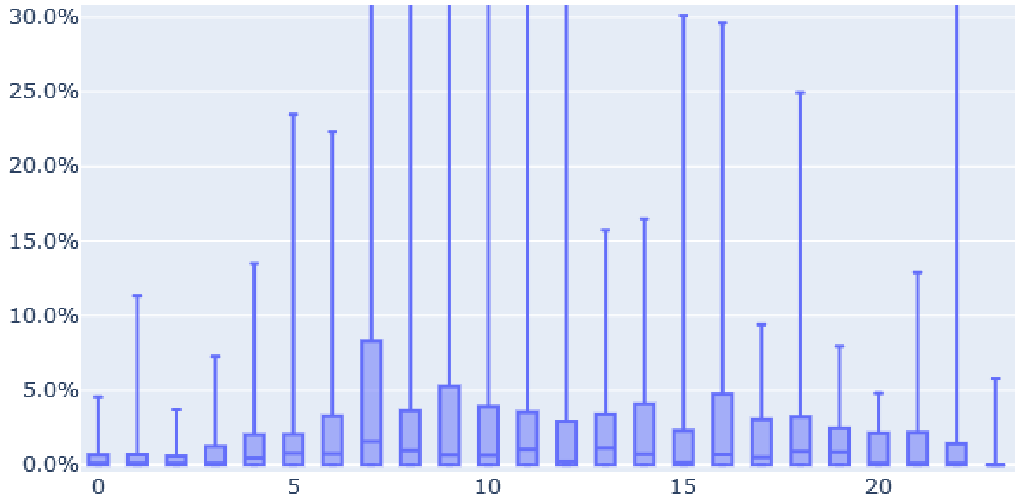


FIGURE 30: SAMPLE 03, LOAD CURVE FOR FEEDBACK PHASE OF EXPERIMENT. BOXPLOT WITH QUARTILES.

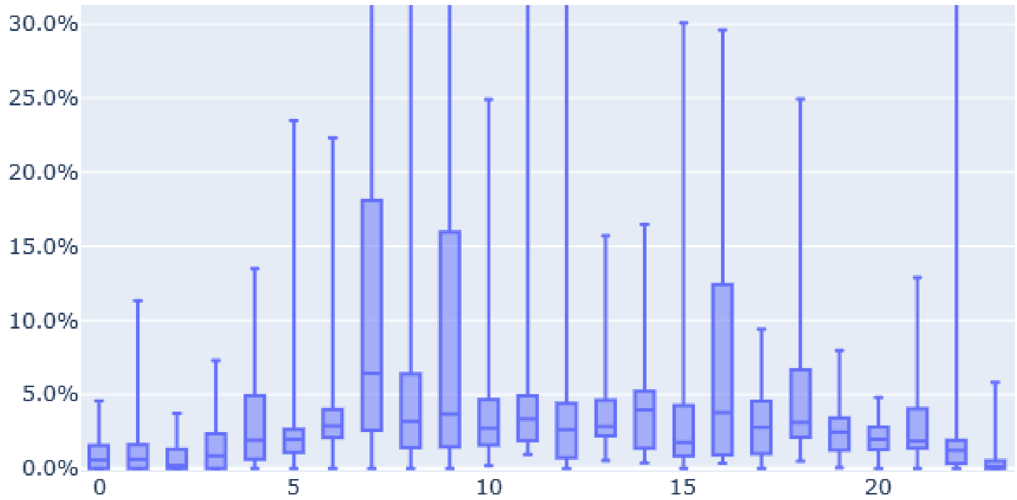


FIGURE 31: SAMPLE 03, LOAD CURVE FOR SPECIAL TARIFF PHASE OF EXPERIMENT. BOXPLOT WITH QUARTILES.

In sample 03 both the variability of electricity use and the hourly share during the daytime hours seem to have increased from one phase of the experiment to the next. One notable difference to the average profile, for both phases of the experiment is, that in this household the morning hump is more pronounced than the evening hump. In this sample significant signs for increased daytime energy use can be observed.

3.5 DISCUSSION

An experiment on the effect of feeding back information on energy consumption was conducted in four households. After a blind reference phase for calibration feeback was given from a set date. A measurable effect was obtained in three out of four samples, while in one case the situation remained virtually unchanged.

In the three cases with observable changes one sample showed an even increased average daily consumption. There is no hint on possible reasons; Probably it is not due to but in spite of the added information.

In two cases the feedback of information had a reducing effect on the average daily energy use. In sample 03 the change was significant while in sample 04 it was only small.

As the observed population has only been very limited no definite conclusions are possible. The available data do not, however, support the assumption of a meaningful energy savings potential from feeding back information on energy use.

Probably energy consulting and incentives for the replacement of old, inefficient white goods and entertainment equipment, including standby kill switches as observed and discussed in the previous section is more promising.

In the third experiment phase the effectiveness of shifting energy use to the daytime hours was tested by means of a special tariff with reduced energy price during high-yield hours of PV systems. Two out of three samples, however, did not support the viability of this approach, while one responded clearly. Given the very small population no authoritative conclusions are possible, however. The question should be considered unanswered until further investigations with larger populations can be conducted.

The feedback experiment (likewise limited by a small population) supports the hypothesis that electrical energy is a convenience that is used with little awareness. On households with regular income it has a limited monetary impact, particularly in Austria, where electricity prices are not very high. The results could be interpreted in a way that the financial incentive of saving small amounts from optimised energy use or from incentivising tariffs is not strong enough to overcome the inhibiting factors of laziness on one end and a focus on the challenges of daily life on the other.

The simple approach of using pulse counts from the meter as the data source is considered a successful element of the experiment. No “smart” metering was required to this end and related general privacy issues could be avoided. However, the EnOcean low power radio connection was not always reliable. This did not adversely affect the calculation of average daily energy use, but posed a problem in the evaluation of the temporal distribution of energy use in some cases. Coventionally wired connections should be considered in future studies.

4. RECOMMENDATIONS ON BEST PRACTICES AND DESIGN ASSUMPTIONS

Energy consulting and identifying the low hanging fruits is an effective approach to reduce the household electricity use by about 25 % in the short term. Economic benefits can be incurred in the lifecycle of the products if the user lives to benefit from them. Clearly in households of elderly people there is sometimes little motivation to take action. Nonetheless the data suggest that a large proportion of the potential is actually accessible to this simple process for improvement. **Individual consulting should be encouraged and established as a standard procedure alongside deep retrofit of buildings. Incentivising the replacement of old refrigeration appliances with highly efficient ones is stongly advised, and could be accelerated if kitchens were fitted by the housing companies as part of the deep retrofit action.**

Systems to feed back information on electrical energy use have not proven to be a reliable means to reduce energy consumption in households. They might, however, have a greater impact if combined with flat rate payments for rent and included energy supply quota (e.g. space heating, electicity, domestic hot water, cold water).

In order to gain a better understanding of the potential for shifiting energy use to the high-yield times of PV sytems by special tariffs further investigation is required. However, the results of this study call for limited expectations.

5. SOURCES

BDEW, B. d.-u. Stromverbrauch im Haushalt. Berlin2016

Dupret, M., Zimmermann, J., Schlomann, B., Gruber, E., Kofod, C., Feldberg, N., Vorizek, T. (2007). Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe. Coimbra.

[ecotopten] www.ecotopten.de (march 2020) list of energy efficient appliances

https://stromliste.at/nuetzliche-infos/durchschnittlicher-stromverbrauch. (20. 03 2018).

[FHEM] Freundliche Hausautomation und Energie Messung, online, https://fhem.de

[ISOE] ISOE – Institut für sozial-ökologische Forschung (Projektkoordination): Stromeffizienzklassen für Haushalte. Förderung von Stromsparinnovationen in Haushalt, Markt und Gerätetechnik (Stromeffizienzklassen), online: http://www.stromeffizienzklassen.de/uploads/media/Stromeffizienzklassen_Kurzfassung_20160621.pdf

Pfluger, R., Wagner, W., Spörk-Dür, M., Kapferer, R., Braito, M., Ochs, F., & Suschek-Berger, J. (2012). Forschungsprojekt Passivhauswohnanlage Lodenareal. Gleisdorf: Energie Tirol.

[PHPP] Passive House Planning Package PHPP v. 9.6a, Passive House Institute, Darmstadt 2016

www.stromspiegel.de. (20. 03 2018).

[Zimmermann 2009] Zimmermann, J. (2009). End-use metering campaign in 400 households in Sweden Assesment of the Potential Electricity Savings. Félines-sur-Rimandoule.

[Zimmermann 2012] Zimmermann, J.-P., Ecans, M., Griggs, J., King, N., Harding, L., Roberts, P., & Evans, C. (2012). Household Electricity Survey. Oxford.

SINFONIA; "Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions" has received funding from the European Union's Seventh Programme for research, technological development and demonstration.

Annex: DOCUMENT INFORMATION

SINFONIA DELIVERABLE FACT SHEET		
PROJECT START DATE	1 June 2014	
PROJECT DURATION	60 months	
PROJECT WEBSITE	http://www.sinfonia-smartcities.eu	
DOCUMENT		
DELIVERABLE NUMBER:	This Report belongs under D4.7	
DELIVERABLE TITLE:	Tailored concepts for energy efficient refurbishing of buildings and smart districts	
DUE DATE OF DELIVERABLE:	30 April 2019	
ACTUAL SUBMISSION DATE:	30 June 2020	
EDITORS:		
AUTHORS:	PHI: Wolfgang Hasper, Dr. Oliver Ottinger, Tobias Molitor	
REVIEWERS:	PHI: Laszlo Lepp, Soeren Peper, Witta Ebel	
PARTICIPATING BENEFICIARIES:	PASSIVE HOUSE INSTITUTE	
WORK PACKAGE NO.:	4	
WORK PACKAGE TITLE:	Integrated refurbishment processes coupling building, electricity grids and heat/cold networks	
WORK PACKAGE LEADER:	RISE	
WORK PACKAGE PARTICIPANTS:	RISE, IKB, NHT, UIBK, BOZ, EURAC, IPES, SEL SPA, CASA CLIMA, PHI, ALFA LAVAL CORPORATE, IIG,	
DISSEMINATION LEVEL:		
	CO (CONFIDENTIAL, ONLY FOR MEMBERS OF THE CONSORTIUM INCLUDING THE COMMISSION SERVICES)	
	PU (PUBLIC)	x
	PP (RESTRICTED TO OTHER PROGRAMME PARTICIPANTS, (INCLUDING THE COMMISSION SERVICES)	
	RE (RESTRICTED TO A GROUP SPECIFIED BY THE CONSORTIUM INCLUDING THE COMMISSION SERVICES)	
DRAFT/FINAL:	Final	
NO OF PAGES (INCLUDING COVER):	39	
KEYWORDS:	Energy Efficiency in Domestic Electrical Energy USe	